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**ROCm is built for scale:** it supports multi-GPU computing in and out of server-node communication through RDMA. It also simplifies the stack when the driver directly incorporates RDMA peer-sync support.

**ROCm has a rich system run time** with the critical features that large-scale application, compiler and language-run-time development requires.
GOING TO 11: AMPING UP THE PROGRAMMING-LANGUAGE RUN-TIME FOUNDATION

The ROCr System Runtime is language independent and makes heavy use of the Heterogeneous System Architecture (HSA) Runtime API. This approach provides a rich foundation to execute programming languages such as HCC C++ and HIP, the Khronos Group’s OpenCL, and Continuum’s Anaconda Python.

Important features include the following:

- Multi-GPU coarse-grain shared virtual memory
- Process concurrency and preemption
- Large memory allocations
- HSA signals and atomics
- User-mode queues and DMA
- Standardized loader and code-object format
- Dynamic and offline-compilation support
- Peer-to-peer multi-GPU operation with RDMA support
- Profiler trace and event-collection API
- Systems-management API and tools
SOLID COMPILATION FOUNDATION AND LANGUAGE SUPPORT

• LLVM compiler foundation
• HCC C++ and HIP for application portability
• GCN assembler and disassembler

The frontiers of what you can accomplish with ROCm are vast and uncharted. We look forward to working with you to improve the platform so you can use it more effectively in your own projects. Our efforts have opened the door to unique heterogeneous-computing applications that explore what this growing technology can do.

2.1 Quick Start Guide

2.1.1 Current Release Notes

Release Notes
The Release Notes for the ROCm Latest version.

2.1.2 Installation Guide

Installing from AMD ROCm repositories
This guide discusses how to install and check for correct operation of ROCm using AMD ROCm Repository.

Installing from a Debian repository
This guide discusses how to install and check for correct operation of ROCm using Debian repository on Ubuntu.

Installing from an yum repository
This guide describes how to install and check for correct operation of ROCm using yum on RHEL and CentOS 7.5.

Getting ROCm source code
This guide discusses how to modify the open source code base and rebuild the components of ROCm latest version.

Installing ROCk-Kernel only
This guide discusses how to install ROCm Kernel into the system.
FAQ on Installation
This section provides answers for various frequently asked questions related to installation steps and issues faced during installation.

2.1.3 Programming Guide
This guide provides a detailed discussion of the ROCm programming model and programming interface. It describes the hardware implementation and provides guidance on how to achieve maximum performance. The appendices include a list of all ROCm-enabled devices, detailed description of all extensions to the C language, listings of supported mathematical functions, C++ features supported in host and device code, technical specifications of various devices, and concludes by introducing the low-level driver API.

ROCm Languages
This guide provides information on different ROCm languages. ROCm stack offers multiple programming-language choices found in this section.

HC Programing Guide
This guide provides a detailed discussion on The Heterogeneous Compute programming installation requirements, methods to install on various platforms and how to build it from source.

HC Best Practices
This section deals with detailed working with HCC, build the program, Build-in Macros, HCC Profiler mode and API Documentation.

HIP Programing Guide
This guide provides a detailed discussion of The HIP programming, installation requirements, methods to install on various platforms and how to build it from source.

HIP Best Practices
This section Provides details regarding various concepts of HIP Porting, Debugging, Bugs, FAQ and other aspects of the HIP.

OpenCL Programing Guide
This guide provides a detailed discussion of The OpenCL Architecture, AMD Implementation, Profiling, and other aspects of OpenCL.

OpenCL Best Practices
This section provides information on Performance and optimization for various device types such as GCN devices.

2.1.4 ROCm GPU Tuning Guides

GFX7 Tuning Guide
– In-Progress
2.1.5 GCN ISA Manuals

GCN 1.1
This Section gives information on ISA Manual for Hawaii (Sea Islands Series Instruction Set Architecture)

GCN 2.0
This Section gives information on ISA Manual for Fiji and Polaris (AMD Accelerated Parallel Processing technology)

Vega
This section provides “Vega” Instruction Set Architecture, Program Organization, Mode register and more details.

Inline GCN ISA Assembly Guide
This section covers various concepts of AMDGCN Assembly, DS Permute Instructions, Parameters to a Kernel, GPR Counting.

2.1.6 ROCm API References

Here API References are listed out for users

ROCr System Runtime API
ROCr System Runtime API Details are listed here

HCC Language Runtime API
HCC Language Runtime API Details are listed here

HIP Language Runtime API
HIP Language Runtime API Details are listed here

HIP Math API
Here HIP Math API are listed with sample working classes

Thrust API Documentation
Here you can find all the details on installation, working of Thrust Library and Thrust API List

2.1. Quick Start Guide
Math Library API’s
HIP MAth API with hcRNG, clBLAS, clSPARSE API’s.

Deep Learning API’s
Here MIOpen API and MIOpenGEMM API are listed.

2.1.7 ROCm Tools

HCC
Complete description of Heterogeneous Compute Compiler has been listed and documented.

GCN Assembler and Disassembler
This Section provides details regarding GCN in-detail.

GCN Assembler Tools
In this Section, information related to AMDGPU ISA assembler is documented.

ROCm-GDB
Complete Documentation of ROCm-GDB tool is provided here. Installation, Build steps and working of Debugger and API related to it has been documented here.

ROCm-Profiler
This section gives details on Radeon Compute Profiler- performance analysis tool, and we have details on how to clone and use it.

ROCm-Tracer
This section gives Details on ROCm Tracer, which provides a generic independent from specific runtime profiler to trace API and asynchronous activity. Here we have details on library source tree, steps to build and run test.

CodeXL
This section provides details on CodeXL, a comprehensive tool suite. The Documentation of Installation and builds and other details related to CodeXL is given.

GPUPerfAPI
This section provides details on GPU Performance API. The content related to how to clone, system requirements and source code directory layout can be found.

ROCm Binary Utilities
– In-progress
2.1.8 ROCm Libraries

rocFFT
This section provides details on rocFFT, it is a AMD’s software library compiled with the CUDA compiler using HIP tools for running on Nvidia GPU devices.

rocBLAS
This section provides details on rocBLAS, it is a library for BLAS on ROCm. rocBLAS is implemented in the HIP programming language and optimized for AMD’s latest discrete GPUs.

hipBLAS
This section provides details on hipBLAS, it is a BLAS marshalling library, with multiple supported backends. hipBLAS exports an interface that does not require the client to change. Currently, it supports rocblas and cuBLAS as backends.

hcRNG
This section provides details on hcRNG. It is a software library, where uniform random number generators targeting the AMD heterogeneous hardware via HCC compiler runtime is implemented.

hipeigen
This section provides details on Eigen. It is a C++ template library which provides linear algebra for matrices, vectors, numerical solvers, and related algorithms.

clFFT
This section provides details on clFFT. It is a software library which contains FFT functions written in OpenCL, and clFFT also supports running on CPU devices to facilitate debugging and heterogeneous programming.

clBLAS
This section provides details on clBLAS. It makes easier for developers to utilize the inherent performance and power efficiency benefits of heterogeneous computing.

clSPARSE
This section provides details on clSPARSE, it is an OpenCL library which implements Sparse linear algebra routines.

clRNG
This section provides details on clRNG, This is a library for uniform random number generation in OpenCL.

hcFFT
This section provides details on hcFFT, it hosts the HCC based FFT Library and targets GPU acceleration of FFT routines on AMD devices.

Tensile
This section provides details on Tensile. It is a tool for creating a benchmark-driven backend library for GEMMs, N-dimensional tensor contractions and multiplies two multi-dimensional objects together on a GPU.

rocALUTION
This section provides details on rocALUTION. It is a sparse linear algebra library with focus on exploring fine-grained parallelism, targeting modern processors and accelerators including multi/many-core CPU and GPU platforms. It can be seen as middle-ware between different parallel backends and application specific packages.

rocSPARSE
This section provides details on rocSPARSE. It is a library that contains basic linear algebra subroutines for sparse matrices and vectors written in HiP for GPU devices. It is designed to be used from C and C++ code.

rocThrust
This section provides details on rocThrust. It is a parallel algorithm library.

2.1.9 ROCm Compiler SDK
GCN Native ISA LLVM Code Generator
This section provide complete description on LLVM such as introduction, Code Object, Code conventions, Source languages, etc.,

ROCm Code Object Format
This section describes about application binary interface (ABI) provided by the AMD, implementation of the HSA runtime. It also provides details on Kernel, AMD Queue and Signals.

ROCm Device Library
Documentation on instruction related to ROCm Device Library overview, Building and Testing related information with respect to Device Library is provided.

ROCr Runtime
This section refers the user-mode API interfaces and libraries necessary for host applications to launch compute kernels to available HSA ROCm kernel agents. we can find installation details and Infrastructure details related to ROCr.

2.1.10 ROCm System Management
ROCM-SMI
ROCM System Management Interface a complete guide to use and work with rocm-smi tool.

SYSFS Interface
This section provides information on sysfs file structure with details related to file structure related to system are captured in sysfs.
KFD Topology
KFD Kernel Topology is the system file structure which describes about AMD GPU related information such as nodes, Memory, Cache and IO-links.

2.1.11 ROCm Virtualization & Containers

PCle Passthrough on KVM
Here PCle Passthrough on KVM is described. A KVM-based instructions assume a headless host with an input/output memory management unit (IOMMU) to pass peripheral devices such as a GPU to guest virtual machines. More information can be found on the same here.

ROCM-Docker
A framework for building the software layers defined in the Radeon Open Compute Platform into portable docker images. Detailed information related to ROCM-Docker can be found.

2.1.12 Remote Device Programming

ROCMRDMA
ROCMRDMA is the solution designed to allow third-party kernel drivers to utilize DMA access to the GPU memory. Complete documentation related to ROCMRDMA is Documented here.

UCX
This section gives information related to UCX, How to install, Running UCX and much more

MPI
This section gives information related to MPI.

IPC
This section gives information related to IPC.

2.1.13 Deep Learning on ROCm

This section provides details on ROCm Deep Learning concepts.

Porting from cuDNN to MIOpen
The porting guide highlights the key differences between the current cuDNN and MIOpen APIs.

Deep Learning Framework support for ROCm
This section provides detailed chart of Frameworks supported by ROCm and repository details.

Tutorials
Here Tutorials on different Deep Learning Frameworks are documented.
2.1.14 System Level Debug

ROCm Language & System Level Debug, Flags and Environment Variables
Here in this section we have details regarding various system related debugs and commands for issues faced while using ROCm.

2.1.15 Tutorial

This section provides details related to few concepts of HIP and other sections.

2.1.16 ROCm Glossary

ROCm Glossary gives highlights concepts and their main concept of how they work.

2.2 Current Release Notes

2.2.1 New features and enhancements in ROCm 2.6

2.2.1.1 ROCmInfo enhancements

ROCmInfo was extended to do the following: For ROCr API call errors including initialization determine if the error could be explained by:

- ROCk (driver) is not loaded / available
- User does not have membership in appropriate group - “video”
- If not above print the error string that is mapped to the returned error code
- If no error string is available, print the error code in hex

2.2.1.2 [Thrust] Functional Support on Vega20

ROCm2.6 contains the first official release of rocThrust and hipCUB. rocThrust is a port of thrust, a parallel algorithm library. hipCUB is a port of CUB, a reusable software component library. Thrust/CUB has been ported to the HIP/ROCm platform to use the rocPRIM library. The HIP ported library works on HIP/ROCm platforms.

Note: rocThrust and hipCUB library replaces hip-thrust, i.e. hip-thrust has been separated into two libraries, rocThrust and hipCUB. Existing hip-thrust users are encouraged to port their code to rocThrust and/or hipCUB. Hip-thrust will be removed from official distribution later this year.

2.2.1.3 MiGraphX v0.3

MiGraphX optimizer adds support to read models frozen from Tensorflow framework. Further details and an example usage at https://github.com/ROCmSoftwarePlatform/AMDMiGraphX/wiki/Getting-started:-using-the-new-features-of-MiGraphX-0.3
2.2.1.4 MIOpen 2.0

- This release contains several new features including an immediate mode for selecting convolutions, bfloat16 support, new layers, modes, and algorithms.
- MIOpenDriver, a tool for benchmarking and developing kernels is now shipped with MIOpen. BFloat16 now supported in HIP requires an updated rocBLAS as a GEMM backend.
- Immediate mode API now provides the ability to quickly obtain a convolution kernel.
- MIOpen now contains HIP source kernels and implements the ImplicitGEMM kernels. This is a new feature and is currently disabled by default. Use the environmental variable “MIOPEN_DEBUG_CONV_IMPLICIT_GEMM=1” to activation this feature. ImplicitGEMM requires an up to date HIP version of at least 1.5.9211.
- A new “loss” category of layers has been added, of which, CTC loss is the first. See the API reference for more details. 2.0 is the last release of active support for gfx803 architectures. In future releases, MIOpen will not actively debug and develop new features specifically for gfx803.
- System Find-Db in memory cache is disabled by default. Please see build instructions to enable this feature. Additional documentation can be found here.

2.2.1.5 Bloat16 software support in rocBLAS/Tensile

Added mixed precision bfloat16/IEEE f32 to gemm_ex. The input and output matrices are bfloat16. All arithmetic is in IEEE f32.

2.2.1.6 AMD Infinity Fabric™ Link enablement

The ability to connect four Radeon Instinct MI60 or Radeon Instinct MI50 boards in two hives or two Radeon Instinct MI60 or Radeon Instinct MI50 boards in four hives via AMD Infinity Fabric™ Link GPU interconnect technology has been added.

2.2.1.7 ROCm-smi features and bug fixes

- mGPU & Vendor check
- Fix clock printout if DPM is disabled
- Fix finding marketing info on CentOS
- Clarify some error messages

2.2.1.8 ROCm-smi-lib enhancements

- Documentation updates
- Improvements to *name_get functions

2.2.1.9 RCCL2 Enablement

RCCL2 supports collectives intranode communication using PCIe, Infinity Fabric™, and pinned host memory, as well as internode communication using Ethernet (TCP/IP sockets) and Infiniband/RoCE (Infiniband Verbs). Note: For Infiniband/RoCE, RDMA is not currently supported.
2.2.1.10 rocFFT enhancements

- Added: Debian package with FFT test, benchmark, and sample programs
- Improved: hipFFT interfaces
  - Improved: rocFFT CPU reference code, plan generation code and logging code

Features and enhancements introduced in previous versions of ROCm can be found in version_history.md

2.2.2 New features and enhancements in ROCm 2.5

2.2.2.1 UCX 1.6 support

Support for UCX version 1.6 has been added.

2.2.2.2 BFloat16 GEMM in rocBLAS/Tensile

Software support for BFloat16 on Radeon Instinct MI50, MI60 has been added. This includes:

- Mixed precision GEMM with BFloat16 input and output matrices, and all arithmetic in IEEE32 bit
- Input matrix values are converted from BFloat16 to IEEE32 bit, all arithmetic and accumulation is IEEE32 bit. Output values are rounded from IEEE32 bit to BFloat16
- Accuracy should be correct to 0.5 ULP

2.2.2.3 ROCm-SMI enhancements

CLI support for querying the memory size, driver version, and firmware version has been added to ROCm-smi.

2.2.2.4 [PyTorch] multi-GPU functional support (CPU aggregation/Data Parallel)

Multi-GPU support is enabled in PyTorch using Dataparallel path for versions of PyTorch built using the 06c8aaa7a3bbd91cda2fd6255ec82aad21fa1c0d5 commit or later.

2.2.2.5 rocSparse optimization on Radeon Instinct MI50 and MI60

This release includes performance optimizations for csrsv routines in the rocSparse library.

2.2.2.6 [Thrust] Preview

Preview release for early adopters. rocThrust is a port of thrust, a parallel algorithm library. Thrust has been ported to the HIP/ROCm platform to use the rocPRIM library. The HIP ported library works on HIP/ROCm platforms.

Note: This library will replace thrust in a future release. The package for rocThrust (this library) currently conflicts with version 2.5 package of thrust. They should not be installed together.

2.2.2.7 Support overlapping kernel execution in same HIP stream

HIP API has been enhanced to allow independent kernels to run in parallel on the same stream.
2.2.2.8 AMD Infinity Fabric™ Link enablement

The ability to connect four Radeon Instinct MI60 or Radeon Instinct MI50 boards in one hive via AMD Infinity Fabric™ Link GPU interconnect technology has been added.

Features and enhancements introduced in previous versions of ROCm can be found in version_history.md

2.2.3 New features and enhancements in ROCm 2.4

2.2.3.1 TensorFlow 2.0 support

ROCm 2.4 includes the enhanced compilation toolchain and a set of bug fixes to support TensorFlow 2.0 features natively

2.2.3.2 AMD Infinity Fabric™ Link enablement

ROCm 2.4 adds support to connect two Radeon Instinct MI60 or Radeon Instinct MI50 boards via AMD Infinity Fabric™ Link GPU interconnect technology.

2.2.4 New features and enhancements in ROCm 2.3

2.2.4.1 Mem usage per GPU

Per GPU memory usage is added to rocm-smi. Display information regarding used/total bytes for VRAM, visible VRAM and GTT, via the –showmeminfo flag

2.2.4.2 MIVisionX, v1.1 - ONNX

ONNX parser changes to adjust to new file formats

2.2.4.3 MiGraphX, v0.2

MiGraphX 0.2 supports the following new features:

- New Python API
- Support for additional ONNX operators and fixes that now enable a large set of Imagenet models
- Support for RNN Operators
- Support for multi-stream Execution
- [Experimental] Support for Tensorflow frozen protobuf files

See: Getting-started:-using-the-new-features-of-MiGraphX-0.2 for more details

2.2.4.4 MIOpen, v1.8 - 3d convolutions and int8

- This release contains full 3-D convolution support and int8 support for inference.
- Additionally, there are major updates in the performance database for major models including those found in Torchvision.

See: MIOpen releases

2.2. Current Release Notes
2.2.4.5 Caffe2 - mGPU support

Multi-gpu support is enabled for Caffe2.

2.2.4.6 rocTracer library, ROCm tracing API for collecting runtimes API and asynchronous GPU activity traces

HIP/HCC domains support is introduced in rocTracer library.

2.2.4.7 BLAS - Int8 GEMM performance, Int8 functional and performance

Introduces support and performance optimizations for Int8 GEMM, implements TRSV support, and includes improvements and optimizations with Tensile.

2.2.4.8 Prioritized L1/L2/L3 BLAS (functional)

Functional implementation of BLAS L1/L2/L3 functions

2.2.4.9 BLAS - tensile optimization

Improvements and optimizations with tensile

2.2.4.10 MIOpen Int8 support

Support for int8

2.2.5 New features and enhancements in ROCm 2.2

2.2.5.1 rocSparse Optimization on Vega20

Cache usage optimizations for csrsv (sparse triangular solve), coomv (SpMV in COO format) and ellmv (SpMV in ELL format) are available.

2.2.5.2 DGEMM and DTRSM Optimization

Improved DGEMM performance for reduced matrix sizes (k=384, k=256)

2.2.5.3 Caffe2

Added support for multi-GPU training

2.2.6 New features and enhancements in ROCm 2.1

2.2.6.1 RocTracer v1.0 preview release – ‘rocprof’ HSA runtime tracing and statistics support -

Supports HSA API tracing and HSA asynchronous GPU activity including kernels execution and memory copy
2.2.6.2 Improvements to ROCM-SMI tool -

Added support to show real-time PCIe bandwidth usage via the -b/--showbw flag

2.2.6.3 DGEMM Optimizations -

Improved DGEMM performance for large square and reduced matrix sizes (k=384, k=256)

2.2.7 New features and enhancements in ROCm 2.0

Features and enhancements introduced in previous versions of ROCm can be found in version_history.md

2.2.7.1 Adds support for RHEL 7.6 / CentOS 7.6 and Ubuntu 18.04.1

2.2.7.2 Adds support for Vega 7nm, Polaris 12 GPUs

2.2.7.3 Introduces MIVisionX

A comprehensive computer vision and machine intelligence libraries, utilities and applications bundled into a single toolkit.

2.2.7.4 Improvements to ROCm Libraries

- rocSPARSE & hipSPARSE
- rocBLAS with improved DGEMM efficiency on Vega 7nm

2.2.7.5 MIOpen

- This release contains general bug fixes and an updated performance database
- Group convolutions backwards weights performance has been improved
- RNNs now support fp16

2.2.7.6 Tensorflow multi-gpu and Tensorflow FP16 support for Vega 7nm

- TensorFlow v1.12 is enabled with fp16 support

2.2.7.7 PyTorch/Caffe2 with Vega 7nm Support

- fp16 support is enabled
- Several bug fixes and performance enhancements
- Known Issue: breaking changes are introduced in ROCm 2.0 which are not addressed upstream yet. Meanwhile, please continue to use ROCm fork at https://github.com/ROCmSoftwarePlatform/pytorch

2.2.7.8 Improvements to ROCProfiler tool

- Support for Vega 7nm
2.2.7.9 Support for hipStreamCreateWithPriority

- Creates a stream with the specified priority. It creates a stream on which enqueued kernels have a different priority for execution compared to kernels enqueued on normal priority streams. The priority could be higher or lower than normal priority streams.

2.2.7.10 OpenCL 2.0 support

- ROCm 2.0 introduces full support for kernels written in the OpenCL 2.0 C language on certain devices and systems. Applications can detect this support by calling the “clGetDeviceInfo” query function with “param_name” argument set to “CL_DEVICE_OPENCL_C_VERSION”. In order to make use of OpenCL 2.0 C language features, the application must include the option “-cl-std=CL2.0” in options passed to the runtime API calls responsible for compiling or building device programs. The complete specification for the OpenCL 2.0 C language can be obtained using the following link: https://www.khronos.org/registry/OpenCL/specs/opencl-2.0-openclc.pdf

2.2.7.11 Improved Virtual Addressing (48 bit VA) management for Vega 10 and later GPUs

- Fixes Clang AddressSanitizer and potentially other 3rd-party memory debugging tools with ROCm
- Small performance improvement on workloads that do a lot of memory management
- Removes virtual address space limitations on systems with more VRAM than system memory

2.2.7.12 Kubernetes support

2.2.7.13 Removed features

- HCC: removed support for C++AMP

2.2.8 New features and enhancements in ROCm 1.9.2

2.2.8.1 RDMA(MPI) support on Vega 7nm

- Support ROCnRDMA based on Mellanox InfiniBand.

2.2.8.2 Improvements to HCC

- Improved link time optimization.

2.2.8.3 Improvements to ROCProfiler tool

- General bug fixes and implemented versioning APIs.

2.2.8.4 Critical bug fixes

2.2.9 New features and enhancements in ROCm 1.9.1

2.2.9.1 Added DPM support to Vega 7nm

Dynamic Power Management feature is enabled on Vega 7nm.
2.2.9.2 Fix for ‘ROCm profiling’ “Version mismatch between HSA runtime and libhsa-runtime-tools64.so.1” error

2.2.10 New features and enhancements in ROCm 1.9.0

2.2.10.1 Preview for Vega 7nm

• Enables developer preview support for Vega 7nm

2.2.10.2 System Management Interface

• Adds support for the ROCm SMI (System Management Interface) library, which provides monitoring and management capabilities for AMD GPUs.

2.2.10.3 Improvements to HIP/HCC

• Support for gfx906
• Added deprecation warning for C++AMP. This will be the last version of HCC supporting C++AMP.
• Improved optimization for global address space pointers passing into a GPU kernel
• Fixed several race conditions in the HCC runtime
• Performance tuning to the unpinned copy engine
• Several codegen enhancement fixes in the compiler backend

2.2.10.4 Preview for rocprof Profiling Tool

Developer preview (alpha) of profiling tool ‘rpl_run.sh’, cmd-line front-end for rocProfiler, enables: * Cmd-line tool for dumping public per kernel perf-counters/metrics and kernel timestamps * Input file with counters list and kernels selecting parameters * Multiple counters groups and app runs supported * Output results in CSV format The tool location is: /opt/rocm/bin/rpl_run.sh

2.2.10.5 Preview for rocr Debug Agent rocr_debug_agent

The ROCr Debug Agent is a library that can be loaded by ROCm Platform Runtime to provide the following functionality: * Print the state for wavefronts that report memory violation or upon executing a “s_trap 2” instruction. * Allows SIGINT (ctrl c) or SIGTERM (kill -15) to print wavefront state of aborted GPU dispatches. * It is enabled on Vega10 GPUs on ROCm1.9. The ROCm1.9 release will install the ROCr Debug Agent library at /opt/rocm/lib/librocr_debug_agent64.so

2.2.10.6 New distribution support

• Binary package support for Ubuntu 18.04
2.2.10.7 ROCm 1.9 is ABI compatible with KFD in upstream Linux kernels.

Upstream Linux kernels support the following GPUs in these releases: 4.17: Fiji, Polaris 10, Polaris 11 4.18: Fiji, Polaris 10, Polaris 11, Vega10

Some ROCm features are not available in the upstream KFD: * More system memory available to ROCm applications * Interoperability between graphics and compute * RDMA * IPC

To try ROCm with an upstream kernel, install ROCm as normal, but do not install the rock-dkms package. Also add a udev rule to control /dev/kfd permissions:

```
echo 'SUBSYSTEM=="kfd", KERNEL=="kfd", TAG+="uaccess", GROUP="video"' | sudo tee /etc/udev/rules.d/70-kfd.rules
```

2.3 ROCm Installation Guide

2.3.1 Are You Ready to ROCK?

The ROCm Platform brings a rich foundation to advanced computing by seamlessly integrating the CPU and GPU with the goal of solving real-world problems. This software enables the high-performance operation of AMD GPUs for computation oriented tasks in the Linux operating system.

2.3.2 Current ROCm Version: 2.6

2.3.3 Hardware Support

ROCm is focused on using AMD GPUs to accelerate computational tasks such as machine learning, engineering workloads, and scientific computing. In order to focus our development efforts on these domains of interest, ROCm supports a targeted set of hardware configurations which are detailed further in this section.

2.3.3.1 Supported GPUs

Because the ROCm Platform has a focus on particular computational domains, we offer official support for a selection of AMD GPUs that are designed to offer good performance and price in these domains.

ROCm officially supports AMD GPUs that use following chips:

- GFX8 GPUs
  - “Fiji” chips, such as on the AMD Radeon R9 Fury X and Radeon Instinct MI8
  - “Polaris 10” chips, such as on the AMD Radeon RX 580 and Radeon Instinct MI6
  - “Polaris 11” chips, such as on the AMD Radeon RX 570 and Radeon Pro WX 4100
  - “Polaris 12” chips, such as on the AMD Radeon RX 550 and Radeon RX 540
- GFX9 GPUs
  - “Vega 10” chips, such as on the AMD Radeon RX Vega 64 and Radeon Instinct MI25
  - “Vega 7nm” chips, such as on the Radeon Instinct MI50, Radeon Instinct MI60 or AMD Radeon VII
ROCm is a collection of software ranging from drivers and runtimes to libraries and developer tools. Some of this software may work with more GPUs than the “officially supported” list above, though AMD does not make any official claims of support for these devices on the ROCm software platform. The following list of GPUs are enabled in the ROCm software, though full support is not guaranteed:

- GFX7 GPUs
  - “Hawaii” chips, such as the AMD Radeon R9 390X and FirePro W9100

As described in the next section, GFX8 GPUs require PCI Express 3.0 (PCIe 3.0) with support for PCIe atomics. This requires both CPU and motherboard support. GFX9 GPUs, by default, also require PCIe 3.0 with support for PCIe atomics, but they can operate in most cases without this capability.

At this time, the integrated GPUs in AMD APUs are not officially supported targets for ROCm. As described below, “Carrizo”, “Bristol Ridge”, and “Raven Ridge” APUs are enabled in our upstream drivers and the ROCm OpenCL runtime. However, they are not enabled in our HCC or HIP runtimes, and may not work due to motherboard or OEM hardware limitations. As such, they are not yet officially supported targets for ROCm.

For a more detailed list of hardware support, please see the following documentation.

### 2.3.3.2 Supported CPUs

As described above, GFX8 GPUs require PCIe 3.0 with PCIe atomics in order to run ROCm. In particular, the CPU and every active PCIe point between the CPU and GPU require support for PCIe 3.0 and PCIe atomics. The CPU root must indicate PCIe AtomicOp Completion capabilities and any intermediate switch must indicate PCIe AtomicOp Routing capabilities.

Current CPUs which support PCIe Gen3 + PCIe Atomics are:

- AMD Ryzen CPUs;
- The CPUs in AMD Ryzen APUs;
- AMD Ryzen Threadripper CPUs
- AMD EPYC CPUs;
- Intel Xeon E7 v3 or newer CPUs;
- Intel Xeon E5 v3 or newer CPUs;
- Intel Xeon E3 v3 or newer CPUs;
- Intel Core i7 v4, Core i5 v4, Core i3 v4 or newer CPUs (i.e. Haswell family or newer).
- Some Ivy Bridge-E systems

Beginning with ROCm 1.8, GFX9 GPUs (such as Vega 10) no longer require PCIe atomics. We have similarly opened up more options for number of PCIe lanes. GFX9 GPUs can now be run on CPUs without PCIe atomics and on older PCIe generations, such as PCIe 2.0. This is not supported on GPUs below GFX9, e.g. GFX8 cards in the Fiji and Polaris families.

If you are using any PCIe switches in your system, please note that PCIe Atomics are only supported on some switches, such as Broadcom PLX. When you install your GPUs, make sure you install them in a PCIe 3.0 x16, x8, x4, or x1 slot attached either directly to the CPU’s Root I/O controller or via a PCIe switch directly attached to the CPU’s Root I/O controller.

In our experience, many issues stem from trying to use consumer motherboards which provide physical x16 connectors that are electrically connected as e.g. PCIe 2.0 x4, PCIe slots connected via the Southbridge PCIe I/O controller, or PCIe slots connected through a PCIe switch that does not support PCIe atomics.

If you attempt to run ROCm on a system without proper PCIe atomic support, you may see an error in the kernel log (`dmesg`):
Experimental support for our Hawaii (GFX7) GPUs (Radeon R9 290, R9 390, FirePro W9100, S9150, S9170) does not require or take advantage of PCIe Atomics. However, we still recommend that you use a CPU from the list provided above for compatibility purposes.

2.3.3.3 Not supported or limited support under ROCm

2.3.3.3.1 Limited support

- ROCm 2.6.x should support PCIe 2.0 enabled CPUs such as the AMD Opteron, Phenom, Phenom II, Athlon, Athlon X2, Athlon II and older Intel Xeon and Intel Core Architecture and Pentium CPUs. However, we have done very limited testing on these configurations, since our test farm has been catering to CPUs listed above. This is where we need community support. If you find problems on such setups, please report these issues.

- Thunderbolt 1, 2, and 3 enabled breakout boxes should now be able to work with ROCm. Thunderbolt 1 and 2 are PCIe 2.0 based, and thus are only supported with GPUs that do not require PCIe 3.0 atomics (e.g. Vega 10). However, we have done no testing on this configuration and would need community support due to limited access to this type of equipment.

- AMD “Carrizo” and “Bristol Ridge” APUs are enabled to run OpenCL, but do not yet support HCC, HIP, or our libraries built on top of these compilers and runtimes.
  - As of ROCm 2.1, “Carrizo” and “Bristol Ridge” require the use of upstream kernel drivers.
  - In addition, various “Carrizo” and “Bristol Ridge” platforms may not work due to OEM and ODM choices when it comes to key configurations parameters such as inclusion of the required CRAT tables and IOMMU configuration parameters in the system BIOS.
  - Before purchasing such a system for ROCm, please verify that the BIOS provides an option for enabling IOMMUv2 and that the system BIOS properly exposes the correct CRAT table. Inquire with your vendor about the latter.

- AMD “Raven Ridge” APUs are enabled to run OpenCL, but do not yet support HCC, HIP, or our libraries built on top of these compilers and runtimes.
  - As of ROCm 2.1, “Raven Ridge” requires the use of upstream kernel drivers.
  - In addition, various “Raven Ridge” platforms may not work due to OEM and ODM choices when it comes to key configurations parameters such as inclusion of the required CRAT tables and IOMMU configuration parameters in the system BIOS.
  - Before purchasing such a system for ROCm, please verify that the BIOS provides an option for enabling IOMMUv2 and that the system BIOS properly exposes the correct CRAT table. Inquire with your vendor about the latter.

2.3.3.3.2 Not supported

- “Tonga”, “Iceland”, “Vega M”, and “Vega 12” GPUs are not supported in ROCm 2.6.x

- We do not support GFX8-class GPUs (Fiji, Polaris, etc.) on CPUs that do not have PCIe 3.0 with PCIe atoms.
  - As such, we do not support AMD Carrizo and Kaveri APUs as hosts for such GPUs.
  - Thunderbolt 1 and 2 enabled GPUs are not supported by GFX8 GPUs on ROCm. Thunderbolt 1 & 2 are based on PCIe 2.0.
2.3.4 The latest ROCm platform - ROCm 2.6

The latest supported version of the drivers, tools, libraries and source code for the ROCm platform have been released and are available from the following GitHub repositories:

- ROCm Core Components
  - ROCk Kernel Driver
  - ROCr Runtime
  - ROCt Thunk Interface
- ROCm Support Software
  - ROCm SMI
  - ROCm cmake
  - rocminfo
  - ROCm Bandwidth Test
- ROCm Development Tools
  - HCC compiler
  - HIP
  - ROCm Device Libraries
  - ROCm OpenCL, which is created from the following components:
    * ROCm OpenCL Runtime
    * ROCm OpenCL Driver
      * The ROCm OpenCL compiler, which is created from the following components:
        · ROCm LLVM OCL
        · ROCm LLVM HCC
        · ROCm Clang
        · ROCm lld OCL
        · ROCm lld HCC
        · ROCm Device Libraries
  - ROCM Clang-OCL Kernel Compiler
  - Asynchronous Task and Memory Interface (ATMI)
  - ROCr Debug Agent
  - ROCm Code Object Manager
  - ROC Profiler
  - ROC Tracer
  - Radeon Compute Profiler
  - Example Applications:
    * HCC Examples
    * HIP Examples
• ROCm Libraries
  – rocBLAS
  – hipBLAS
  – rocFFT
  – rocRAND
  – rocSPARSE
  – hipSPARSE
  – rocALUTION
  – MIOpenGEMM
  – MIOpen
  – rocThrust
  – ROCm SMI Lib
  – RCCL
  – MIVisionX
  – HIP Thrust
  – hipCUB

2.3.4.1 Supported Operating Systems - New operating systems available

The ROCm 2.6.x platform supports the following operating systems:

• Ubuntu 16.04.x and 18.04.1 and 18.04.2 (Version 16.04.3 and newer or kernels 4.13-4.15)
• CentOS 7.4, 7.5, and 7.6 (Using devtoolset-7 runtime support)
• RHEL 7.4, 7.5, and 7.6 (Using devtoolset-7 runtime support)

2.3.4.2 ROCm support in upstream Linux kernels

As of ROCm 1.9.0, the ROCm user-level software is compatible with the AMD drivers in certain upstream Linux kernels. As such, users have the option of either using the ROCK kernel driver that are part of AMD’s ROCm repositories or using the upstream driver and only installing ROCm user-level utilities from AMD’s ROCm repositories.

These releases of the upstream Linux kernel support the following GPUs in ROCm:

• 4.17: Fiji, Polaris 10, Polaris 11
• 4.18: Fiji, Polaris 10, Polaris 11, Vega 10
• 4.20: Fiji, Polaris 10, Polaris 11, Vega 10, Vega 7nm

The upstream driver may be useful for running ROCm software on systems that are not compatible with the kernel driver available in AMD’s repositories. For users that have the option of using either AMD’s or the upstreamed driver, there are various tradeoffs to take into consideration:
<table>
<thead>
<tr>
<th>Using AMD’s rock-dkms package</th>
<th>Using the upstream kernel driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pros</td>
<td>Cons</td>
</tr>
<tr>
<td>More GPU features, and they are enabled earlier</td>
<td>May not work on all Linx distributions or versions</td>
</tr>
<tr>
<td>Tested by AMD on supported distributions</td>
<td>Not currently supported on kernels newer than 4.18.</td>
</tr>
<tr>
<td>Supported GPUs enabled regardless of kernel version</td>
<td>Limits GPU’s usage of system memory to 3/8 of system memory</td>
</tr>
<tr>
<td>Includes the latest GPU firmware</td>
<td>IPC and RDMA capabilities not yet enabled</td>
</tr>
<tr>
<td>Pros</td>
<td>Cons</td>
</tr>
<tr>
<td>Includes the latest Linux kernel features</td>
<td>Not tested by AMD to the same level as rock-dkms package</td>
</tr>
<tr>
<td>May work on other distributions and with custom kernels</td>
<td>Does not include most up-to-date firmware</td>
</tr>
</tbody>
</table>

### 2.3.5 Installing from AMD ROCm repositories

AMD hosts both Debian and RPM repositories for the ROCm 2.6.x packages at this time.

The packages in the Debian repository have been signed to ensure package integrity.

#### 2.3.5.1 ROCm Binary Package Structure

ROCM is a collection of software ranging from drivers and runtimes to libraries and developer tools. In AMD’s package distributions, these software projects are provided as a separate packages. This allows users to install only the packages they need, if they do not wish to install all of ROCm. These packages will install most of the ROCm software into `/opt/rocm/` by default.

The packages for each of the major ROCm components are:

- ROCm Core Components
  - ROCk Kernel Driver: rock-dkms
  - ROCr Runtime: hsa-rocr-dev, hsa-ext-rocr-dev
  - ROCt Thunk Interface: hsakmt-roct, hsakmt-roct-dev

- ROCm Support Software
  - ROCm SMI: rocm-smi
  - ROCm cmake: rocm-cmake
  - rocminfo: rocminfo
  - ROCm Bandwidth Test: rocm_bandwidth_test

- ROCm Development Tools
  - HCC compiler: hcc
  - HIP: hip_base, hip_doc, hip_hcc, hip_samples
  - ROCm Device Libraries: rocm-device-libs
  - ROCm OpenCL: rocm-opencl, rocm-opencl-devel (on RHEL/CentOS), rocm-opencl-dev (on Ubuntu)
- ROCM Clang-OCL Kernel Compiler: rocm-clang-ocl
- Asynchronous Task and Memory Interface (ATMI): atmi
- ROCr Debug Agent: rocr_debug_agent
- ROCm Code Object Manager: comgr
- ROC Profiler: rocprofiler-dev
- ROC Tracer: roctracer-dev
- Radeon Compute Profiler: rocm-profiler

- ROCm Libraries
  - rocBLAS: rocblas
  - hipBLAS: hipblas
  - rocFFT: rocfft
  - rocRAND: rocrand
  - rocSPARSE: rocsparse
  - hipSPARSE: hipsparse
  - rocALUTION: rocalution
  - MIOpenGEMM: miopengemm
  - MIOpen: MIOpen-HIP (for the HIP version), MIOpen-OpenCL (for the OpenCL version)
  - HIP Thrust: thrust (on RHEL/CentOS), hip-thrust (on Ubuntu)
  - ROCm SMI Lib: rocm_smi_lib64
  - RCCL: rccl
  - MIVisionX: mivisionx
  - rocThrust: roctracer-dev
  - hipCUB: hipCUB

To make it easier to install ROCm, the AMD binary repos provide a number of meta-packages that will automatically install multiple other packages. For example, rocm-dkms is the primary meta-package that is used to install most of the base technology needed for ROCm to operate. It will install the rock-dkms kernel driver, and another meta-package (rocm-dev) which installs most of the user-land ROCm core components, support software, and development tools.

The rocm-utils meta-package will install useful utilities that, while not required for ROCm to operate, may still be beneficial to have. Finally, the rocm-libs meta-package will install some (but not all) of the libraries that are part of ROCm.

The chain of software installed by these meta-packages is illustrated below

```
rocm-dkms
|-- rock-dkms
 \-- rocm-dev
      |-- hsa-rocr-dev
      |-- hsa-ext-rocr-dev
      |-- rocm-device-libs
      |-- rocm-utils
          |-- rocminfo
```

(continues on next page)
These meta-packages are not required but may be useful to make it easier to install ROCm on most systems. Some users may want to skip certain packages. For instance, a user that wants to use the upstream kernel drivers (rather than those supplied by AMD) may want to skip the `rocm-dkms` and `rock-dkms` packages, and instead directly install `rocm-dev`.

Similarly, a user that only wants to install OpenCL support instead of HCC and HIP may want to skip the `rocm-dkms` and `rocm-dev` packages. Instead, they could directly install `rock-dkms`, `rocm-opencl`, and `rocm-opencl-dev` and their dependencies.

### 2.3.5.2 Ubuntu Support - installing from a Debian repository

The following directions show how to install ROCm on supported Debian-based systems such as Ubuntu 18.04. These directions may not work as written on unsupported Debian-based distributions. For example, newer versions of Ubuntu may not be compatible with the `rock-dkms` kernel driver. As such, users may want to skip the `rocm-dkms` and `rock-dkms` packages, as described above, and instead use the upstream kernel driver.

#### 2.3.5.2.1 First make sure your system is up to date

```
sudo apt update
sudo apt dist-upgrade
sudo apt install libnuma-dev
sudo reboot
```

#### 2.3.5.2.2 Add the ROCm apt repository

For Debian-based systems like Ubuntu, configure the Debian ROCm repository as follows:

```
wget -qO - http://repo.radeon.com/rocm/apt/debian/rocm.gpg.key | sudo apt-key add -
echo 'deb [arch=amd64] http://repo.radeon.com/rocm/apt/debian/ xenial main' | sudo tee /etc/apt/sources.list.d/rocm.list
```
The gpg key might change, so it may need to be updated when installing a new release. If the key signature verification is failed while update, please re-add the key from ROCm apt repository. The current rocm.gpg.key is not available in a standard key ring distribution, but has the following sha1sum hash:

\[ \text{f7f8147431c75e505c58a6f3a3548510869357a6 rocm.gpg.key} \]

### 2.3.5.2.3 Install

Next, update the apt repository list and install the `rocm-dkms` meta-package:

```
sudo apt update
sudo apt install rocm-dkms
```

### 2.3.5.2.4 Next set your permissions

Users will need to be in the `video` group in order to have access to the GPU. As such, you should ensure that your user account is a member of the `video` group prior to using ROCm. You can find which groups you are a member of with the following command:

```
groups
```

To add yourself to the video group you will need the sudo password and can use the following command:

```
sudo usermod -a -G video $LOGNAME
```

You may want to ensure that any future users you add to your system are put into the “video” group by default. To do that, you can run the following commands:

```
echo 'ADD_EXTRA_GROUPS=1' | sudo tee -a /etc/adduser.conf
echo 'EXTRA_GROUPS=video' | sudo tee -a /etc/adduser.conf
```

Once complete, reboot your system.

### 2.3.5.2.5 Test basic ROCm installation

After rebooting the system run the following commands to verify that the ROCm installation was successful. If you see your GPUs listed by both of these commands, you should be ready to go!

```
/opt/rocm/bin/rocminfo
/opt/rocm/opencl/bin/x86_64/clinfo
```

Note that, to make running ROCm programs easier, you may wish to put the ROCm binaries in your PATH.

```
echo 'export PATH=$PATH:/opt/rocm/bin:/opt/rocm/profiler/bin:/opt/rocm/opencl/bin/x86_64' | sudo tee -a /etc/profile.d/rocm.sh
```

If you have an install issue please read this FAQ.

### 2.3.5.2.6 Performing an OpenCL-only Installation of ROCm

Some users may want to install a subset of the full ROCm installation. In particular, if you are trying to install on a system with a limited amount of storage space, or which will only run a small collection of known applications,
you may want to install only the packages that are required to run OpenCL applications. To do that, you can run the following installation command instead of the command to install rocm-dkms.

```shell
sudo apt-get install dkms rock-dkms rocm-opencl-dev
```

### 2.3.5.2.7 How to uninstall from Ubuntu 16.04 or Ubuntu 18.04

To uninstall the ROCm packages installed in the above directions, you can execute:

```shell
sudo apt autoremove rocm-dkms rocm-dev rocm-utils
```

### 2.3.5.2.8 Installing development packages for cross compilation

It is often useful to develop and test on different systems. For example, some development or build systems may not have an AMD GPU installed. In this scenario, you may prefer to avoid installing the ROCK kernel driver to your development system.

In this case, install the development subset of packages:

```shell
sudo apt update
sudo apt install rocm-dev
```

**Note:** To execute ROCm enabled apps you will require a system with the full ROCm driver stack installed

### 2.3.5.2.9 Using Debian-based ROCm with upstream kernel drivers

As described in the above section about upstream Linux kernel support, users may want to try installing ROCm user-level software without installing AMD’s custom ROCK kernel driver. Users who do want to use upstream kernels can run the following commands instead of installing rocm-dkms

```shell
sudo apt update
sudo apt install rocm-dev
echo 'SUBSYSTEM=="kfd", KERNEL=="kfd", TAG+="uaccess", GROUP="video"' | sudo tee /etc/udev/rules.d/70-kfd.rules
```

### 2.3.5.3 CentOS/RHEL 7 (7.4, 7.5, 7.6) Support

The following directions show how to install ROCm on supported RPM-based systems such as CentOS 7.6. These directions may not work as written on unsupported RPM-based distributions. For example, Fedora may work but may not be compatible with the rock-dkms kernel driver. As such, users may want to skip the rocm-dkms and rock-dkms packages, as described above, and instead use the upstream kernel driver.

Support for CentOS/RHEL 7 was added in ROCm 1.8, but ROCm requires a special runtime environment provided by the RHEL Software Collections and additional dkms support packages to properly install and run.

### 2.3.5.3.1 Preparing RHEL 7 (7.4, 7.5, 7.6) for installation

RHEL is a subscription-based operating system, and you must enable several external repositories to enable installation of the devtoolset-7 environment and the DKMS support files. These steps are not required for CentOS.
First, the subscription for RHEL must be enabled and attached to a pool id. Please see Obtaining an RHEL image and license page for instructions on registering your system with the RHEL subscription server and attaching to a pool id.

Second, enable the following repositories:

```
sudo subscription-manager repos --enable rhel-server-rhscl-7-rpms
sudo subscription-manager repos --enable rhel-7-server-optional-rpms
sudo subscription-manager repos --enable rhel-7-server-extras-rpms
```

Third, enable additional repositories by downloading and installing the epel-release-latest-7 repository RPM:

```
```

### 2.3.5.3.2 Install and setup Devtoolset-7

To setup the Devtoolset-7 environment, follow the instructions on this page:


Note that devtoolset-7 is a Software Collections package, and it is not supported by AMD.

### 2.3.5.3.3 Prepare CentOS/RHEL (7.4, 7.5, 7.6) for DKMS Install

Installing kernel drivers on CentOS/RHEL 7.4/7.5/7.6 requires dkms tool being installed:

```
sudo yum install -y epel-release
sudo yum install -y dkms kernel-headers-`uname -r` kernel-devel-`uname -r`
```

### 2.3.5.3.4 Installing ROCm on the system

It is recommended to remove previous ROCm installations before installing the latest version to ensure a smooth installation.

At this point ROCm can be installed on the target system. Create a `/etc/yum.repos.d/rocm.repo` file with the following contents:

```
[ROCm]
name=ROCm
baseurl=http://repo.radeon.com/rocm/yum.rpm
enabled=1
gpgcheck=0
```

The repo’s URL should point to the location of the repositories repodata database. Install ROCm components using these commands:

```
sudo yum install rocm-dkms
```

The rock-dkms component should be installed and the `/dev/kfd` device should be available on reboot.

### 2.3.5.3.5 Set up permissions

Ensure that your user account is a member of the “video” or “wheel” group prior to using the ROCm driver. You can find which groups you are a member of with the following command:
To add yourself to the video (or wheel) group you will need the sudo password and can use the following command:

```bash
sudo usermod -a -G video $LOGNAME
```

You may want to ensure that any future users you add to your system are put into the “video” group by default. To do that, you can run the following commands:

```bash
echo 'ADD_EXTRA_GROUPS=1' | sudo tee -a /etc/adduser.conf
echo 'EXTRA_GROUPS=video' | sudo tee -a /etc/adduser.conf
```

Current release supports CentOS/RHEL 7.4, 7.5, 7.6. If users want to update the OS version, they should completely remove ROCm packages before updating to the latest version of the OS, to avoid DKMS related issues.

Once complete, reboot your system.

### 2.3.5.3.6 Test basic ROCm installation

After rebooting the system run the following commands to verify that the ROCm installation was successful. If you see your GPUs listed by both of these commands, you should be ready to go!

```
/opt/rocm/bin/rocminfo
/opt/rocm/opencl/bin/x86_64/clinfo
```

Note that, to make running ROCm programs easier, you may wish to put the ROCm binaries in your PATH.

```bash
echo 'export PATH=$PATH:/opt/rocm/bin:/opt/rocm/profiler/bin:/opt/rocm/opencl/bin/x86_64' | sudo tee -a /etc/profile.d/rocm.sh
```

If you have an install issue please read this FAQ.

### 2.3.5.3.7 Performing an OpenCL-only Installation of ROCm

Some users may want to install a subset of the full ROCm installation. In particular, if you are trying to install on a system with a limited amount of storage space, or which will only run a small collection of known applications, you may want to install only the packages that are required to run OpenCL applications. To do that, you can run the following installation command instead of the command to install rocm-dkms.

```bash
sudo yum install rock-dkms rocm-opencl-devel
```

### 2.3.5.3.8 Compiling applications using HCC, HIP, and other ROCm software

To compile applications or samples, please use gcc-7.2 provided by the devtoolset-7 environment. To do this, compile all applications after running this command:

```
scl enable devtoolset-7 bash
```

### 2.3.5.3.9 How to uninstall ROCm from CentOS/RHEL 7.4, 7.5 and 7.6

To uninstall the ROCm packages installed by the above directions, you can execute:
2.3.5.3.10 Installing development packages for cross compilation

It is often useful to develop and test on different systems. For example, some development or build systems may not have an AMD GPU installed. In this scenario, you may prefer to avoid installing the ROCK kernel driver to your development system.

In this case, install the development subset of packages:

```
sudo yum install rocm-dev
```

**Note:** To execute ROCm enabled apps you will require a system with the full ROCm driver stack installed

2.3.5.3.11 Using ROCm with upstream kernel drivers

As described in the above section about upstream Linux kernel support, use rs may want to try installing ROCm user-level software without installing AMD’s custom ROCK kernel driver. Users who do want to use upstream kernels can run the following commands instead of installing `rocm-dkms`

```
sudo yum install rocm-dev
echo 'SUBSYSTEM=="kfd", KERNEL=="kfd", TAG+="uaccess", GROUP="video"' | sudo tee /etc/udev/rules.d/70-kfd.rules
```

2.3.6 Known issues / workarounds

2.3.6.1 Tensor flow

Observed memory access fault while running SAGAN TensorFlow model in Polaris based ASIC

2.3.6.2 Radeon Instinct MI50, MI60

PU reset is not currently supported on Radeon Instinct MI50, MI60, in single card configurations or with boards connected with AMD Infinity Fabric™ Link GPU interconnect technology. Workaround is to reboot the system.

2.3.6.3 Gromacs

There are known failures with a few tests on Gromacs on CentOS

2.3.6.4 HIP sample

HIP sample test fails at module_api_global with a segmentation fault
2.3.7 Closed source components

The ROCm platform relies on a few closed source components to provide functionality such as HSA image support. These components are only available through the ROCm repositories, and they will either be deprecated or become open source components in the future. These components are made available in the following packages:

- hsa-ext-rocr-dev

2.3.8 Getting ROCm source code

ROCm is built from open source software. As such, it is possible to make modifications to the various components of ROCm by downloading the source code, making modifications to it, and rebuilding the components. The source code for ROCm components can be cloned from each of the GitHub repositories using git. In order to make it easier to download the correct versions of each of these tools, this ROCm repository contains a repo manifest file, default.xml. Interested users can thus use this manifest file to download the source code for all of the ROCm software.

2.3.8.1 Installing repo

Google’s repo tool allows you to manage multiple git repositories simultaneously. You can install it by executing the following example commands:

```bash
mkdir -p ~/bin/
curl https://storage.googleapis.com/git-repo-downloads/repo > ~/bin/repo
chmod a+x ~/bin/repo
```

Note that you can choose a different folder to install repo into if you desire. `~/bin/` is simply used as an example.

2.3.8.2 Downloading the ROCm source code

The following example shows how to use the repo binary downloaded above to download all of the ROCm source code. If you chose a directory other than `~/bin/` to install repo, you should use that directory below.

```bash
mkdir -p ~/ROCm/
cd ~/ROCm/
~/bin/repo init -u https://github.com/RadeonOpenCompute/ROCm.git -b roc-2.6.0
repo sync
```

This will cause repo to download all of the open source code associated with this ROCm release. You may want to ensure that you have ssh-keys configured on your machine for your GitHub ID.

2.3.8.3 Building the ROCm source code

Each ROCm component repository contains directions for building that component. As such, you should go to the repository you are interested in building to find how to build it.

That said, AMD also offers a project that demonstrates how to download, build, package, and install ROCm software on various distributions. The scripts here may be useful for anyone looking to build ROCm components.

2.3.9 Deprecation Notice - HCC

AMD is deprecating HCC to put more focus on HIP development and on other languages supporting heterogeneous compute. We will no longer develop any new feature in HCC and we will stop maintaining HCC after its final release,
which is planned for end of the year, 2019. If your application was developed with the hc C++ API, we would
encourage you to transition it to other languages supported by AMD, such as HIP or OpenCL. HIP and hc language
share the same compiler technology, so many hc kernel language features (including inline assembly) are also available
through the HIP compilation path.

2.3.10 Final notes

- OpenCL Runtime and Compiler will be submitted to the Khronos Group for conformance testing prior to its
  final release.

2.4 Programming Guide

2.4.1 ROCm Languages

2.4.1.1 ROCm, Lingua Franca, C++, OpenCL and Python

The open-source ROCm stack offers multiple programming-language choices. The goal is to give you a range of tools
to help solve the problem at hand. Here, we describe some of the options and how to choose among them.

2.4.1.2 HCC: Heterogeneous Compute Compiler

What is the Heterogeneous Compute (HC) API? It’s a C++ dialect with extensions to launch kernels and manage
accelerator memory. It closely tracks the evolution of C++ and will incorporate parallelism and concurrency features
as the C++ standard does. For example, HC includes early support for the C++17 Parallel STL. At the recent ISO
C++ meetings in Kona and Jacksonville, the committee was excited about enabling the language to express all forms
of parallelism, including multicore CPU, SIMD and GPU. We’ll be following these developments closely, and you’ll
see HC move quickly to include standard C++ capabilities.

The Heterogeneous Compute Compiler (HCC) provides two important benefits:

Ease of development

- A full C++ API for managing devices, queues and events
- C++ data containers that provide type safety, multidimensional-array indexing and automatic data management
- C++ kernel-launch syntax using parallel_for_each plus C++11 lambda functions
- A single-source C++ programming environment—the host and device code can be in the same source file and
  use the same C++ language; templates and classes work naturally across the host/device boundary
- HCC generates both host and device code from the same compiler, so it benefits from a consistent view of the
  source code using the same Clang-based language parser

Full control over the machine

- Access AMD scratchpad memories (“LDS”)
- Fully control data movement, prefetch and discard
- Fully control asynchronous kernel launch and completion
- Get device-side dependency resolution for kernel and data commands (without host involvement)
- Obtain HSA agents, queues and signals for low-level control of the architecture using the HSA Runtime API
- Use [direct-to-ISA](https://github.com/RadeonOpenCompute/HCC-Native-GCN-ISA) compilation
2.4.1.3 When to Use HC

Use HC when you’re targeting the AMD ROCm platform: it delivers a single-source, easy-to-program C++ environment without compromising performance or control of the machine.

2.4.1.4 HIP: Heterogeneous-Computing Interface for Portability

What is Heterogeneous-Computing Interface for Portability (HIP)? It’s a C++ dialect designed to ease conversion of Cuda applications to portable C++ code. It provides a C-style API and a C++ kernel language. The C++ interface can use templates and classes across the host/kernel boundary.

The Hipify tool automates much of the conversion work by performing a source-to-source transformation from Cuda to HIP. HIP code can run on AMD hardware (through the HCC compiler) or Nvidia hardware (through the NVCC compiler) with no performance loss compared with the original Cuda code.

Programmers familiar with other GPGPU languages will find HIP very easy to learn and use. AMD platforms implement this language using the HC dialect described above, providing similar low-level control over the machine.

2.4.1.5 When to Use HIP

Use HIP when converting Cuda applications to portable C++ and for new projects that require portability between AMD and Nvidia. HIP provides a C++ development language and access to the best development tools on both platforms.

2.4.1.6 OpenCL™: Open Compute Language

What is OpenCL? It’s a framework for developing programs that can execute across a wide variety of heterogeneous platforms. AMD, Intel and Nvidia GPUs support version 1.2 of the specification, as do x86 CPUs and other devices (including FPGAs and DSPs). OpenCL provides a C run-time API and C99-based kernel language.

2.4.1.7 When to Use OpenCL

Use OpenCL when you have existing code in that language and when you need portability to multiple platforms and devices. It runs on Windows, Linux and Mac OS, as well as a wide variety of hardware platforms (described above).

2.4.1.8 Anaconda Python With Numba

What is Anaconda? It’s a modern open-source analytics platform powered by Python. Continuum Analytics, a ROCm platform partner, is the driving force behind it. Anaconda delivers high-performance capabilities including acceleration of HSA APUs, as well as ROCm-enabled discrete GPUs via Numba. It gives superpowers to the people who are changing the world.

2.4.1.9 Numba

Numba gives you the power to speed up your applications with high-performance functions written directly in Python. Through a few annotations, you can just-in-time compile array-oriented and math-heavy Python code to native machine instructions—offering performance similar to that of C, C++ and Fortran—without having to switch languages or Python interpreters.
Numba works by generating optimized machine code using the LLVM compiler infrastructure at import time, run time or statically (through the included Pycc tool). It supports Python compilation to run on either CPU or GPU hardware and is designed to integrate with Python scientific software stacks, such as NumPy.

- Anaconda® with Numba acceleration

### 2.4.1.10 When to Use Anaconda

Use Anaconda when you’re handling large-scale data-analytics, scientific and engineering problems that require you to manipulate large data arrays.

### 2.4.1.11 Wrap-Up

From a high-level perspective, ROCm delivers a rich set of tools that allow you to choose the best language for your application.

- HCC (Heterogeneous Compute Compiler) supports HC dialects
- HIP is a run-time library that layers on top of HCC (for AMD ROCm platforms; for Nvidia, it uses the NVCC compiler)
- The following will soon offer native compiler support for the GCN ISA:
  - OpenCL 1.2+
  - Anaconda (Python) with Numba

All are open-source projects, so you can employ a fully open stack from the language down to the metal. AMD is committed to providing an open ecosystem that gives developers the ability to choose; we are excited about innovating quickly using open source and about interacting closely with our developer community. More to come soon!
### 2.4.1.12 Table Comparing Syntax for Different Compute APIs

<table>
<thead>
<tr>
<th>Term</th>
<th>CUDA</th>
<th>HIP</th>
<th>HC</th>
<th>C++-AMP</th>
<th>OpenCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
<td>int deviceId</td>
<td>int deviceId</td>
<td>hc::accelerator</td>
<td>concurrency::accelerator</td>
<td>cl_device</td>
</tr>
<tr>
<td>Queue</td>
<td>cudaStream_t</td>
<td>hipStream_t</td>
<td>hc::accelerator_view</td>
<td>concurrency::accelerator_view</td>
<td>cl_command_queue</td>
</tr>
<tr>
<td>Event</td>
<td>cudaEvent_t</td>
<td>hipEvent_t</td>
<td>hc::completion_future</td>
<td>concurrency::completion_future</td>
<td>cl_event</td>
</tr>
<tr>
<td>Memory</td>
<td>void *</td>
<td>void *</td>
<td>void *; hc::array; hc::array_view</td>
<td>concurrency::array; concurrency::array_view</td>
<td>cl_mem</td>
</tr>
</tbody>
</table>

| | grid | grid | extent | tile | extent | tile | NDRange |
| | block | block | thread | thread | N/A | work-item | work-group |
| | thread | thread | warp | warp | N/A | N/A |
| | warp | warp | N/A | N/A | N/A | N/A |

| Thread index | threadIdx.x | hipThreadIdx_x | t_idx.local[0] | t_idx.local[0] | get_local_id(0) |
| Block index  | blockIdx.x  | hipBlockIdx_x  | t_idx.tile[0]  | t_idx.tile[0]  | get_group_id(0) |
| Block dim    | blockDim.x  | hipBlockDim_x  | t_ext.tile_dim[0] | t_idx.tile_dim0 | get_local_size(0) |
| Grid-dim     | gridDim.x   | hipGridDim_x   | t_ext[0]       | t_ext[0]       | get_global_size(0) |

| Device Function | __device___ | __device___ | [hc] (detected automatically in many case) | restrict(amp) | Implied in device Compilation |
| Host Function   | __host___ (default) | __host___ (default) | [cpu] (default) | strict(cpu) (default) | Implied in host Compilation |

| Host + Device Function | __host___ __device___ | __host___ __device___ | [hc] [cpu] | restrict(amp, cpu) | No equivalent |

| Kernel Launch | <<< >>> | hipLaunchKernel | hc::parallel_for_each | concurrency::parallel_for_each | clEnqueueNDRangeKernel |

| Global Memory  | __global___ | __global___ | Unnecessary/Implied | Unnecessary/Implied | Unspecified |
| Group Memory   | __shared___ | __shared___ | tile_static | tile_static | __local |
| Constant       | __constant___ | __constant___ | Unnecessary/Implied | Unnecessary / Implied | __constant |

| __syncthreads | __syncthreads | tile_static.barrier() | t_idx.local() | barrier(CK_LOCAL_MEMFENCE) |

| Atomic Builtins | atomicAdd | atomicAdd | hc::atomic_fetch_add | concurrency::atomic_fetch_add | atomic_add |
| Precise Math    | cos(f) | cos(f) | hc::precise_math::cos(f) | concurrency::precise_math::cos(f) | native_cos(f) |
| Fast Math       | __cos(f) | __cos(f) | hc::fast_math::cos(f) | concurrency::fast_math::cos(f) | native_cos(f) |
2.4.1.13 Notes

1. For HC and C++AMP, assume a captured _tiled_ext_ named “t_ext” and captured _extent_ named “ext”. These languages use captured variables to pass information to the kernel rather than using special built-in functions so the exact variable name may vary.

2. The indexing functions (starting with thread-index) show the terminology for a 1D grid. Some APIs use reverse order of xyz / 012 indexing for 3D grids.

3. HC allows tile dimensions to be specified at runtime while C++AMP requires that tile dimensions be specified at compile-time. Thus hc syntax for tile dims is t_ext.tile_dim[0] while C++AMP is t_ext.tile_dim0.

4. From ROCm version 2.0 onwards C++AMP is no longer available in HCC.

2.4.2 HC Programming Guide

What is the Heterogeneous Compute (HC) API ?

It’s a C++ dialect with extensions to launch kernels and manage accelerator memory. It closely tracks the evolution of C++ and will incorporate parallelism and concurrency features as the C++ standard does. For example, HC includes early support for the C++17 Parallel STL. At the recent ISO C++ meetings in Kona and Jacksonville, the committee was excited about enabling the language to express all forms of parallelism, including multicore CPU, SIMD and GPU. We’ll be following these developments closely, and you’ll see HC move quickly to include standard C++ capabilities.

The Heterogeneous Compute Compiler (HCC) provides two important benefits:

Ease of development

- A full C++ API for managing devices, queues and events
- C++ data containers that provide type safety, multidimensional-array indexing and automatic data management
- C++ kernel-launch syntax using parallel_for_each plus C++11 lambda functions
- A single-source C++ programming environment—the host and source code can be in the same source file and use the same C++ language; templates and classes work naturally across the host/device boundary
- HCC generates both host and device code from the same compiler, so it benefits from a consistent view of the source code using the same Clang-based language parser

Full control over the machine

- Access AMD scratchpad memories (“LDS”)
- Fully control data movement, prefetch and discard
- Fully control asynchronous kernel launch and completion
- Get device-side dependency resolution for kernel and data commands (without host involvement)
- Obtain HSA agents, queues and signals for low-level control of the architecture using the HSA Runtime API
- Use direct-to-ISA compilation

2.4.2.1 Platform Requirements

Accelerated applications could be run on Radeon discrete GPUs from the Fiji family (AMD R9 Nano, R9 Fury, R9 Fury X, FirePro S9300 x2, Polaris 10, Polaris 11) paired with an Intel Haswell CPU or newer. HCC would work with AMD HSA APUs (Kaveri, Carrizo); however, they are not our main support platform and some of the more advanced compute capabilities may not be available on the APUs.
HCC currently only works on Linux and with the open source ROCK kernel driver and the ROCR runtime (see Installation for details). It will not work with the closed source AMD graphics driver.

### 2.4.2.2 Compiler Backends

This backend compiles GPU kernels into native GCN ISA, which can be directly executed on the GPU hardware. It’s being actively developed by the Radeon Technology Group in LLVM.

**When to Use HC** Use HC when you’re targeting the AMD ROCm platform: it delivers a single-source, easy-to-program C++ environment without compromising performance or control of the machine.

### 2.4.2.3 Installation

**Prerequisites**

Before continuing with the installation, please make sure any previously installed hcc compiler has been removed from on your system. Install ROCm and make sure it works correctly.

#### 2.4.2.4 Ubuntu

**Ubuntu 14.04**

Support for 14.04 has been deprecated.

**Ubuntu 16.04**

Follow the instruction here to setup the ROCm apt repository and install the rocm or the rocm-dev meta-package.

**Fedora 24**

Follow the instruction here to setup the ROCm apt repository and install the rocm or the rocm-dev meta-package.

**RHEL 7.4/CentOS 7**

Follow the instruction here to setup the ROCm apt repository and install the rocm or the rocm-dev meta-package for RHEL/CentOS. Currently, HCC support for RHEL 7.4 and CentOS 7 is experimental and the compiler has to be built from source. Note: CentOS 7 cmake is outdated, will need to use alternate cmake3.

**openSUSE Leap 42.3**

Currently, HCC support for openSUSE is experimental and the compiler has to be built from source.

### 2.4.2.5 Download HCC

The project now employs git submodules to manage external components it depends upon. It it advised to add `--recursive` when you clone the project so all submodules are fetched automatically.

For example

```bash
# automatically fetches all submodules
```

---

Chapter 2. Solid Compilation Foundation and Language Support
## 2.4.2.6 Build HCC from source

First, install the build dependencies

```sh
# Ubuntu 14.04
sudo apt-get install git cmake make g++ g++-multilib gcc-multilib libc++-dev libc++1-
   _libc++abi-dev libc++abi1 python findutils libelf1 libpci3 file debianutils-
   _libunwind8-dev hsa-rocr-dev hsa-ext-rocr-dev hsakmt-roct-dev pkg-config rocm-utils

# Ubuntu 16.04
sudo apt-get install git cmake make g++ g++-multilib gcc-multilib python findutils-
   __libelf1 libpci3 file debianutils libunwind- dev hsa-rocr-dev hsa-ext-rocr-dev-
   _hsakmt-roct-dev pkg-config rocm-utils

# Fedora 23/24
sudo dnf install git cmake make gcc-c++ python findutils elfutils-libelf ppciutils-
   _-libs file pth rpm-build libunwind-devel hsa- rocr- dev hsa-ext-rocr-dev hsakmt-roct-
   _-dev pkgconfig rocm-utils
```

Clone the HCC source tree

```sh
# automatically fetches all submodules
   _git
```

Create a build directory and run cmake in that directory to configure the build

```sh
mkdir build;
cd build;
cmake ../hcc
```

Compile HCC

```sh
make -j
```

Run the unit tests

```sh
make test
```

Create an installer package (DEB or RPM file)

```sh
make package
```

To configure and build HCC from source, use the following steps

```sh
mkdir -p build; cd build
# NUM_BUILD_THREADS is optional
# set the number to your CPU core numbers time 2 is recommended
# in this example we set it to 96
   cmake -DNUM_BUILD_THREADS=96 \,
   -DCMAKE_BUILD_TYPE=Release \,
   ..
make
```

To install it, use the following steps
2.4.2.7 Use HCC

For C++AMP source codes

```
hcc `clamp-config --cxxflags --ldflags` foo.cpp
```

**WARNING:** From ROCm version 2.0 onwards C++AMP is no longer available in HCC.

For HC source codes

```
hcc `hcc-config --cxxflags --ldflags` foo.cpp
```

In case you build HCC from source and want to use the compiled binaries directly in the build directory:

For C++AMP source codes

```
# notice the --build flag
bin/hcc `bin/clamp-config --build --cxxflags --ldflags` foo.cpp
```

**WARNING:** From ROCm version 2.0 onwards C++AMP is no longer available in HCC.

For HC source codes

```
# notice the --build flag
bin/hcc `bin/hcc-config --build --cxxflags --ldflags` foo.cpp
```

### Compiling for Different GPU Architectures

By default, HCC will auto-detect all the GPU’s local to the compiling machine and set the correct GPU architectures. Users could use the `--amdgpu-target=<GCN Version>` option to compile for a specific architecture and to disable the auto-detection. The following table shows the different versions currently supported by HCC.

There exists an environment variable HCC_AMDGPU_TARGET to override the default GPU architecture globally for HCC; however, the usage of this environment variable is NOT recommended as it is unsupported and it will be deprecated in a future release.

<table>
<thead>
<tr>
<th>GCN Version</th>
<th>GPU/APU Family</th>
<th>Examples of Radeon GPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>gfx701</td>
<td>GFX7</td>
<td>FirePro W8100, FirePro W9100, Radeon R9 290, Radeon R9 390</td>
</tr>
<tr>
<td>gfx801</td>
<td>Carrizo APU</td>
<td>FX-8800P</td>
</tr>
<tr>
<td>gfx803</td>
<td>GFX8</td>
<td>R9 Fury, R9 Fury X, R9 Nano, FirePro S9300 x2, Radeon RX 480, Radeon RX 470, Radeon RX 460</td>
</tr>
<tr>
<td>gfx900</td>
<td>GFX9</td>
<td>Vega10</td>
</tr>
</tbody>
</table>

2.4.2.8 Multiple ISA

HCC now supports having multiple GCN ISAs in one executable file. You can do it in different ways: use :: `--amdgpu-target= command line option` It’s possible to specify multiple `--amdgpu-target=` option.

Example
# ISA for Hawaii(gfx701), Carrizo(gfx801), Tonga(gfx802) and Fiji(gfx803) would be produced

hcc `hcc-config --cxxflags --ldflags`
  --amdgpu-target=gfx701
  --amdgpu-target=gfx801
  --amdgpu-target=gfx802
  --amdgpu-target=gfx803
  foo.cpp

use :: HCC_AMDGPU_TARGET env var

Use, to delimit each AMDGPU target in HCC. Example

```bash
export HCC_AMDGPU_TARGET=gfx701,gfx801,gfx802,gfx803
```

# ISA for Hawaii(gfx701), Carrizo(gfx801), Tonga(gfx802) and Fiji(gfx803) would be produced

hcc `hcc-config --cxxflags --ldflags` foo.cpp

configure HCC using the CMake HSA_AMDGPU_GPU_TARGET variable

If you build HCC from source, it's possible to configure it to automatically produce multiple ISAs via ::

HSA_AMDGPU_GPU_TARGET CMake variable. Use ; to delimit each AMDGPU target. Example

```bash
# ISA for Hawaii(gfx701), Carrizo(gfx801), Tonga(gfx802) and Fiji(gfx803) would be produced by default
cmake \
  -DCMAKE_BUILD_TYPE=Release \
  -DRoCM_DEVICE_LIB_DIR=~hcc/ROCm-Device-Libs/build/dist/lib \
  -DHSA_AMDGPU_GPU_TARGET="gfx701;gfx801;gfx802;gfx803" \
  ../hcc
```

## 2.4.2.9 CodeXL Activity Logger

To enable the CodeXL Activity Logger, use the USE_CODEXL_ACTIVITY_LOGGER environment variable.

Configure the build in the following way

```bash
cmake \
  -DCMAKE_BUILD_TYPE=Release \
  -DHSA_AMDGPU_GPU_TARGET=<AMD GPU ISA version string> \
  -DRoCM_DEVICE_LIB_DIR=<location of the ROCm-Device-Libs bitcode> \
  -DUSE_CODEXL_ACTIVITY_LOGGER=1 \
  <ToT HCC checkout directory>
```

In your application compiled using hcc, include the CodeXL Activity Logger header

```c
#include <CXLActivityLogger.h>
```

For information about the usage of the Activity Logger for profiling, please refer to documentation

### 2.4.3 HC Best Practices

HC comes with two header files as of now:

- `hc.hpp`: Main header file for HC
- `hc_math.hpp`: Math functions for HC

# 2.4. Programming Guide
Most HC APIs are stored under “hc” namespace, and the class name is the same as their counterpart in C++AMP “Concurrency” namespace. Users of C++AMP should find it easy to switch from C++AMP to HC.

<table>
<thead>
<tr>
<th>C++AMP</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concurrency::accelerator</td>
<td>hc::accelerator</td>
</tr>
<tr>
<td>Concurrency::accelerator_view</td>
<td>hc::accelerator_view</td>
</tr>
<tr>
<td>Concurrency::extent</td>
<td>hc::extent</td>
</tr>
<tr>
<td>Concurrency::index</td>
<td>hc::index</td>
</tr>
<tr>
<td>Concurrency::completion_future</td>
<td>hc::completion_future</td>
</tr>
<tr>
<td>Concurrency::array</td>
<td>hc::array</td>
</tr>
<tr>
<td>Concurrency::array_view</td>
<td>hc::array_view</td>
</tr>
</tbody>
</table>

### 2.4.3.1 HCC built-in macros

#### Built-in macros:

<table>
<thead>
<tr>
<th>Macro</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HCC</strong></td>
<td>always be 1</td>
</tr>
<tr>
<td><strong>hcc_major</strong></td>
<td>major version number of HCC</td>
</tr>
<tr>
<td><strong>hcc_minor</strong></td>
<td>minor version number of HCC</td>
</tr>
<tr>
<td><strong>hcc_patchlevel</strong></td>
<td>patchlevel of HCC</td>
</tr>
<tr>
<td><strong>hcc_version</strong></td>
<td>combined string of <strong>hcc_major</strong>, <strong>hcc_minor</strong>, <strong>hcc_patchlevel</strong></td>
</tr>
</tbody>
</table>

The rule for __hcc_patchlevel__ is: yyWW-(HCC driver git commit #)-(HCC clang git commit #)

- yy stands for the last 2 digits of the year
- WW stands for the week number of the year

Macros for language modes in use:

<table>
<thead>
<tr>
<th>Macro</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KALMAR_AMP</strong></td>
<td>1 in case in C++ AMP mode (-std=c++amp; Removed from ROCm 2.0 onwards)</td>
</tr>
<tr>
<td><strong>KALMAR_HC</strong></td>
<td>1 in case in HC mode (-hc)</td>
</tr>
</tbody>
</table>

Compilation mode: HCC is a single-source compiler where kernel codes and host codes can reside in the same file. Internally HCC would trigger 2 compilation iterations, and the following macros can be used by user programs to determine which mode the compiler is in.

<table>
<thead>
<tr>
<th>Macro</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KALMAR_ACCELERATOR</strong></td>
<td>not 0 in case the compiler runs in kernel code compilation mode</td>
</tr>
<tr>
<td><strong>KALMAR_CPU</strong></td>
<td>not 0 in case the compiler runs in host code compilation mode</td>
</tr>
</tbody>
</table>

### 2.4.3.2 HC-specific features

- relaxed rules in operations allowed in kernels
- new syntax of tiled_extent and tiled_index
- dynamic group segment memory allocation
- true asynchronous kernel launching behavior
• additional HSA-specific APIs

2.4.3.3 Differences between HC API and C++ AMP

Despite HC and C++ AMP sharing many similar program constructs (e.g. parallel_for_each, array, array_view, etc.), there are several significant differences between the two APIs.

Support for explicit asynchronous parallel_for_each In C++ AMP, the parallel_for_each appears as a synchronous function call in a program (i.e. the host waits for the kernel to complete); however, the compiler may optimize it to execute the kernel asynchronously and the host would synchronize with the device on the first access of the data modified by the kernel. For example, if a parallel_for_each writes the an array_view, then the first access to this array_view on the host after the parallel_for_each would block until the parallel_for_each completes.

HC supports the automatic synchronization behavior as in C++ AMP. In addition, HC’s parallel_for_each supports explicit asynchronous execution. It returns a completion_future (similar to C++ std::future) object that other asynchronous operations could synchronize with, which provides better flexibility on task graph construction and enables more precise control on optimization.

Annotation of device functions

C++ AMP uses the restrict(amp) keyword to annotate functions that runs on the device.

```cpp
void foo() restrict(amp) { .. } ... parallel_for_each(..., [=] () restrict(amp) { foo(); });
```

HC uses a function attribute ([[hc]]) or __attribute__((hc)) to annotate a device function.

```cpp
void foo() [[hc]] { .. } ... parallel_for_each(..., [=] () [[hc]] { foo(); });
```

The [[hc]] annotation for the kernel function called by parallel_for_each is optional as it is automatically annotated as a device function by the hcc compiler. The compiler also supports partial automatic [[hc]] annotation for functions that are called by other device functions within the same source file:

```cpp
void bar() { .. } void foo() [[hc]] { bar(); }
```

Dynamic tile size

C++ AMP doesn’t support dynamic tile size. The size of each tile dimensions has to be a compile-time constant specified as template arguments to the tile_extent object:

```cpp
extent<2> ex(x, y)
```

To create a tile extent of 8x8 from the extent object, note that the tile dimensions have to be constant values:

```cpp
tiled_extent<8,8> t_ex(ex)
parallel_for_each(t_ex, [=](tiled_index<8,8> t_id) restrict(amp) { .. });
```

HC supports both static and dynamic tile size:

```cpp
extent<2> ex(x,y)
```

To create a tile extent from dynamically calculated values, note that the the tiled_extent template takes the rank instead of dimensions:

```cpp
tx = test_x ? tx_a : tx_b;
ty = test_y ? ty_a : ty_b;
tiled_extent<2> t_ex(ex, tx, ty);
```
parallel_for_each(t_ex, [=](tiled_index<2> t_id) [[hc]] { ... });

**Support for memory pointer**

C++ AMP doesn’t support lambda capture of memory pointer into a GPU kernel.

HC supports capturing memory pointer by a GPU kernel.

allocate GPU memory through the HSA API .. code:: sh

```sh
int* gpu_pointer; hsa_memory_allocate(…, &gpu_pointer); … parallel_for_each(ext, [=](index i) [[hc]]
{ gpu_pointer[i[0]]++; }
```

For HSA APUs that supports system wide shared virtual memory, a GPU kernel can directly access system memory allocated by the host: .. code:: sh

```sh
int* cpu_memory = (int*) malloc(…); … parallel_for_each(ext, [=](index i) [[hc]]
{ cpu_memory[i[0]]++; })
```

### 2.4.3.4 HCC Profile Mode

HCC supports low-overhead profiler to trace or summarize command timestamp information to stderr for any HCC or HIP program. Tho profiler messages are interleaved with the trace output from the application - which is handy to identify the region-of-interest and can complement deeper analysis with the CodeXL GUI. Additionally, the hcc profiler requires only console mode access and can be used on machine where graphics are not available or are hard to access.

Some other useful features:

- Calculates the actual bandwidth for memory transfers
- Identifies PeerToPeer memory copies
- Shows start / stop timestamps for each command (if requested)
- Shows barrier commands and the time they spent waiting to resolve (if requested)

**Enable and configure**

HCC_PROFILE=1 shows a summary of kernel and data commands when hcc exits (under development).

HCC_PROFILE=2 enables a profile message after each command (kernel or data movement) completes.

Additionally, the HCC_PROFILE_VERBOSE variable controls the information shown in the profile log. This is a bit-vector:

- 0x2 : Show start and stop timestamps for each command.
- 0x4 : Show the device.queue.cmdseqnum for each command.
- 0x8 : Show the short CPU TID for each command (not supported).
- 0x10 : Show logs for barrier commands.

**Sample Output**

### 2.4.3.4.1 Kernel Commands

This shows the simplest trace output for kernel commands with no additional verbosity flags.
This example shows profiled kernel commands with full verbose output:

```
$ HCC_PROFILE=2 ./my-hcc-app ...
profile: kernel; Im2Col; 17.8 us;
profile: kernel; tg_betac_alphaab; 32.6 us;
profile: kernel; MIOpenConvUni; 125.4 us;
```

**PROFILE:** always “profile:” to distinguish it from other output.

**TYPE:** the command type: kernel, copy, copy slo, or barrier. The examples and descriptions in this section are all kernel commands.

**KERNEL_NAME:** the (short) kernel name.

**DURATION:** command duration measured in us. This is measured using the GPU timestamps and represents the command execution on the accelerator device.

**START:** command start time in ns. (if HCC_PROFILE_VERBOSE & 0x2)

**STOP:** command stop time in ns. (if HCC_PROFILE_VERBOSE & 0x2)

**ID:** command id in device.queue.cmd format. (if HCC_PROFILE_VERBOSE & 0x4). The cmdseqnum is a unique monotonically increasing number per-queue, so the triple of device.queue.cmdseqnum uniquely identifies the command during the process execution.

### 2.4.3.4.2 Memory Copy Commands

This example shows memory copy commands with full verbose output:

```
$ HCC_PROFILE=2 HCC_PROFILE_VERBOSE=0xf ./my-hcc-app ...
profile: copyslo; HostToDevice_sync_slow; 909.2 us; 94859076277181; 94859076294941; #0.3.
→0; 2359296 bytes; 2.2 MB; 2.5 GB/s;
profile: copy; DeviceToHost_sync_fast; 117.0 us; 94859537593679; 94859537626319; #0.3.
→0; 1228800 bytes; 1.2 MB; 10.0 GB/s;
profile: copy; DeviceToHost_sync_fast; 9.0 us; 94860077852212; 94860077977651; #0.3.
→0; 400 bytes; 0.0 MB; 0.0 GB/s;
profile: copy; HostToDevice_sync_fast; 15.2 us; 94858726668; 94858726677; #0.0.
→0; 9600 bytes; 0.0 MB; 0.6 GB/s;
profile: copy; HostToDevice_async_fast; 131.5 us; 94858729198; 94858729330; #0.6.
→1; 1228800 bytes; 1.2 MB; 8.9 GB/s;
```

**PROFILE:** always “profile:” to distinguish it from other output.

**TYPE:** the command type: kernel, copy, copy slo, or barrier. The examples and descriptions in this section are all copy or copy slo commands.
• **COPY_NAME has 3 parts:**
  - Copy kind: HostToDevice, HostToHost, DeviceToHost, DeviceToDevice, or PeerToPeer. DeviceToDevice indicates the copy occurs on a single device while PeerToPeer indicates a copy between devices.
  - Sync or Async. Synchronous copies indicate the host waits for the completion for the copy. Asynchronous copies are launched by the host without waiting for the copy to complete.
  - Fast or Slow. Fast copies use the GPUs optimized copy routines from the hsa_amd_memory_copy routine. Slow copies typically involve unpinned host memory and can’t take the fast path.
  - For example *HostToDevice_async_fast*.

• **DURATION:** command duration measured in us. This is measured using the GPU timestamps and represents the command execution on the accelerator device.

• **START:** command start time in ns. (if HCC_PROFILE_VERBOSE & 0x2)

• **STOP:** command stop time in ns. (if HCC_PROFILE_VERBOSE & 0x2)

• **ID:** command id in device.queue.cmd format. (if HCC_PROFILE_VERBOSE & 0x4). The cmdsequm is a unique monotonically increasing number per-queue, so the triple of device.queue.cmdseqnum uniquely identifies the command during the process execution.

• **SIZE_BYTES:** the size of the transfer, measured in bytes.

• **SIZE_MB:** the size of the transfer, measured in megabytes.

• **BANDWIDTH:** the bandwidth of the transfer, measured in GB/s.

### 2.4.3.4.3 Barrier Commands

Barrier commands are only enabled if HCC_PROFILE_VERBOSE 0x10

An example barrier command with full verbosity

```
profile: barrier; deps:0_acq:none_rel:sys; 5.3 us; 9458731419410; 9458731424690;
→# 0.0.2;
PROFILE: TYPE; BARRIER_NAME ; DURATION; START ; STOP ;
→ID ;
```

- **PROFILE:** always “profile:” to distinguish it from other output.
- **TYPE:** the command type: either kernel, copy, copysslo, or barrier. The examples and descriptions in this section are all copy commands. Copy indicates that the runtime used a call to the fast hsa memory copy routine while copysslo indicates that the copy was implemented with staging buffers or another less optimal path. copy computes the commands using device-side timestamps while copysslo computes the bandwidth based on host timestamps.

- **BARRIER_NAME has 3 parts:**
  - *deps:#* - the number of input dependencies into the barrier packet.
  - *acq:* - the acquire fence for the barrier. May be none, acc(accelerator or agent), sys(system). See HSA AQL spec for additional information.
  - *rel:* - the release fence for the barrier. May be none, acc(accelerator or agent), sys(system). See HSA AQL spec for additional information.

- **DURATION:** command duration measured in us. This is measured using the GPU timestamps from the time the barrier reaches the head of the queue to when it executes. Thus this includes the time to wait for all input dependencies, plus the previous command to complete, plus any fence operations performed by the barrier.
• START: command start time in ns. (if HCC_PROFILE_VERBOSE & 0x2)
• STOP: command stop time in ns. (if HCC_PROFILE_VERBOSE & 0x2)
• ID: the command id in device.queue.cmd format. (if HCC_PROFILE_VERBOSE & 0x4). The cmdseqnum is a unique monotonically increasing number per-queue, so the triple of device.queue.cmdseqnum uniquely identifies the command during the process execution.

2.4.3.4.4 Overhead

The hcc profiler does not add any additional synchronization between commands or queues. Profile information is recorded when a command is deleted. The profile mode will allocate a signal for each command to record the timestamp information. This can add 1-2 us to the overall program execution for command which do not already use a completion signal. However, the command duration (start-stop) is still accurate. Trace mode will generate strings to stderr which will likely impact the overall application execution time. However, the GPU duration and timestamps are still valid. Summary mode accumulates statistics into an array and should have little impact on application execution time.

2.4.3.4.5 Additional Details and tips

• Commands are logged in the order they are removed from the internal HCC command tracker. Typically this is the same order that commands are dispatched, though sometimes these may diverge. For example, commands from different devices, queues, or cpu threads may be interleaved on the hcc trace display to stderr. If a single view in timeline order is required, enable and sort by the profiler START timestamps (HCC_PROFILE_VERBOSE=0x2)
• If the application keeps a reference to a completion_future, then the command timestamp may be reported significantly after it occurs.
• HCC_PROFILE has an (untested) feature to write to a log file.

2.4.3.5 API documentation

API reference of HCC

2.4.4 HIP Programing Guide

HIP provides a C++ syntax that is suitable for compiling most code that commonly appears in compute kernels, including classes, namespaces, operator overloading, templates and more. Additionally, it defines other language features designed specifically to target accelerators, such as the following:

• A kernel-launch syntax that uses standard C++, resembles a function call and is portable to all HIP targets
• Short-vector headers that can serve on a host or a device
• Math functions resembling those in the “math.h” header included with standard C++ compilers
• Built-in functions for accessing specific GPU hardware capabilities

This section describes the built-in variables and functions accessible from the HIP kernel. It’s intended for readers who are familiar with Cuda kernel syntax and want to understand how HIP is different.

• HIP-GUIDE
2.4.5 HIP Best Practices

• HIP-porting-guide
• HIP-terminology
• hip_profiling
• HIP_Debugging
• Kernel_language
• HIP-Terms
• HIP-bug
• hipporting-driver-api
• CUDAAPIHIP
• CUDAAPIHIPTEXTURE
• HIP-FAQ
• HIP-Term2

2.4.6 OpenCL Programming Guide

• Opencl-Programming-Guide

2.4.7 OpenCL Best Practices

• Optimization-Opencl

2.5 ROCm GPU Tuning Guides

2.5.1 GFX7 Tuning Guide

2.5.2 GFX8 Tuning Guide

2.5.3 Vega Tuning Guide

2.6 GCN ISA Manuals

2.6.1 GCN 1.1

ISA Manual for Hawaii pdf

2.6.2 GCN 2.0

ISA Manual for Fiji and Polaris pdf
2.6.3 Vega

- testdocbook

2.6.4 Inline GCN ISA Assembly Guide

2.6.4.1 The Art of AMDGCN Assembly: How to Bend the Machine to Your Will

The ability to write code in assembly is essential to achieving the best performance for a GPU program. In a previous blog we described how to combine several languages in a single program using ROCm and Hsaco. This article explains how to produce Hsaco from assembly code and also takes a closer look at some new features of the GCN architecture. I’d like to thank Ilya Perminov of Luxsoft for co-authoring this blog post. Programs written for GPUs should achieve the highest performance possible. Even carefully written ones, however, won’t always employ 100% of the GPU’s capabilities. Some reasons are the following:

- The program may be written in a high level language that does not expose all of the features available on the hardware.
- The compiler is unable to produce optimal ISA code, either because the compiler needs to ‘play it safe’ while adhering to the semantics of a language or because the compiler itself is generating un-optimized code.

Consider a program that uses one of GCN’s new features (source code is available on GitHub). Recent hardware architecture updates—DPP and DS Permute instructions—enable efficient data sharing between wavefront lanes. To become more familiar with the instruction set, review the GCN ISA Reference Guide. Note: the assembler is currently experimental; some of syntax we describe may change.

2.6.4.2 DS Permute Instructions

Two new instructions, ds_permute_b32 and ds_bpermute_b32, allow VGPR data to move between lanes on the basis of an index from another VGPR. These instructions use LDS hardware to route data between the 64 lanes, but they don’t write to LDS memory. The difference between them is what to index: the source-lane ID or the destination-lane ID. In other words, ds_permute_b32 says “put my lane data in lane i,” and ds_bpermute_b32 says “read data from lane i.” The GCN ISA Reference Guide provides a more formal description. The test kernel is simple: read the initial data and indices from memory into GPRs, do the permutation in the GPRs and write the data back to memory. An analogous OpenCL kernel would have this form:

```
__kernel void hello_world(__global const uint * in, __global const uint * index, __global uint * out)
{
    size_t i = get_global_id(0);
    out[i] = in[index[i]];
}
```

2.6.4.3 Passing Parameters to a Kernel

Formal HSA arguments are passed to a kernel using a special read-only memory segment called kernarg. Before a wavefront starts, the base address of the kernarg segment is written to an SGPR pair. The memory layout of variables in kernarg must employ the same order as the list of kernel formal arguments, starting at offset 0, with no padding between variables—except to honor the requirements of natural alignment and any align qualifier. The example host program must create the kernarg segment and fill it with the buffer base addresses. The HSA host code might look like the following:

2.6. GCN ISA Manuals
/*
 * This is the host-side representation of the kernel arguments that the simplePermute_
 * kernel expects.
 */

struct simplePermute_args_t {
    uint32_t * in;
    uint32_t * index;
    uint32_t * out;
};

/* Allocate the kernel-argument buffer from the correct region. */

hsa_status_t status;
simplePermute_args_t * args = NULL;
status = hsa_memory_allocate(kernarg_region, sizeof(simplePermute_args_t), (void**)&args);
assert(HSA_STATUS_SUCCESS == status);
aql->kernarg_address = args;

/* Write the args directly to the kernargs buffer;
 * the code assumes that memory is already allocated for the
 * buffers that in_ptr, index_ptr and out_ptr point to
 */

args->in = in_ptr;
args->index = index_ptr;
args->out = out_ptr;

The host program should also allocate memory for the in, index and out buffers. In the GitHub repository, all the
run-time-related stuff is hidden in the Dispatch and Buffer classes, so the sample code looks much cleaner:

// Create Kernarg segment
if (!AllocateKernarg(3 * sizeof(void*))) { return false; }

// Create buffers
Buffer *in, *index, *out;
in = AllocateBuffer(size);
index = AllocateBuffer(size);
out = AllocateBuffer(size);

// Fill Kernarg memory
Kernarg(in); // Add base pointer to “in” buffer
Kernarg(index); // Append base pointer to “index” buffer
Kernarg(out); // Append base pointer to “out” buffer

Initial Wavefront and Register State To launch a kernel in real hardware, the run time needs information about the
kernel, such as

- The LDS size
- The number of GPRs
- Which registers need initialization before the kernel starts

All this data resides in the amd_kernel_code_t structure. A full description of the structure is available in
the AMDGPU-ABI specification. This is what it looks like in source code:

.hsa_code_object_version 2,0
.hsa_code_object_isa 8, 0, 3, "AMD", "AMDGPU"

(continues on next page)
Currently, a programmer must manually set all non-default values to provide the necessary information. Hopefully, this situation will change with new updates that bring automatic register counting and possibly a new syntax to fill that structure. Before the start of every wavefront execution, the GPU sets up the register state on the basis of the enable_sgpr_* and enable_vgpr_* flags. VGPR v0 is always initialized with a work-item ID in the x dimension. Registers v1 and v2 can be initialized with work-item IDs in the y and z dimensions, respectively. Scalar GPRs can be initialized with a work-group ID and work-group count in each dimension, a dispatch ID, and pointers to kernarg, the aql packet, the aql queue, and so on. Again, the AMDGPU-ABI specification contains a full list in the section on initial register state. For this example, a 64-bit base kernarg address will be stored in the s[0:1] registers (enable_sgpr_kernarg_segment_ptr = 1), and the work-item thread ID will occupy v0 (by default). Below is the scheme showing initial state for our kernel: initial_state

```
2.6.4.4 The GPR Counting

The next amd_kernel_code_t fields are obvious: is_ptr64 = 1 says we are in 64-bit mode, and kernarg_segment_byte_size = 24 describes the kernarg segment size. The GPR counting is less straightforward,
however. The workitem_vgpr_count holds the number of vector registers that each work item uses, and wavefront_sgpr_count holds the number of scalar registers that a wavefront uses. The code above employs v0–v4, so workitem_vgpr_count = 5. But wavefront_sgpr_count = 8 even though the code only shows s0–s5, since the special registers VCC, FLAT_SCRATCH and XNACK are physically stored as part of the wavefront’s SGPRs in the highest-numbered SGPRs. In this example, FLAT_SCRATCH and XNACK are disabled, so VCC has only two additional registers. In current GCN3 hardware, VGPRs are allocated in groups of 4 registers and SGPRs in groups of 16. Previous generations (GCN1 and GCN2) have a VGPR granularity of 4 registers and an SGPR granularity of 8 registers. The fields compute_pgm_rsrc1_gprs contain a device-specific number for each register-block type to allocate for a wavefront. As we said previously, future updates may enable automatic counting, but for now you can use following formulas for all three GCN GPU generations:

compute_pgm_rsrc1_vgprs = (workitem_vgpr_count-1)/4
compute_pgm_rsrc1_sgprs = (wavefront_sgpr_count-1)/8

Now consider the corresponding assembly:

```assembly
// initial state:
// s[0:1] - kernarg base address
// v0 - workitem id
s_load_dwordx2 s[4:5], s[0:1], 0x10 // load out_ptr into s[4:5] from kernarg
s_load_dwordx4 s[0:3], s[0:1], 0x00 // load in_ptr into s[0:1] and index_ptr into
--s[2:3] from kernarg
v_lshlrev_b32 v0, 2, v0 // v0 *= 4;
s_waitcnt lgkmcnt(0) // wait for memory reads to finish

// compute address of corresponding element of index buffer
// i.e. v[1:2] = index[workitem_id]
v_add_u32 v1, vcc, s2, v0
v_mov_b32 v2, s3
v_addc_u32 v2, vcc, v2, 0, vcc

// compute address of corresponding element of in buffer
// i.e. v[3:4] = in[workitem_id]
v_add_u32 v3, vcc, s0, v0
v_mov_b32 v4, s1
v_addc_u32 v4, vcc, v4, 0, vcc

flat_load_dword v1, v[1:2] // load index[workitem_id] into v1
s_waitcnt vmcnt(0) & lgkmcnt(0) // wait for memory reads to finish

// v1 *= 4; ds_bpermute_b32 uses byte offset and registers are dwords
v_lshlrev_b32 v1, 2, v1

// perform permutation
// temp[thread_id] = v2
// v1 = temp[v1]
// effectively we got v1 = in[index[thread_id]]
ds_bpermute_b32 v1, v1, v2

// compute address of corresponding element of out buffer
// i.e. v[3:4] = out[workitem_id]
v_add_u32 v3, vcc, s4, v0
v_mov_b32 v2, s5
v_addc_u32 v4, vcc, v2, 0, vcc
```

(continues on next page)
2.6.4.5 Compiling GCN ASM Kernel Into Hsaco

The next step is to produce a Hsaco from the ASM source. LLVM has added support for the AMDGCN assembler, so you can use Clang to do all the necessary magic:

```
clang -x assembler -target amdgcn--amdhsa -mcpu=fiji -c -o test.o asm_source.s
clang -target amdgcn--amdhsa test.o -o test.co
```

The first command assembles an object file from the assembly source, and the second one links everything (you could have multiple source files) into a Hsaco. Now, you can load and run kernels from that Hsaco in a program. The GitHub examples use Cmake to automatically compile ASM sources. In a future post we will cover DPP, another GCN cross-lane feature that allows vector instructions to grab operands from a neighboring lane.

2.7 ROCm API References

2.7.1 ROCr System Runtime API

- ROCr-API

2.7.2 HCC Language Runtime API

- HCC-API

2.7.3 HIP Language Runtime API

- HIP-API

2.7.4 HIP Math API

- HIP-MATH

2.7.5 hipThrust API Documentation

- HIP-thrust
2.7.6 Math Library API’s

- hcRNG
- clBLAS
- clSPARSE_API

2.7.7 Deep Learning API’s

- MIOpen API
- MIOpenGEMM API

2.8 ROCm Tools

2.8.1 HCC

**HCC is an Open Source, Optimizing C++ Compiler for Heterogeneous Compute**

This repository hosts the HCC compiler implementation project. The goal is to implement a compiler that takes a program that conforms to a parallel programming standard such as C++ AMP, HC, C++ 17 ParallelSTL, or OpenMP, and transforms it into the AMD GCN ISA.

The project is based on LLVM+CLANG. For more information, please visit the HCCwiki

2.8.1.1 Download HCC

The project now employs git submodules to manage external components it depends upon. It it advised to add --recursive when you clone the project so all submodules are fetched automatically.

For example:

```
# automatically fetches all submodules
```

For more information about git submodules, please refer to git documentation.

2.8.1.2 Build HCC from source

To configure and build HCC from source, use the following steps:

```
mkdir -p build; cd build
cmake -DCMAKE_BUILD_TYPE=Release ..
make
```

To install it, use the following steps:

```
sudo make install
```
2.8.1.3 Use HCC

For C++AMP source codes:

```
hcc `clamp-config --cxxflags --ldflags` foo.cpp
```

**WARNING:** From ROCm version 2.0 onwards C++AMP is no longer available in HCC.

For HC source codes:

```
hcc `hcc-config --cxxflags --ldflags` foo.cpp
```

In case you build HCC from source and want to use the compiled binaries directly in the build directory:

For C++AMP source codes:

```
# notice the --build flag
bin/hcc `bin/clamp-config --build --cxxflags --ldflags` foo.cpp
```

**WARNING:** From ROCm version 2.0 onwards C++AMP is no longer available in HCC.

For HC source codes:

```
# notice the --build flag
bin/hcc `bin/hcc-config --build --cxxflags --ldflags` foo.cpp
```

2.8.1.4 Multiple ISA

HCC now supports having multiple GCN ISAs in one executable file. You can do it in different ways: use `--amdgpu-target=` command line option.

It's possible to specify multiple `--amdgpu-target=` option.

Example:

```
# ISA for Hawaii(gfx701), Carrizo(gfx801), Tonga(gfx802) and Fiji(gfx803) would be produced
hcc `hcc-config --cxxflags --ldflags`
    --amdgpu-target=gfx701
    --amdgpu-target=gfx801
    --amdgpu-target=gfx802
    --amdgpu-target=gfx803
    foo.cpp
```

use `HCC_AMDGPU_TARGET` env var

use `,` to delimit each AMDGPU target in HCC. Example:

```
export HCC_AMDGPU_TARGET=gfx701,gfx801,gfx802,gfx803
# ISA for Hawaii(gfx701), Carrizo(gfx801), Tonga(gfx802) and Fiji(gfx803) would be produced
hcc `hcc-config --cxxflags --ldflags` foo.cpp
```

configure HCC use CMake `HSA_AMDGPU_GPU_TARGET` variable

If you build HCC from source, it's possible to configure it to automatically produce multiple ISAs via `HSA_AMDGPU_GPU_TARGET` CMake variable.

Use `,` to delimit each AMDGPU target. Example:
# ISA for Hawaii(gfx701), Carrizo(gfx801), Tonga(gfx802) and Fiji(gfx803) would
# be produced by default

cmake \n    -DCMAKE_BUILDTYPE=Release \n    -DROCM_DEVICE_LIB_DIR=~hcc/ROCm-Device-Libs/build/dist/lib \n    -DHSA_AMDGPU_GPU_TARGET="gfx701;gfx801;gfx802;gfx803" \n../hcc

2.8.1.5 CodeXL Activity Logger

To enable the CodeXL Activity Logger, use the USE_CODEXL_ACTIVITY_LOGGER environment variable.

Configure the build in the following way:

cmake \
    -DCMAKE_BUILDTYPE=Release \
    -DHSA_AMDGPU_GPU_TARGET=<AMD GPU ISA version string> \
    -DROCM_DEVICE_LIB_DIR=<location of the ROCm-Device-Libs bitcode> \
    -DUSE_CODEXL_ACTIVITY_LOGGER=1 \
    <ToT HCC checkout directory>

In your application compiled using hcc, include the CodeXL Activity Logger header:

```
#include <CXLActivityLogger.h>
```

For information about the usage of the Activity Logger for profiling, please refer to its documentation.

2.8.1.6 HCC with ThinLTO Linking

To enable the ThinLTO link time, use the KMTHINLTO environment variable.

Set up your environment in the following way:

```
export KMTHINLTO=1
```

**ThinLTO Phase 1 - Implemented**

For applications compiled using hcc, ThinLTO could significantly improve link-time performance. This implementation will maintain kernels in their .bc file format, create module-summaries for each, perform llvm-lto’s cross-module function importing and then perform clamp-device (which uses opt and llc tools) on each of the kernel files. These files are linked with lld into one .hsaco per target specified.

**ThinLTO Phase 2 - Under development** This ThinLTO implementation which will use llvm-lto LLVM tool to replace clamp-device bash script. It adds an optllc option into ThinLTOGenerator, which will perform in-program opt and codegen in parallel.

2.8.2 GCN Assembler and Disassembler

The ability to write code in assembly is essential to achieving the best performance for a GPU program. In a previous blog we described how to combine several languages in a single program using ROCm and Hsaco. This article explains how to produce Hsaco from assembly code and also takes a closer look at some new features of the GCN architecture.

I’d like to thank Ilya Perminov of Luxsoft for co-authoring this blog post. Programs written for GPUs should achieve the highest performance possible. Even carefully written ones, however, won’t always employ 100% of the GPU’s capabilities. Some reasons are the following:
The program may be written in a high level language that does not expose all of the features available on the hardware.

The compiler is unable to produce optimal ISA code, either because the compiler needs to ‘play it safe’ while adhering to the semantics of a language or because the compiler itself is generating un-optimized code.

Consider a program that uses one of GCN’s new features (source code is available on GitHub). Recent hardware architecture updates—DPP and DS Permute instructions—enable efficient data sharing between wavefront lanes. To become more familiar with the instruction set, review the GCN ISA Reference Guide. Note: the assembler is currently experimental; some of syntax we describe may change.

Two new instructions, ds_permute_b32 and ds_bpermute_b32, allow VGPR data to move between lanes on the basis of an index from another VGPR. These instructions use LDS hardware to route data between the 64 lanes, but they don’t write to LDS memory. The difference between them is what to index: the source-lane ID or the destination-lane ID. In other words, ds_permute_b32 says “put my lane data in lane i,” and ds_bpermute_b32 says “read data from lane i.” The GCN ISA Reference Guide provides a more formal description. The test kernel is simple: read the initial data and indices from memory into GPRs, do the permutation in the GPRs and write the data back to memory. An analogous OpenCL kernel would have this form:

```c
__kernel void hello_world(__global const uint * in, __global const uint * index, __global uint * out)
{
    size_t i = get_global_id(0);
    out[i] = in[index[i]]
}
```

Formal HSA arguments are passed to a kernel using a special read-only memory segment called kernarg. Before a wavefront starts, the base address of the kernarg segment is written to an SGPR pair. The memory layout of variables in kernarg must employ the same order as the list of kernel formal arguments, starting at offset 0, with no padding between variables—except to honor the requirements of natural alignment and any align qualifier. The example host program must create the kernarg segment and fill it with the buffer base addresses. The HSA host code might look like the following:

```c
/*
 * This is the host-side representation of the kernel arguments that the simplePermute
 * kernel expects.
 */
struct simplePermute_args_t {
    uint32_t * in;
    uint32_t * index;
    uint32_t * out;
};
/*
 * Allocate the kernel-argument buffer from the correct region.
 */
hsa_status_t status;
simplePermute_args_t * args = NULL;
status = hsa_memory_allocate(kernarg_region, sizeof(simplePermute_args_t), (void**)(&args));
assert(HSA_STATUS_SUCCESS == status);
aql->kernarg_address = args;
/*
 * Write the args directly to the kernargs buffer;
 * the code assumes that memory is already allocated for the
 * buffers that in_ptr, index_ptr and out_ptr point to
 */
args->in = in_ptr;
```

(continues on next page)
The host program should also allocate memory for the in, index and out buffers. In the GitHub repository, all the run-time-related stuff is hidden in the Dispatch and Buffer classes, so the sample code looks much cleaner:

```c
// Create Kernarg segment
if (!AllocateKernarg(3 * sizeof(void*))) { return false; }

// Create buffers
Buffer *in, *index, *out;
in = AllocateBuffer(size);
index = AllocateBuffer(size);
out = AllocateBuffer(size);

// Fill Kernarg memory
Kernarg(in); // Add base pointer to "in" buffer
Kernarg(index); // Append base pointer to "index" buffer
Kernarg(out); // Append base pointer to "out" buffer
```

Initial Wavefront and Register State To launch a kernel in real hardware, the run time needs information about the kernel, such as

- The LDS size
- The number of GPRs
- Which registers need initialization before the kernel starts

All this data resides in the amd_kernel_code_t structure. A full description of the structure is available in the AMDGPU-ABI specification. This is what it looks like in source code:

```c
.hsa_code_object_version 2,0
.hsa_code_object_isa 8, 0, 3, "AMD", "AMDGPU"

.text
.p2align 8
.amdgpu_hsa_kernel hello_world

hello_world:

.amd_kernel_code_t
enable_sgpr_kernarg_segment_ptr = 1
is_ptr64 = 1
compute_pgm_rsrc1_vgprs = 1
compute_pgm_rsrc1_sgprs = 0
compute_pgm_rsrc2_user_sgpr = 2
kernarg_segment_byte_size = 24
wavefront_sgpr_count = 8
workitem_vgpr_count = 5
.end_amd_kernel_code_t

s_load_dwordx2 s[4:5], s[0:1], 0x10
s_load_dwordx4 s[0:3], s[0:1], 0x00
v_lshlrev_b32 v0, 2, v0
s_waitcnt lgkmcnt(0)
v_add_u32 v1, vcc, s2, v0
v_mov_b32 v2, s3
```

(continues on next page)
Currently, a programmer must manually set all non-default values to provide the necessary information. Hopefully, this situation will change with new updates that bring automatic register counting and possibly a new syntax to fill that structure. Before the start of every wavefront execution, the GPU sets up the register state on the basis of the enable_sgpr_* and enable_vgpr_* flags. VGPR v0 is always initialized with a work-item ID in the x dimension. Registers v1 and v2 can be initialized with work-item IDs in the y and z dimensions, respectively. Scalar GPRs can be initialized with a work-group ID and work-group count in each dimension, a dispatch ID, and pointers to kernarg, the aql packet, the aql queue, and so on. Again, the AMDGPU-ABI specification contains a full list in the section on initial register state. For this example, a 64-bit base kernarg address will be stored in the s[0:1] registers (enable_sgpr_kernarg_segment_ptr = 1), and the work-item thread ID will occupy v0 (by default). Below is the scheme showing initial state for our kernel:

```c
// initial state:
// s[0:1] - kernarg base address
// v0 - workitem id
s_load_dwordx2 s[4:5], s[0:1], 0x10 // load out_ptr into s[4:5] from kernarg
s_load_dwordx4 s[0:3], s[0:1], 0x00 // load in_ptr into s[0:1] and index_ptr into
  from kernarg
v_lshlrev_b32 v0, 2, v0 // v0 *= 4;
```

The next amd_kernel_code_t fields are obvious: is_ptr64 = 1 says we are in 64-bit mode, and kernarg_segment_byte_size = 24 describes the kernarg segment size. The GPR counting is less straightforward, however. The workitem_vgpr_count holds the number of vector registers that each work item uses, and wavefront_sgpr_count holds the number of scalar registers that a wavefront uses. The code above employs v0–v4, so workitem_vgpr_count = 5. But wavefront_sgpr_count = 8 even though the code only shows s0–s5, since the special registers VCC, FLAT_SCRATCH and XNACK are physically stored as part of the wavefront’s SGPRs in the highest-numbered SGPRs. In this example, FLAT_SCRATCH and XNACK are disabled, so VCC has only two additional registers. In current GCN3 hardware, VGPRs are allocated in groups of 4 registers and SGPRs in groups of 16. Previous generations (GCN1 and GCN2) have a VGPR granularity of 4 registers and an SGPR granularity of 8 registers. The fields compute_pgm_rsrc1_*gprs contain a device-specific number for each register-block type to allocate for a wavefront. As we said previously, future updates may enable automatic counting, but for now you can use following formulas for all three GCN GPU generations:

```c
compute_pgm_rscl_vgprs = (workitem_vgpr_count-1)/4
compute_pgm_rscl_sgprs = (wavefront_sgpr_count-1)/8
```

Now consider the corresponding assembly:

```c
// initial state:
// s[0:1] - kernarg base address
// v0 - workitem id
s_load_dwordx2 s[4:5], s[0:1], 0x10 // load out_ptr into s[4:5] from kernarg
s_load_dwordx4 s[0:3], s[0:1], 0x00 // load in_ptr into s[0:1] and index_ptr into
  from kernarg
v_lshlrev_b32 v0, 2, v0 // v0 *= 4;
s_waitcnt lgkmcnt(0) // wait for memory reads to finish
```

(continues on next page)
The next step is to produce a Hsaco from the ASM source. LLVM has added support for the AMDGCN assembler, so you can use Clang to do all the necessary magic:

```
clang -O assembler -target amdgcn--amdhsa -mcpu=fiji -c -o test.o asm_source.s
clang -target amdgcn--amdhsa test.o -o test.co
```

The first command assembles an object file from the assembly source, and the second one links everything (you could have multiple source files) into a Hsaco. Now, you can load and run kernels from that Hsaco in a program. The GitHub examples use Cmake to automatically compile ASM sources. In a future post we will cover DPP, another GCN cross-lane feature that allows vector instructions to grab operands from a neighboring lane.

### 2.8.3 GCN Assembler Tools

This repository contains the following useful items related to AMDGPU ISA assembler:

- **amdphdrs**: utility to convert ELF produced by llvm-mc into AMD Code Object (v1)
• examples/asm-kernel: example of AMDGPU kernel code
• examples/gfx8/ds_bpermute: transfer data between lanes in a wavefront with ds_bpermute_b32
• examples/gfx8/dpp_reduce: calculate prefix sum in a wavefront with DPP instructions
• examples/gfx8/s_memrealtime: use s_memrealtime instruction to create a delay
• examples/gfx8/s_memrealtime_inline: inline assembly in OpenCL kernel version of s_memrealtime
• examples/api/assemble: use LLVM API to assemble a kernel
• examples/api/disassemble: use LLVM API to disassemble a stream of instructions
• bin/sp3_to_mc.pl: script to convert some AMD sp3 legacy assembler syntax into LLVM MC
• examples/sp3: examples of sp3 convertable code

At the time of this writing (February 2016), LLVM trunk build and latest ROCR runtime is needed. LLVM trunk (May or later) now uses lld as linker and produces AMD Code Object (v2).

Top-level CMakeLists.txt is provided to build everything included. The following CMake variables should be set:

• HSA_DIR (default /opt/hsa/bin): path to ROCR Runtime
• LLVM_DIR: path to LLVM build directory

To build everything, create build directory and run cmake and make:

```bash
mkdir build
cd build
cmake -DLLVM_DIR=/srv/git/llvm.git/build ..
make
```

Examples that require clang will only be built if clang is built as part of llvm.

**Assembling to code object with llvm-mc from command line**

The following llvm-mc command line produces ELF object asm.o from assembly source asm.s:

```bash
llvm-mc -arch=amdgcn -mcpu=fiji -filetype=obj -o asm.o asm.s
```

**Assembling to raw instruction stream with llvm-mc from command line**

It is possible to extract contents of .text section after assembling to code object:

```bash
llvm-mc -arch=amdgcn -mcpu=fiji -filetype=obj -o asm.o asm.s
objdump -h asm.o | grep .text | awk '{print "dd if='asm.o' of='asm' bs=1 count=$["$3 "] skip=$["0x" "$6 "]"'} | bash
```

**Disassembling code object from command line**

The following command line may be used to dump contents of code object:

```bash
llvm-objdump -disassemble -mcpu=fiji asm.o
```

This includes text disassembly of .text section.

**Disassembling raw instruction stream from command line**

The following command line may be used to disassemble raw instruction stream (without ELF structure):

```bash
hexdump -v -e '/1 "0x%02X "' asm | llvm-mc -arch=amdgcn -mcpu=fiji -disassemble
```
Here, hexdump is used to display contents of file in hexadecimal (0x.. form) which is then consumed by llvm-mc. Refer to examples/api/assemble. Refer to examples/api/disassemble.

Using amdphdrs

Note that normally standard lld and Code Object version 2 should be used which is closer to standard ELF format. amdphdrs (now obsolete) is complimentary utility that can be used to produce AMDGPU Code Object version 1. For example, given assembly source in asm.s, the following will assemble it and link using amdphdrs:

```
llvm-mc -arch=amdgcn -mcpu=fiji -filetype=obj -o asm.o asm.s
amdphdrs asm.o asm.co
```

Macro support

SP3 supports proprietary set of macros/tools. sp3_to_mc.pl script attempts to translate them into GAS syntax understood by llvm-mc. flat_atomic_cmpswap instruction has 32-bit destination

LLVM AMDGPU:

```
flat_atomic_cmpswap v7, v[9:10], v[7:8]
```

SP3:

```
flat_atomic_cmpswap v[7:8], v[9:10], v[7:8]
```

Atomic instructions that return value should have glc flag explicitly

LLVM AMDGPU:

```
flat_atomic_swap_x2 v[0:1], v[0:1], v[2:3] glc
```

SP3:

```
flat_atomic_swap_x2 v[0:1], v[0:1], v[2:3]
```

- LLVM Use Guide for AMDGPU Back-End
- AMD ISA Documents
  - AMD GCN3 Instruction Set Architecture (2016)
  - AMD_Southern_Islands_Instruction_Set_Architecture

2.8.4 ROC Profiler


HW specific low-level performance analysis interface for profiling of GPU compute applications. The profiling includes HW performance counters with complex performance metrics and HW traces.

Profiling tool ‘rocprof’:

- Cmd-line tool for dumping public per kernel perf-counters/metrics and kernel timestamps
- Input file with counters list and kernels selecting parameters
- Multiple counters groups and app runs supported
- Kernel execution is serialized
• HSA API/activity stats and tracing
• Output results in CSV and JSON chrome tracing formats

2.8.4.1 Download

To clone ROC Profiler from GitHub use the following command:

```bash
git clone https://github.com/ROCm-Developer-Tools/rocprofiler
```

The library source tree:

- **bin**
  - rocprof - Profiling tool run script
- **doc** - Documentation
- **inc/rocprofiler.h** - Library public API
- **src - Library sources**
  - core - Library API sources
  - util - Library utils sources
  - xml - XML parser
- **test - Library test suite**
  - **tool - Profiling tool**
    * tool.cpp - tool sources
    * metrics.xml - metrics config file
  - **ctrl - Test control**
  - **util - Test utils**
  - simple_convolution - Simple convolution test kernel

2.8.4.2 Build

Build environment:

```bash
export CMAKE_PREFIX_PATH=<path to hsa-runtime include>:<path to hsa-runtime library>
export CMAKE_BUILD_TYPE=debug/release  # release by default
export CMAKE_DEBUG_TRACE=1  # to enable debug tracing
```

To configure, build, install to /opt/rocm/rocprofiler:

```bash
mkdir -p build
cd build
export CMAKE_PREFIX_PATH=/opt/rocm
cmake -DCMAKE_INSTALL_PREFIX=/opt/rocm ..
make
sudo make install
```

To test the built library:
cd build
./run.sh

To enable error messages logging to ‘/tmp/rocprofiler_log.txt’:

```bash
export ROCPROFILER_LOG=1
```

To enable verbose tracing:

```bash
export ROCPROFILER_TRACE=1
```

### 2.8.4.3 Profiling Tool ‘rocprof’ Usage

The following shows the command-line usage of the ‘rocprof’ tool:

```
rocprof [-h] [--list-basic] [--list-derived] [-i <input .txt/.xml file>] [-o <output CSV file>] <app command line>
```

**Options:**
- `--help` - this help
- `--verbose` - verbose mode, dumping all base counters used in the input metrics
- `--list-basic` - to print the list of basic HW counters
- `--list-derived` - to print the list of derived metrics with formulas

- `-i <.txt|.xml file>` - input file
  - Input file .txt format, automatically rerun application for every pmc line:
    ```
    # Perf counters group 1
    pmc : Wavefronts VALUInsts SALUInsts SFetchInsts FlatVMemInsts LDSInsts FlatLDSInsts GDSInsts VALUUtilization FetchSize
    # Perf counters group 2
    pmc : WriteSize L2CacheHit
    # Filter by dispatches range, GPU index and kernel names
    # supported range formats: "3:9", "3:", "3"
    range: 1 : 4
    gpu: 0 1 2 3
    kernel: simple Pass1 simpleConvolutionPass2
    ```

- `-o <.txt|.xml file>` - output file
  - Input file .xml format, for single profiling run:
    ```
    <metric name=SQ:4,SQ_WAVES,VFetchInsts>
    # Filter by dispatches range, GPU index and kernel names
    range: "3:9", "3:", "3"
    gpu_index: "0,1,2,3"
    kernel: "Simple1,Conv1,SimpleConvolution"
    </metric>
    ```

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2.8.5 ROCr Debug Agent

The ROCr Debug Agent is a library that can be loaded by ROCm Platform Runtime to provide the following functionality:

- Print the state of wavefronts that report memory violation or upon executing a `s_trap` instruction.
- Allows SIGINT (`ctrl c`) or SIGTERM (`kill -15`) to print wavefront state of aborted GPU dispatches.
- It is enabled on Vega10 GPUs on ROCm2.6.

To use the ROCr Debug Agent set the following environment variable:

```bash
export HSA_TOOLS_LIB=librocr_debug_agent64.so
```

This will use the ROCr Debug Agent library installed at `/opt/rocm/lib/librocr_debug_agent64.so` by default since the ROCm installation adds `/opt/rocm/lib` to the system library path. To use a different version set the `LD_LIBRARY_PATH`, for example:
To display the machine code instructions of wavefronts, together with the source text location, the ROCr Debug Agent uses the llvm-objdump tool. Ensure that a version that supports AMD GCN GPUs is on your $PATH. For example, for ROCm 2.6:

```
export PATH=/opt/rocm/opencl/bin/x86_64:$PATH
```

Execute your application.

If the application encounters a GPU error it will display the wavefront state of the GPU to stdout. Possible error states include:

- The GPU executes a memory instruction that causes a memory violation. This is reported as an XNACK error state.
- Queue error.
- The GPU executes an S_TRAP instruction. The __builtin_trap() language builtin can be used to generate an S_TRAP.
- A SIGINT (ctrl c) or SIGTERM (kill -15) signal is sent to the application while executing GPU code. Enabled by the ROCM_DEBUG_ENABLE_LINUX_SIGNALS environment variable.

For example, a sample print out for GPU memory fault is:

```
Memory access fault by GPU agent: AMD gfx900
Node: 1
Address: 0x18DB4xxx (page not present;write access to a read-only page;)

64 wavefront(s) found in XNACK error state @PC: 0x0000001100E01310
printing the first one:

- EXEC: 0xFFFFFFFFFFFFFFFF
- STATUS: 0x00412460
- TRAPSTS: 0x30000000
- M0: 0x00100100

s0: 0x00010000 s1: 0x80000000 s2: 0x10000000 s3: 0x00EA4FAC
s4: 0x17D8400 s5: 0x00000000 s6: 0x01039000 s7: 0x00000000
s8: 0x00000000 s9: 0x00000000 s10: 0x17D8400 s11: 0x04000000
s12: 0x00000000 s13: 0x00000000 s14: 0x00000000 s15: 0x00000000
s16: 0x0103C000 s17: 0x00000000 s18: 0x00000000 s19: 0x00000000
s20: 0x01037060 s21: 0x00000000 s22: 0x00000000 s23: 0x00000000
s24: 0x00004000 s25: 0x00000000 s26: 0x00000000 s27: 0x00000000
s28: 0x00000000 s29: 0x00000000 s30: 0x00000000 s31: 0x00000000

Lane 0x0
- v0: 0x00000000 v1: 0x18DB4400 v2: 0x18DB4400 v3: 0x00000000
- v4: 0x00000000 v5: 0x00000000 v6: 0x00700000 v7: 0x00800000

Lane 0x1
- v0: 0x00000000 v1: 0x18DB4400 v2: 0x18DB4400 v3: 0x00000000
- v4: 0x00000000 v5: 0x00000000 v6: 0x00700000 v7: 0x00800000

Lane 0x2
- v0: 0x00000000 v1: 0x18DB4400 v2: 0x18DB4400 v3: 0x00000000
- v4: 0x00000000 v5: 0x00000000 v6: 0x00700000 v7: 0x00800000

Lane 0x3
- v0: 0x00000000 v1: 0x18DB4400 v2: 0x18DB4400 v3: 0x00000000
- v4: 0x00000000 v5: 0x00000000 v6: 0x00700000 v7: 0x00800000
```

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Faulty Code Object:

/tmp/ROCm_Tmp_PID_5764/ROCm_Code_Object_0: file format ELF64-amdgpu-hsacobj

Disassembly of section .text:

the_kernel:

; /home/qingchuan/tests/faulty_test/vector_add_kernel.cl:12
; d[100000000] = ga[gid & 31];
   v_mov_b32_e32 v1, v2 // 0000000012F0:
   v_mov_b32_e32 v4, v3 // 0000000012F4:
   v_add_i32_e32 v1, vcc, s10, v1 // 0000000012F8:
   v_mov_b32_e32 v5, s22 // 0000000012FC:
   v_addc_u32_e32 v4, vcc, v4, v5, vcc // 000000001300:
   v_mov_b32_e32 v2, v1 // 000000001304:
   v_mov_b32_e32 v3, v4 // 000000001308:
   s_waitcnt lgkmcnt(0) // 00000000130C:
   flat_store_dword v[2:3], v0 // 000000001310:

; /home/qingchuan/tests/faulty_test/vector_add_kernel.cl:13
;
   s_endpgm // 000000001318:
   BF810000

Faulty PC offset: 1310

Aborted (core dumped)

By default the wavefront dump is sent to stdout.

To save to a file use:
export ROCM_DEBUG_WAVE_STATE_DUMP=file

This will create a file called ROCm_Wave_State_Dump in code object directory (see below).

To return to the default stdout use either of the following:

export ROCM_DEBUG_WAVE_STATE_DUMP=stdout
unset ROCM_DEBUG_WAVE_STATE_DUMP

The following environment variable can be used to enable dumping wavefront states when SIGINT (ctrl c) or SIGTERM (kill -15) is sent to the application:

export ROCM_DEBUG_ENABLE_LINUX_SIGNALS=1

Either of the following will disable this behavior:

export ROCM_DEBUG_ENABLE_LINUX_SIGNALS=0
unset ROCM_DEBUG_ENABLE_LINUX_SIGNALS

When the ROCr Debug Agent is enabled, each GPU code object loaded by the ROCm Platform Runtime will be saved in a file in the code object directory. By default the code object directory is /tmp/ROCm_Tmp_PID_XXXX/ where XXXX is the application process ID. The code object directory can be specified using the following environment variable:

export ROCM_DEBUG_SAVE_CODE_OBJECT=code_object_directory

This will use the path /code_object_directory.

Loaded code objects will be saved in files named ROCm_Code_Object_N where N is a unique integer starting at 0 of the order in which the code object was loaded.

If the default code object directory is used, then the saved code object file will be deleted when it is unloaded with the ROCm Platform Runtime, and the complete code object directory will be deleted when the application exits normally. If a code object directory path is specified then neither the saved code objects, nor the code object directory will be deleted.

To return to using the default code object directory use:

unset ROCM_DEBUG_SAVE_CODE_OBJECT

By default ROCr Debug Agent logging is disabled. It can be enabled to display to stdout using:

export ROCM_DEBUG_ENABLE_AGENTLOG=stdout

Or to a file using:

export ROCM_DEBUG_ENABLE_AGENTLOG=<filename>

Which will write to the file <filename>_AgentLog_PID_XXXX.log.

To disable logging use:

unset ROCM_DEBUG_ENABLE_AGENTLOG

### 2.8.6 ROCm-GDB

The ROCm-GDB is being revised to work with the ROCr Debug Agent to support debugging GPU kernels on Radeon Open Compute platforms (ROCM) and will be available in an upcoming release.
2.8.7 Radeon Compute Profiler

The Radeon Compute Profiler (RCP) is a performance analysis tool that gathers data from the API run-time and GPU for OpenCL™ and ROCm/HSA applications. This information can be used by developers to discover bottlenecks in the application and to find ways to optimize the application’s performance.

Please see the RCP GitHub repository for more information.

2.8.8 ROC Tracer

ROC-tracer library, Runtimes Generic Callback/Activity APIs. The goal of the implementation is to provide a generic independent from specific runtime profiler to trace API and asynchronous activity.

The API provides functionality for registering the runtimes API callbacks and asynchronous activity records pool support.

The library source tree:

- inc/roctracer.h - Library public API
- src - Library sources
  - core - Library API sources
  - util - Library utils sources
- test - test suit
  - MatrixTranspose - test based on HIP MatrixTranspose sample

2.8.8.1 Documentation

- API description: inc/roctracer.h
- Code example: test/MatrixTranspose/MatrixTranspose.cpp

2.8.8.2 To build and run test

```bash
cpy <your path>

- CLone development branches of roctracer and HIP/HCC:
  git clone -b amd-master https://github.com/ROCmSoftwarePlatform/roctracer.git
  git clone -b master https://github.com/ROCm-Developer-Tools/HIP.git

- Set environment:
  export HIP_PATH=<your path>/HIP
  export HCC_HOME=<your path>/hcc/build
  export CMAKE_PREFIX_PATH=/opt/rocm

- Build HCC:
  cd <your path>/hcc
  mkdir build
  cd build
  cmake -DUSE_PROF_API=1 -DPROF_API_HEADER_PATH=<your path>/roctracer/inc/ext..
  make -j <nproc>

- Build HIP:
```

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**2.8.9 CodeXL**

CodeXL is a comprehensive tool suite that enables developers to harness the benefits of GPUs and APUs. It includes powerful GPU debugging, comprehensive GPU profiling, and static OpenCL™, OpenGL®, Vulkan® and DirectX® kernel/shader analysis capabilities, enhancing accessibility for software developers to enter the era of heterogeneous computing. CodeXL is available as a standalone user interface application for Windows® and Linux®.

Please see the [CodeXL GitHub repository](https://github.com/amd/CodeXL) for more information.

**2.8.10 GPUPerfAPI**

The GPU Performance API (GPUPerfAPI, or GPA) is a powerful library, providing access to GPU Performance Counters. It can help analyze the performance and execution characteristics of applications using a Radeon™ GPU. This library is used by Radeon Compute Profiler and CodeXL as well as several third-party tools.

Please see the [GPA GitHub repository](https://github.com/amd/GPUPerfAPI) for more information.

**2.8.11 ROCm Binary Utilities**

Documentation need to be updated.

**2.8.12 MIVisionX**

MIVisionX toolkit is a set of comprehensive computer vision and machine intelligence libraries, utilities, and applications bundled into a single toolkit. AMD MIVisionX delivers highly optimized open source implementation of the Khronos OpenVX™ and OpenVX™ Extensions along with Convolution Neural Net Model Compiler & Optimizer supporting ONNX, and Khronos NNEF™ exchange formats. The toolkit allows for rapid prototyping and deployment of optimized workloads on a wide range of computer hardware, including small embedded x86 CPUs, APUs, discrete GPUs, and heterogeneous servers.
2.8.12.1 AMD OpenVX (amd_openvx)

AMD OpenVX is a highly optimized open source implementation of the Khronos OpenVX computer vision specification. It allows for rapid prototyping as well as fast execution on a wide range of computer hardware, including small embedded x86 CPUs and large workstation discrete GPUs.

2.8.12.2 AMD OpenVX Extensions

The OpenVX framework provides a mechanism to add new vision functions to OpenVX by 3rd party vendors. This project has below mentioned OpenVX modules and utilities to extend amd_openvx project, which contains the AMD OpenVX Core Engine.

- **amd_looms**: AMD Radeon Loom stitching library for live 360 degree video applications
- **amd_nn**: OpenVX neural network module
- **amd_opencv**: OpenVX module that implements a mechanism to access OpenCV functionality as OpenVX kernels
- **amd_winml**: WinML extension will allow developers to import a pre-trained ONNX model into an OpenVX graph and add hundreds of different pre & post processing vision/generic/user-defined functions, available in OpenVX and OpenCV interop, to the input and output of the neural net model. This will allow developers to build an end to end application for inference.

2.8.12.2.1 Features

- The code is highly optimized for both x86 CPU and OpenCL for GPU
- Supported hardware spans the range from low power embedded APUs (like the new G series) to laptop, desktop and workstation graphics
- Supports Windows, Linux, and OS X
- Includes a “graph optimizer” that looks at the entire processing pipeline and removes/replaces/merges functions to improve performance and minimize bandwidth at runtime
- Scripting support allows for rapid prototyping, without re-compiling at production performance levels.

2.8.12.2.2 Pre-requisites:

- **CPU**: SSE4.1 or above CPU, 64-bit.
- **GPU**: Radeon Professional Graphics Cards or Vega Family of Products (16GB required for vx_looms and vx_nn libraries)
  - Windows: install the latest drivers and OpenCL SDK [Download](#).
  - Linux: install ROCm.
- **OpenCV 3 (optional)** [download for RunVX](#)
  - Set OpenCV_DIR environment variable to OpenCV/build folder.
2.8.12.2.3 Build Instructions

Build this project to generate AMD OpenVX library and RunVX executable.
- Refer to openvx/include/VX for Khronos OpenVX standard header files.
- Refer to openvx/include/vx_ext_amd.h for vendor extensions in AMD OpenVX library.
- Refer to runvx/README.md for RunVX details.
- Refer to runcl/README.md for RunCL details.

2.8.12.2.4 Build using Visual Studio Professional 2013 on 64-bit Windows 10/8.1/7

- Install OpenCV 3 with contrib download for RunVX tool to support camera capture and image display (optional)
- OpenCV_DIR environment variable should point to OpenCV/build folder
- Use amdovx-core/amdovx.sln to build for x64 platform
- If AMD GPU (or OpenCL) is not available, set build flag ENABLE_OPENCL=0 in openvx/openvx.vcxproj and runvx/runvx.vcxproj.

2.8.12.2.5 Build using CMake

- Install CMake 2.8 or newer download.
- Install OpenCV 3 with contrib download for RunVX tool to support camera capture and image display (optional)
- OpenCV_DIR environment variable should point to OpenCV/build folder
- Install libssl-dev on linux (optional)
- Use CMake to configure and generate Makefile
- If AMD GPU (or OpenCL) is not available, use build flag -DCMAKE_DISABLE_FIND_PACKAGE_OpenCL=TRUE.

2.8.12.2.6 Radeon Loom Stitching Library (vx_loomsl)

Radeon Loom Stitching Library (beta preview) is a highly optimized library for 360 degree video stitching applications. This library consists of:
- Live Stitch API: stitching framework built on top of OpenVX kernels (see live_stitch_api.h for API)
- OpenVX module [vx_loomsl]: additional OpenVX kernels needed for 360 degree video stitching

The loom_shell command-line tool can be used to build your application quickly. It provides direct access to Live Stitch API by encapsulating the calls to enable rapid prototyping.

This software is provided under a MIT-style license, see the file COPYRIGHT.txt for details.

Features
- Real-time live 360 degree video stitching optimized for Radeon Pro Graphics
- Upto 31 cameras
- Upto 7680x3840 output resolution
- RGB and YUV 4:2:2 image formats
- Overlay other videos on top of stitched video
- Support for 3rd party LoomIO plug-ins for camera capture and stitched output
- Support PtGui project export/import for camera calibration

**Live Stitch API: Simple Example**

Let’s consider a 360 rig that has 3 1080p cameras with Circular FishEye lenses. The below example demonstrates how to stitch images from these cameras into a 4K Equirectangular buffer.

```c
#include "vx_loomsl/live_stitch_api.h"
#include "utils/loom_shell/loom_shell_util.h"

int main()
{
    # define camera orientation and lens parameters
    camera_params cam1_par = { { 120,0,90,0,0,0},{176,1094,547,0,-37,ptgui_lens_fisheye_circ,-0.1719,0.1539,1.0177} };
    camera_params cam2_par = { { 0,0,90,0,0,0},{176,1094,547,0,-37,ptgui_lens_fisheye_circ,-0.1719,0.1539,1.0177} };
    camera_params cam3_par = { {-120,0,90,0,0,0},{176,1094,547,0,-37,ptgui_lens_fisheye_circ,-0.1719,0.1539,1.0177} };

    # create a live stitch instance and initialize
    ls_context context;
    context = lsCreateContext();
    lsSetOutputConfig(context,VX_DF_IMAGE_RGB,3840,1920);
    lsSetCameraConfig(context,3,1,VX_DF_IMAGE_RGB,1920,1080*3);
    lsSetCameraParams(context, 0, &cam1_par);
    lsSetCameraParams(context, 1, &cam2_par);
    lsSetCameraParams(context, 2, &cam3_par);
    lsInitialize(context);

    # Get OpenCL context and create OpenCL buffers for input and output
    cl_context opencl_context;
    cl_mem buf[2];
    lsGetOpenCLContext(context,&opencl_context);
    createBuffer(opencl_context,3*1920*1080*3, &buf[0]);
    createBuffer(opencl_context,3*3840*1920, &buf[1]);

    # load CAM00.bmp, CAM01.bmp, and CAM02.bmp (1920x1080 each) into buf[0]
    loadBufferFromMultipleImages(buf[0],"CAM%02d.bmp",3,1,VX_DF_IMAGE_RGB,1920, -1080*3);

    # set input and output buffers and stitch a frame
    lsSetCameraBuffer(context, &buf[0]);
    lsSetOutputBuffer(context, &buf[1]);
    lsScheduleFrame(context);
    lsWaitForCompletion(context);

    # save the stitched output into "output.bmp"
    saveBufferToImage(buf[1],"output.bmp",VX_DF_IMAGE_RGB,3840,1920);

    # release resources
    releaseBuffer(&buf[0]);
    releaseBuffer(&buf[1]);
    lsReleaseContext(&context);

    return 0;
}
```
Live Stitch API: Real-time Live Stitch using LoomIO

This example makes use of a 3rd party LoomIO plug-ins for live camera capture and display.

```c
#include "vx_loomio/live_stitch_api.h"

int main()
{
    // create context, configure, and initialize
    ls_context context;
    context = lsCreateContext();
    lsSetOutputConfig(context, VX_DF_IMAGE_RGB, 3840, 1920);
    lsSetCameraConfig(context, 16, 1, VX_DF_IMAGE_RGB, 1920, 1080 * 16);
    lsImportConfiguration(context, "pts", "myrig.pts");
    lsSetCameraModule(context, "vx_loomio_bm", "com.amd.loomio_bm.capture", "30,0,0,-16");
    lsSetOutputModule(context, "vx_loomio_bm", "com.amd.loomio_bm.display", "30,0,0,-4");
    lsInitialize(context);

    // process live from camera until aborted by input capture plug-in
    for (;;) {
        vx_status status;
        status = lsScheduleFrame(context);
        if (status != VX_SUCCESS) break;
        status = lsWaitForCompletion(context);
        if (status != VX_SUCCESS) break;
    }

    // release the context
    lsReleaseContext(&context);

    return 0;
}
```

2.8.12.7 OpenVX Neural Network Extension Library (vx_nn)

vx_nn is an OpenVX Neural Network extension module. This implementation supports only floating-point tensor datatype and does not support 8-bit and 16-bit fixed-point datatypes specified in the OpenVX specification.

List of supported tensor and neural network layers:

<table>
<thead>
<tr>
<th>Layer name</th>
<th>Function</th>
<th>Kernel name</th>
</tr>
</thead>
</table>
Example 1: Convert an image to a tensor of type float32

Use the below GDF with RunVX.

```python
import vx_nn
data input = image:32,32,RGB2
data output = tensor:4,{32,32,3,1},VX_TYPE_FLOAT32,0
data a = scalar:FLOAT32,1.0
data b = scalar:FLOAT32,0.0
data reverse_channel_order = scalar:BOOL,0
read input input.png
node com.amd.nn_extension.convert_image_to_tensor input output a b reverse_channel_order
write output input.f32
```

Example 2: 2x2 Upsample a tensor of type float32

Use the below GDF with RunVX.

```python
import vx_nn
data input = tensor:4,{80,80,3,1},VX_TYPE_FLOAT32,0
data output = tensor:4,{160,160,3,1},VX_TYPE_FLOAT32,0
read input tensor.f32
node com.amd.nn_extension.upsample_nearest_layer input output
write output upsample.f32
```

2.8.12.2.8 AMD Module for OpenCV-interop from OpenVX (vx_opencv)

The vx_opencv is an OpenVX module that implemented a mechanism to access OpenCV functionality as OpenVX kernels. These kernels can be access from within OpenVX framework using OpenVX API call `vxLoadKernels` (context, “vx_opencv”).

List of OpenCV-interop kernels

The following is a list of OpenCV functions that have been included in the vx_opencv module.

<table>
<thead>
<tr>
<th>Function</th>
<th>OpenCV Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>bilateralFilter</td>
<td>org.opencv.bilateralfilter</td>
</tr>
<tr>
<td>blur</td>
<td>org.opencv.blur</td>
</tr>
<tr>
<td>boxfilter</td>
<td>org.opencv.boxfilter</td>
</tr>
<tr>
<td>buildPyramid</td>
<td>org.opencv.buildpyramid</td>
</tr>
<tr>
<td>Dilate</td>
<td>org.opencv.dilate</td>
</tr>
<tr>
<td>Erode</td>
<td>org.opencv.erode</td>
</tr>
<tr>
<td>filter2D</td>
<td>org.opencv.filter2d</td>
</tr>
<tr>
<td>GaussianBlur</td>
<td>org.opencv.gaussianblur</td>
</tr>
<tr>
<td>MedianBlur</td>
<td>org.opencv.medianblur</td>
</tr>
<tr>
<td>morphologyEx</td>
<td>org.opencv.morphologyex</td>
</tr>
<tr>
<td>Laplacian</td>
<td>org.opencv.laplacian</td>
</tr>
<tr>
<td>pyrDown</td>
<td>org.opencv.pyrdown</td>
</tr>
<tr>
<td>pyrUp</td>
<td>org.opencv.pyrup</td>
</tr>
<tr>
<td>sepFilter2D</td>
<td>org.opencv.sepfilter2d</td>
</tr>
<tr>
<td>Sobel</td>
<td>org.opencv.sobel</td>
</tr>
</tbody>
</table>

(continues on next page)
2.8.12.2.8.1 Build Instructions

Pre-requisites

- OpenCV 3 download.
- CMake 2.8 or newer download.
- Build amdovx-core project at the same level folder as amdovx-modules build folder
- OpenCV_DIR environment variable should point to OpenCV/build folder

Build using Visual Studio Professional 2013 on 64-bit Windows 10/8.1/7

Use amdovx-modules/vx_opencv/vx_opencv.sln to build for x64 platform

Build using CMake on Linux (Ubuntu 15.10 64-bit)
• Use CMake to configure and generate Makefile

2.8.12.3 Applications

MIVisionX has a number of applications built on top of OpenVX modules, it uses AMD optimized libraries to build applications which can be used to prototype or used as models to develop a product.

2.8.12.3.1 Cloud Inference Application (cloud_inference)

• Cloud Inference Server: sample Inference Server
• Cloud Inference Client: sample Inference Client Application

2.8.12.3.2 Convert Neural Net models into AMD NNIR and OpenVX Code

This tool converts ONNX or Caffe models to AMD NNIR format and OpenVX code.

You need MIVisionX libraries to be able to build and run the generated OpenVX code.

Dependencies

• numpy
• onnx (0.2.1+)

How to use?

To convert an ONNX model into AMD NNIR model:

% python onnx2nnir.py model.pb nnirModelFolder

To convert a caffemodel into AMD NNIR model:

% python caffe2nnir.py <net.caffeModel> <nnirOutputFolder> --input-dims n,c,h,w [--verbose 0|1]

To update batch size in AMD NNIR model:

% python nnir-update.py --batch-size N nnirModelFolder nnirModelFolderN

To fuse operations in AMD NNIR model (like batch normalization into convolution):

% python nnir-update.py --fuse-ops 1 nnirModelFolderN nnirModelFolderFused

To workaround groups using slice and concat operations in AMD NNIR model:

% python nnir-update.py --slice-groups 1 nnirModelFolderFused nnirModelFolderSliced

To convert an AMD NNIR model into OpenVX C code:

% python --help

Usage: python nnir2openvx.py OPTIONS <nnirInputFolder> <outputFolder>

OPTIONS:

--argmax UINT8 - argmax at the end with 8-bit output

2.8. ROCm Tools
--argmax UINT16  – argmax at the end with 16-bit output

–argmax <fileNamePrefix>rgb.txt  – argmax at the end with RGB color mapping using LUT –argmax
<fileNamePrefix>rgba.txt  – argmax at the end with RGBA color mapping using LUT –help – show
this help message

LUT File Format (RGB): 8-bit R G B values one per each label in text format    R0 G0 B0 R1 G1 B1

LUT File Format (RGBA): 8-bit R G B A values one per each label in text format   R0 G0 B0 A0 R1
G1 B1 A1 ...

Here are few examples of OpenVX C code generation

Generate OpenVX and test code that can be used dump and compare raw tensor data:

```
% python nnir2openvx.py nnirInputFolderFused openvxCodeFolder
% mkdir openvxCodeFolder/build
% cd openvxCodeFolder/build
% cmake ..
% make
% ./anntest
```

Usage: anntest <weights.bin> [<input-data-file(s)> [<output-data-file(s)>]]

<input-data-file>: is filename to initialize tensor

.jpg or .png: decode and initialize for 3 channel tensors (use %04d in fileName to when batch-
size > 1: batch index starts from 0)

other: initialize tensor with raw data from the file

<output-data-file>[,<reference-for-compare>,<maxErrorLimit>,<rmsErrorLimit>]: <reference-to-
compare> is raw tensor data for comparison <maxErrorLimit> is max absolute error allowed
<rmsErrorLimit> is max RMS error allowed <output-data-file> is filename for saving output tensor
data

'-' to ignore other: save raw tensor into the file

% ./anntest ./weights.bin input.f32 output.f32,reference.f32,1e-6,1e-9 ...

Generate OpenVX and test code with argmax that can be used dump and compare 16-bit argmax output tensor:

```
% python nnir2openvx.py --argmax UINT16 nnirInputFolderFused openvxCodeFolder
% mkdir openvxCodeFolder/build
% cd openvxCodeFolder/build
% cmake ..
% make
% ./anntest
```

Usage: anntest <weights.bin> [<input-data-file(s)> [<output-data-file(s)>]]

<input-data-file>: is filename to initialize tensor

.jpg or .png: decode and initialize for 3 channel tensors (use %04d in fileName to when batch-
size > 1: batch index starts from 0)

other: initialize tensor with raw data from the file

<output-data-file>[,<reference-for-compare>,<percentErrorLimit>]: <reference-to-
compare> is raw tensor data of argmax output for comparison <percentMismatchLimit> is max mismatch (per-
centage) allowed <output-data-file> is filename for saving output tensor data

'-' to ignore other: save raw tensor into the file
Generate OpenVX and test code with argmax and LUT that is designed for semantic segmentation use cases. You can dump output in raw format or PNGs and additionally compare with reference data in raw format.

```bash
% python nnir2openvx.py --argmax lut-rgb.txt nnirInputFolderFused openvxCodeFolder
% mkdir openvxCodeFolder/build
% cd openvxCodeFolder/build
% cmake ..
% make
% ./anntest
```

Usage: anntest <weights.bin> [<input-data-file(s)> [<output-data-file(s)>]]

- `<input-data-file>`: is filename to initialize tensor
  - `.jpg` or `.png`: decode and initialize for 3 channel tensors (use `%04d` in fileName to when batch-size > 1: batch index starts from 0)
  - other: initialize tensor with raw data from the file

- `<output-data-file>[,<reference-for-compare>,<percentErrorLimit>]`: <reference-to-compare> is raw tensor data of LUT output for comparison <percentMismatchLimit> is max mismatch (percentage) allowed <output-data-file> is filename for saving output tensor data
  - `.png`: save LUT output as PNG file(s) (use `%04d` in fileName when batch-size > 1: batch index starts from 0)
  - `-` to ignore other: save raw tensor into the file

```bash
% ./anntest ../weights.bin input-%04d.png output.rgb,reference.rgb,0.01 . . . % ./anntest ../weights.bin input-%04d.png output-%04d.png,reference.rgb,0.01 . . .
```

2.8.12.3.3 Currently supported

Models

Support the below models from [https://github.com/onnx/models](https://github.com/onnx/models)

- resnet
- inception
- alexnet
- densenet
- sqeezenet

Operators

Supported ONNX operators are:

- Conv
- Relu
- MaxPool
- AveragePool
- GlobalAveragePool
- LRN

2.8. ROCm Tools
• BatchNormalization
• Concat
• Sum
• Add
• Sub
• Mul
• Softmax
• Dropout

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2.8.12.4 Samples

MIVisionX samples using OpenVX and OpenVX extension libraries

2.8.12.4.1 GDF - Graph Description Format

MIVisionX samples using runvx with GDF

skintonedetect.gdf

usage:

```bash
runvx skintonedetect.gdf
```

canny.gdf

usage:

```bash
runvx canny.gdf
```

skintonedetect-LIVE.gdf

Using live camera

usage:

```bash
runvx -frames:live skintonedetect-LIVE.gdf
```

canny-LIVE.gdf

Using live camera

usage:

```bash
runvx -frames:live canny-LIVE.gdf
```

OpenCV_orb-LIVE.gdf

Using live camera

usage:
2.8.12.5 MIVisionX Toolkit

AMD MIVisionX Toolkit is a comprehensive set of help tools for neural net creation, development, training and deployment. The Toolkit provides you with help tools to design, develop, quantize, prune, retrain, and infer your neural network work in any framework. The Toolkit is designed to help you deploy your work to any AMD or 3rd party hardware, from embedded to servers.

MIVisionX provides you with tools for accomplishing your tasks throughout the whole neural net life-cycle, from creating a model to deploying them for your target platforms.

2.8.12.6 Utilities

MIVisionX has utility applications which could be used by developers to test, quick prototype or develop sample applications.

- **inference_generator**: generate inference library from pre-trained CAFFE models
- **loom_shell**: an interpreter to prototype 360 degree video stitching applications using a script
- **RunVX**: command-line utility to execute OpenVX graph described in GDF text file
- **RunCL**: command-line utility to build, execute, and debug OpenCL programs

If you’re interested in Neural Network Inference, start with the sample cloud inference application in apps folder.

2.8.12.7 Prerequisites

- **CPU**: SSE4.1 or above CPU, 64-bit
- **GPU**: GFX7 or above [optional]
- **APU**: Carrizo or above [optional]

**Note**: Some modules in MIVisionX can be built for CPU only. To take advantage of advanced features and modules we recommend using AMD GPUs or AMD APUs.
## 2.8.12.7.1 Windows

- Windows 10
- Windows SDK
- Visual Studio 2017
- Install the latest drivers and OpenCL SDK <https://github.com/GPUOpen-LibrariesAndSDKs/OCL-SDK/releases/tag/1.0>
- OpenCV 3.4
  - Set OpenCV_DIR environment variable to OpenCV/build folder
  - Add `%OpenCV_DIR%x64vc14bin` or `%OpenCV_DIR%x64vc15bin` to your PATH

## 2.8.12.7.2 Linux

- Install ROCm
- ROCm CMake, MIOpenGEMM & MIOpen for Neural Net Extensions (vx_nn)
- CMake 2.8 or newer download
- Qt Creator for Cloud Inference Client
- Protobuf for inference generator & model compiler
  - install libprotobuf-dev and protobuf-compiler needed for vx_nn
- OpenCV 3.4
  - Set OpenCV_DIR environment variable to OpenCV/build folder
- FFMPEG n4.0.4 - Optional
  - FFMPEG is required for amd_media & mv_deploy modules

## 2.8.12.7.3 Pre-requisites setup script - MIVisionX-setup.py

For the convenience of the developer, we here provide the setup script which will install all the dependencies required by this project.

MIVisionX-setup.py - This script builds all the prerequisites required by MIVisionX. The setup script creates a deps folder and installs all the prerequisites, this script only needs to be executed once. If `-d` option for directory is not given the script will install deps folder in `~` directory by default, else in the user specified folder.

## 2.8.12.7.4 Prerequisites for running the scripts

- ubuntu 16.04/18.04 or CentOS 7.5/7.6
- ROCm supported hardware
- ROCm

Usage:
```{code}
python MIVisionX-setup.py --directory [setup directory - optional]
  --installer [Package management tool - optional (default:apt-get)]
  --miopen [MIOpen Version - optional (default:1.8.1)]
  --ffmpeg [FFMPEG Installation - optional (default:no)]
```

### 2.8.12.8 Build MIVisionX

**Note:** use `--installer yum` for CentOS Refer to Wiki page for developer instructions.

### 2.8.12.9 Build & Install MIVisionX

**Windows**

Using `.msi` packages

- MIVisionX-installer.msi: MIVisionX
- MIVisionX_WinML-installer.msi: MIVisionX for WinML

Using Visual Studio 2017 on 64-bit Windows 10

- Install OpenCL_SDK
- Install OpenCV with/without contrib to support camera capture, image display, & opencv extensions
  - Set `OpenCV_DIR` environment variable to OpenCV/build folder
  - Add `%OpenCV_DIR%\x64\vc14\bin` or `%OpenCV_DIR%\x64\vc15\bin` to your PATH
- Use MIVisionX.sln to build for x64 platform

**NOTE:** `vx_nn` is not supported on Windows in this release

**Linux**

Using `apt-get/yum`

### 2.8.12.10 Prerequisites

- Ubuntu 16.04/18.04 or CentOS 7.5/7.6
- ROCm supported hardware
- ROCm

**Ubuntu**

```bash
sudo apt-get install mivisionx
```

**CentOS**

```bash
sudo yum install mivisionx
```

**Note:**

- `vx_winml` is not supported on linux
- source code will not available with `apt-get/yum` install

### 2.8. ROCm Tools
• executables placed in /opt/rocm/mivisionx/bin and libraries in /opt/rocm/mivisionx/lib
• OpenVX and module header files into /opt/rocm/mivisionx/include
• model compiler, toolkit, & samples placed in /opt/rocm/mivisionx
• Package (.deb & .rpm) install requires OpenCV v3.4.0 to execute AMD OpenCV extensions

2.8.12.10.1 Using MIVisionX-setup.py and CMake on Linux (Ubuntu 16.04/18.04 or CentOS 7.5/7.6) with ROCm

• Install ROCm
• Use the below commands to setup and build MIVisionX

```bash
git clone https://github.com/GPUOpen-ProfessionalCompute-Libraries/MIVisionX.git
cd MIVisionX
python MIVisionX-setup.py --directory [setup directory - optional]
  --installer [Package management tool - optional (default: apt-get) [options: Ubuntu: apt-get; CentOS: yum]]
  --miopen [MIOpen Version - optional (default:1.8.1)]
  --ffmpeg [FFMPEG Installation - optional (default:no)]
  [options: Install ffmpeg - yes]
```

Note: Use --installer yum for CentOS

```bash
mkdir build
cd build
cmake ..
make -j8
sudo make install
```

Note:
• vx_winml is not supported on Linux
• the installer will copy all executables into /opt/rocm/mivisionx/bin and libraries into /opt/rocm/mivisionx/lib
• the installer also copies all the OpenVX and module header files into /opt/rocm/mivisionx/include folder

2.8.12.10.2 Build using CMake on Linux (Ubuntu 16.04 64-bit or CentOS 7.5 / 7.6 ) with ROCm

• Install ROCm
• git clone, build and install other ROCm projects (using cmake and % make install) in the below order for vx_nn.
  - rocm-cmake
  - MIOpenGEMM
  - MIOpen – make sure to use -DMIOPEN_BACKEND=OpenCL option with cmake
• install protobuf
• install OpenCV
• install FFMPEG n4.0.4 - Optional
• build and install (using cmake and % make install)
- executables will be placed in bin folder
- libraries will be placed in lib folder
- the installer will copy all executables into /opt/rocm/mivisionx/bin and libraries into /opt/rocm/lib
- the installer also copies all the OpenVX and module header files into /opt/rocm/mivisionx/include folder

• add the installed library path to LD_LIBRARY_PATH environment variable (default /opt/rocm/mivisionx/lib)
• add the installed executable path to PATH environment variable (default /opt/rocm/mivisionx/bin)

### 2.8.12.10.3 Build annInferenceApp using Qt Creator

- build annInferenceApp.pro using Qt Creator
- or use annInferenceApp.py for simple tests

### 2.8.12.10.4 Build Radeon LOOM using Visual Studio Professional 2013 on 64-bit Windows 10/8.1/7

- Use loom.sln to build x64 platform

### 2.8.12.10.5 Verify the Installation

#### 2.8.12.10.6 Linux

- The installer will copy all executables into /opt/rocm/mivisionx/bin and libraries into /opt/rocm/mivisionx/lib
- The installer also copies all the OpenVX and OpenVX module header files into /opt/rocm/mivisionx/include folder
- Apps, Samples, Documents, Model Compiler and Toolkit are placed into /opt/rocm/mivisionx
- Run samples to verify the installation
  - Canny Edge Detection
export PATH=/opt/rocm/mivisionx/bin
export LD_LIBRARY_PATH=/opt/rocm/mivisionx/lib
runvxit /opt/rocm/mivisionx/samples/gdf/canny.gdf

Note: More samples are available here

2.8.12.11 Docker

MIVisionX provides developers with docker images for Ubuntu 16.04, Ubuntu 18.04, CentOS 7.5, & CentOS 7.6. Using docker images developers can quickly prototype and build applications without having to be locked into a single system setup or lose valuable time figuring out the dependencies of the underlying software.

2.8.12.11.1 MIVisionX Docker

- Ubuntu 16.04
- Ubuntu 18.04
- CentOS 7.5
- CentOS 7.6

2.8.12.11.2 Docker Workflow Sample on Ubuntu 16.04

Prerequisites

- Ubuntu 16.04
- rocm supported hardware

2.8.12.11.3 Workflow

Step 1 - Install rocm-dkms

```bash
sudo apt update
sudo apt dist-upgrade
sudo apt install libnuma-dev
sudo reboot
```

```bash
wget -qO - http://repo.radeon.com/rocm/apt/debian/rocm.gpg.key | sudo apt-key add -
echo 'deb [arch=amd64] http://repo.radeon.com/rocm/apt/debian/ xenial main' | sudo tee /etc/apt/sources.list.d/rocm.list
sudo apt update
sudo apt install rocm-dkms
sudo reboot
```

Step 2 - Setup Docker

```bash
sudo apt-get install curl
sudo curl -fsSL https://download.docker.com/linux/ubuntu/gpg | sudo apt-key add -
sudo add-apt-repository "deb [arch=amd64] https://download.docker.com/linux/ubuntu
-$(lsb_release -cs) stable"
sudo apt-get update
```
apt-cache policy docker-ce
sudo apt-get install -y docker-ce
sudo systemctl status docker

Step 3 - Get Docker Image

```bash
sudo docker pull mivisionx/ubuntu-16.04
```

Step 4 - Run the docker image

```bash
sudo docker run -it --device=/dev/kfd --device=/dev/dri --cap-add=SYS_RAWIO --device=/
--dev/mem --group-add video --network host mivisionx/ubuntu-16.04
```

- **Optional**: Map localhost directory on the docker image
  - option to map the localhost directory with trained caffe models to be accessed on the docker image.
  - usage: `-v {LOCAL_HOST_DIRECTORY_PATH}:{DOCKER_DIRECTORY_PATH}`

```bash
sudo docker run -it -v /home/:/root/hostDrive/ --device=/dev/kfd --device=/dev/dri --
--cap-add=SYS_RAWIO --device=/dev/mem --group-add video --network host mivisionx/
--ubuntu-16.04
```

**Note**: Display option with docker

- Using host display

```bash
xhost +local:root
sudo docker run -it --device=/dev/kfd --device=/dev/dri --cap-add=SYS_RAWIO --device=/
--dev/mem --group-add video
--network host --env DISPLAY=unix$DISPLAY --privileged --volume $XAUTH:/root/.
--Xauthority
```

- Test display with MIVisionX sample

```bash
export PATH=$PATH:/opt/rocm/mivisionx/bin
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/opt/rocm/mivisionx/lib
runvx /opt/rocm/mivisionx/samples/gdf/canny.gdf
```

### 2.8.12.11.4 Supported Neural Net Layers

<table>
<thead>
<tr>
<th>Layer name</th>
<th>Activation</th>
<th>Argmax</th>
<th>Batch Normalization</th>
<th>Concat</th>
<th>Convolution</th>
<th>Deconvolution</th>
<th>Fully Connected</th>
<th>Local Response Normalization (LRN)</th>
<th>Pooling</th>
<th>Scale</th>
<th>Slice</th>
<th>Softmax</th>
</tr>
</thead>
</table>
2.8.12.12 Release Notes

2.8.12.12.1 Known issues

- Package (.deb & .rpm) install requires OpenCV v3.4.0 to execute AMD OpenCV extensions

2.8.12.12.2 Tested configurations

- Windows 10
- Linux: Ubuntu - 16.04/18.04 & CentOS - 7.5/7.6
- ROCm: rocm-dkms - 2.4.25
- rocm-cmake - github master:ac45c6e
- MIOpenGEMM - 1.1.5
- MIOpen - 1.8.1
- Protobuf - V3.5.2
- OpenCV - 3.4.0
- Dependencies for all the above packages

2.9 ROCm Libraries

2.9.1 rocFFT

rocFFT is a software library for computing Fast Fourier Transforms (FFT) written in HIP. It is part of AMD’s software ecosystem based on ROCm. In addition to AMD GPU devices, the library can also be compiled with the CUDA compiler using HIP tools for running on Nvidia GPU devices.

The rocFFT library:

- Provides a fast and accurate platform for calculating discrete FFTs.
- Supports single and double precision floating point formats.
- Supports 1D, 2D, and 3D transforms.
- Supports computation of transforms in batches.
- Supports real and complex FFTs.
- Supports lengths that are any combination of powers of 2, 3, 5.
2.9.1.1 API design

Please refer to the rocFFT API for current documentation. Work in progress.

2.9.1.2 Installing pre-built packages

Download pre-built packages either from ROCm’s package servers or by clicking the github releases tab and manually downloading, which could be newer. Release notes are available for each release on the releases tab.

```
sudo apt update && sudo apt install rocfft
```

2.9.1.3 Quickstart rocFFT build

Bash helper build script (Ubuntu only) The root of this repository has a helper bash script install.sh to build and install rocFFT on Ubuntu with a single command. It does not take a lot of options and hard-codes configuration that can be specified through invoking cmake directly, but it’s a great way to get started quickly and can serve as an example of how to build/install. A few commands in the script need sudo access, so it may prompt you for a password. */

```
./install -h -- shows help
./install -id -- build library, build dependencies and install globally (-d flag only needs to be specified once on a system)
./install -c --cuda = build library and clients for cuda backend
```

A local directory Manual build (all supported platforms) If you use a distro other than Ubuntu, or would like more control over the build process, the rocfft build wiki has helpful information on how to configure cmake and manually build.

Library and API Documentation

Please refer to the Library documentation for current documentation.

2.9.1.4 Manual build (all supported platforms)

If you use a distro other than Ubuntu, or would like more control over the build process, the rocfft build wiki has helpful information on how to configure cmake and manually build.

2.9.1.5 Example

The following is a simple example code that shows how to use rocFFT to compute a 1D single precision 16-point complex forward transform.

```c++
#include <iostream>
#include <vector>
#include "hip/hip_runtime_api.h"
#include "hip/hip_vector_types.h"
#include "rocfft.h"

int main()
{
    // rocFFT gpu compute
    // ----------------------------------------------

    size_t N = 16;
    size_t Nbytes = N * sizeof(float2);

    // Create HIP device buffer
    float2 *x;
```

(continues on next page)
```cpp
hipMalloc(&x, Nbytes);

// Initialize data
std::vector<float2> cx(N);
for (size_t i = 0; i < N; i++)
{
    cx[i].x = 1;
    cx[i].y = -1;
}

// Copy data to device
hipMemcpy(x, cx.data(), Nbytes, hipMemcpyHostToDevice);

// Create rocFFT plan
rocfft_plan plan = NULL;
size_t length = N;
rocfft_plan_create(&plan, rocfft_placement_inplace, rocfft_transform_type_‐
→complex_forward, rocfft_precision_single, 1, &length, 1, 0, 
→NULL);

// Execute plan
rocfft_execute(plan, (void**) &x, NULL, NULL);

// Wait for execution to finish
hipDeviceSynchronize();

// Destroy plan
rocfft_plan_destroy(plan);

// Copy result back to host
std::vector<float2> y(N);
hipMemcpy(y.data(), x, Nbytes, hipMemcpyDeviceToHost);

// Print results
for (size_t i = 0; i < N; i++)
{
    std::cout << y[i].x << "", " << y[i].y << std::endl;
}

// Free device buffer
hipFree(x);

return 0;
```

### 2.9.1.6 API

This section provides details of the library API

#### 2.9.1.6.1 Types

There are few data structures that are internal to the library. The pointer types to these structures are given below. The user would need to use these types to create handles and pass them between different library functions.
typedef struct rocfft_plan_t *rocfft_plan
Pointer type to plan structure.
This type is used to declare a plan handle that can be initialized with rocfft_plan_create.

typedef struct rocfft_plan_description_t *rocfft_plan_description
Pointer type to plan description structure.
This type is used to declare a plan description handle that can be initialized with rocfft_plan_description_create.

typedef struct rocfft_execution_info_t *rocfft_execution_info
Pointer type to execution info structure.
This type is used to declare an execution info handle that can be initialized with rocfft_execution_info_create.

2.9.1.6.2 Library Setup and Cleanup

The following functions deals with initialization and cleanup of the library.

rocfft_status rocfft_setup()
Library setup function, called once in program before start of library use.

rocfft_status rocfft_cleanup()
Library cleanup function, called once in program after end of library use.

2.9.1.6.3 Plan

The following functions are used to create and destroy plan objects.

rocfft_status rocfft_plan_create (rocfft_plan *plan, rocfft_result_placement placement, rocfft_transform_type transform_type, rocfft_precision precision, size_t dimensions, const size_t *lengths, size_t number_of_transforms, const rocfft_plan_description description)
Create an FFT plan.
This API creates a plan, which the user can execute subsequently. This function takes many of the fundamental parameters needed to specify a transform. The parameters are self explanatory. The dimensions parameter can take a value of 1,2 or 3. The ‘lengths’ array specifies size of data in each dimension. Note that lengths[0] is the size of the innermost dimension, lengths[1] is the next higher dimension and so on. The ‘number_of_transforms’ parameter specifies how many transforms (of the same kind) needs to be computed. By specifying a value greater than 1, a batch of transforms can be computed with a single api call. Additionally, a handle to a plan description can be passed for more detailed transforms. For simple transforms, this parameter can be set to null ptr.

Parameters

• [out] plan: plan handle
• [in] placement: placement of result
• [in] transform_type: type of transform
• [in] precision: precision
• [in] dimensions: dimensions
• [in] lengths: dimensions sized array of transform lengths
• [in] number_of_transforms: number of transforms
• [in] description: description handle created by rocfft_plan_description_create; can be null ptr for simple transforms
rocfft_status rocfft_plan_destroy (rocfft_plan plan)
Destroy an FFT plan.

This API frees the plan. This function destructs a plan after it is no longer needed.

Parameters
- [in] plan: plan handle

The following functions are used to query for information after a plan is created.

rocfft_status rocfft_plan_get_work_buffer_size (const rocfft_plan plan, size_t *size_in_bytes)
Get work buffer size.

This is one of plan query functions to obtain information regarding a plan. This API gets the work buffer size.

Parameters
- [in] plan: plan handle
- [out] size_in_bytes: size of needed work buffer in bytes

rocfft_status rocfft_plan_get_print (const rocfft_plan plan)
Print all plan information.

This is one of plan query functions to obtain information regarding a plan. This API prints all plan info to stdout to help user verify plan specification.

Parameters
- [in] plan: plan handle

2.9.1.6.4 Plan description

Most of the times, rocfft_plan_create() is all is needed to fully specify a transform. And the description object can be skipped. But when a transform specification has more details a description object need to be created and set up and the handle passed to the rocfft_plan_create(). Functions referred below can be used to manage plan description in order to specify more transform details. The plan description object can be safely deleted after call to the plan api rocfft_plan_create().

rocfft_status rocfft_plan_description_create (rocfft_plan_description *description)
Create plan description.

This API creates a plan description with which the user can set more plan properties

Parameters
- [out] description: plan description handle

rocfft_status rocfft_plan_description_destroy (rocfft_plan_description description)
Destroy a plan description.

This API frees the plan description

Parameters
- [in] description: plan description handle
rocfft_status rocfft_plan_description_set_data_layout(rocfft_plan_description description, rocfft_array_type in_array_type, rocfft_array_type out_array_type, const size_t *in_offsets, const size_t *out_offsets, size_t in_strides_size, const size_t *in_strides, size_t in_distance, size_t out_strides_size, const size_t *out_strides, size_t out_distance)

Set data layout.

This is one of plan description functions to specify optional additional plan properties using the description handle. This API specifies the layout of buffers. This function can be used to specify input and output array types. Not all combinations of array types are supported and error code will be returned for unsupported cases. Additionally, input and output buffer offsets can be specified. The function can be used to specify custom layout of data, with the ability to specify stride between consecutive elements in all dimensions. Also, distance between transform data members can be specified. The library will choose appropriate defaults if offsets/strides are set to null ptr and/or distances set to 0.

Parameters

- [in] description: description handle
- [in] in_array_type: array type of input buffer
- [in] out_array_type: array type of output buffer
- [in] in_offsets: offsets, in element units, to start of data in input buffer
- [in] out_offsets: offsets, in element units, to start of data in output buffer
- [in] in_strides_size: size of in_strides array (must be equal to transform dimensions)
- [in] in_strides: array of strides, in each dimension, of input buffer; if set to null ptr library chooses defaults
- [in] in_distance: distance between start of each data instance in input buffer
- [in] out_strides_size: size of out_strides array (must be equal to transform dimensions)
- [in] out_strides: array of strides, in each dimension, of output buffer; if set to null ptr library chooses defaults
- [in] out_distance: distance between start of each data instance in output buffer

2.9.1.6.5 Execution

The following details the execution function. After a plan has been created, it can be used to compute a transform on specified data. Aspects of the execution can be controlled and any useful information returned to the user.

rocfft_status rocfft_execute(const rocfft_plan plan, void *in_buffer[], void *out_buffer[], rocfft_execution_info info)

Execute an FFT plan.

This API executes an FFT plan on buffers given by the user. If the transform is in-place, only the input buffer is needed and the output buffer parameter can be set to NULL. For not in-place transforms, output buffers have to be specified. Note that both input and output buffer are arrays of pointers, this is to facilitate passing planar buffers where real and imaginary parts are in 2 separate buffers. For the default interleaved format, just a unit sized array holding the pointer to input/output buffer need to be passed. The final parameter in this function is
an execution_info handle. This parameter serves as a way for the user to control execution, as well as for the library to pass any execution related information back to the user.

Parameters

- [in] plan: plan handle
- [inout] in_buffer: array (of size 1 for interleaved data, of size 2 for planar data) of input buffers
- [inout] out_buffer: array (of size 1 for interleaved data, of size 2 for planar data) of output buffers, can be nullptr for inplace result placement
- [in] info: execution info handle created by rocfft_execution_info_create

2.9.1.6.6 Execution info

The execution api rocfft_execute() takes a rocfft_execution_info parameter. This parameter needs to be created and setup by the user and passed to the execution api. The execution info handle encapsulates information such as execution mode, pointer to any work buffer etc. It can also hold information that are side effect of execution such as event objects. The following functions deal with managing execution info object. Note that the set functions below need to be called before execution and get functions after execution.

rocfft_status rocfft_execution_info_create(rocfft_execution_info *info)

Create execution info.

Parameters

- [out] info: execution info handle

rocfft_status rocfft_execution_info_destroy(rocfft_execution_info info)

Destroy an execution info.

Parameters

- [in] info: execution info handle

rocfft_status rocfft_execution_info_set_work_buffer(rocfft_execution_info info, void *work_buffer, size_t size_in_bytes)

Set work buffer in execution info.

This is one of the execution info functions to specify optional additional information to control execution. This API specifies work buffer needed. It has to be called before the call to rocfft_execute. When a non-zero value is obtained from rocfft_plan_get_work_buffer_size, that means the library needs a work buffer to compute the transform. In this case, the user has to allocate the work buffer and pass it to the library via this api.

Parameters

- [in] info: execution info handle
- [in] work_buffer: work buffer
- [in] size_in_bytes: size of work buffer in bytes
rocfft_status rocfft_execution_info_set_stream(rocfft_execution_info info, void *stream)
Set stream in execution info.
This is one of the execution info functions to specify optional additional information to control execution. This API specifies compute stream. It has to be called before the call to rocfft_execute. It is the underlying device queue/stream where the library computations would be inserted. The library assumes user has created such a stream in the program and merely assigns work to the stream.

Parameters
- [in] info: execution info handle
- [in] stream: underlying compute stream

2.9.1.6.7 Enumerations

This section provides all the enumerations used.

**enum rocfft_status**
rocfft status/error codes
Values:
- rocfft_status_success
- rocfft_status_failure
- rocfft_status_invalid_arg_value
- rocfft_status_invalid_dimensions
- rocfft_status_invalid_array_type
- rocfft_status_invalid_strides
- rocfft_status_invalid_distance
- rocfft_status_invalid_offset

**enum rocfft_transform_type**
Type of transform.
Values:
- rocfft_transform_type_complex_forward
- rocfft_transform_type_complex_inverse
- rocfft_transform_type_real_forward
- rocfft_transform_type_real_inverse

**enum rocfft_precision**
Precision.
Values:
- rocfft_precision_single
- rocfft_precision_double

**enum rocfft_result_placement**
Result placement.
Values:
rocfft_placement_inplace
rocfft_placement_notinplace

enum rocfft_array_type
Array type.
Values:
rocfft_array_type_complex_interleaved
rocfft_array_type_complex_planar
rocfft_array_type_real
rocfft_array_type_hermitian_interleaved
rocfft_array_type_hermitian_planar

enum rocfft_execution_mode
Execution mode.
Values:
rocfft_exec_mode_nonblocking
rocfft_exec_mode_nonblocking_with_flush
rocfft_exec_mode_blocking

2.9.2 rocBLAS

Please refer rocBLAS Github link

A BLAS implementation on top of AMD’s Radeon Open Compute ROCm runtime and toolchains. rocBLAS is implemented in the HIP programming language and optimized for AMD’s latest discrete GPUs.

2.9.2.1 Installing pre-built packages

Download pre-built packages either from ROCm’s package servers or by clicking the github releases tab and manually downloading, which could be newer. Release notes are available for each release on the releases tab.

```
sudo apt update && sudo apt install rocblas
```

2.9.2.2 Quickstart rocBLAS build

Bash helper build script (Ubuntu only)

The root of this repository has a helper bash script install.sh to build and install rocBLAS on Ubuntu with a single command. It does not take a lot of options and hard-codes configuration that can be specified through invoking cmake directly, but it’s a great way to get started quickly and can serve as an example of how to build/install. A few commands in the script need sudo access, so it may prompt you for a password.

```
./install -h -- shows help
./install -id -- build library, build dependencies and install (-d flag only needs to be passed once on a system)
```
2.9.2.3 Manual build (all supported platforms)

If you use a distro other than Ubuntu, or would like more control over the build process, the rocblaswiki has helpful information on how to configure cmake and manually build.

Functions supported

A list of exported functions from rocblas can be found on the wiki.

2.9.2.4 rocBLAS interface examples

In general, the rocBLAS interface is compatible with CPU oriented Netlib BLAS and the cuBLAS-v2 API, with the explicit exception that traditional BLAS interfaces do not accept handles. The cuBLAS’ cublasHandle_t is replaced with rocblas_handle everywhere. Thus, porting a CUDA application which originally calls the cuBLAS API to a HIP application calling rocBLAS API should be relatively straightforward. For example, the rocBLAS SGEMV interface is

2.9.2.5 GEMV API

```c
rocblas_status
rocblas_sgemv(rocblas_handle handle,
             rocblas_operation trans,
             rocblas_int m, rocblas_int n,
             const float* alpha,
             const float* A, rocblas_int lda,
             const float* x, rocblas_int incx,
             const float* beta,
             float* y, rocblas_int incy);
```

2.9.2.6 Batched and strided GEMM API

rocBLAS GEMM can process matrices in batches with regular strides. There are several permutations of these API’s, the following is an example that takes everything

```c
rocblas_status
rocblas_sgemm_strided_batched(    rocblas_handle handle,
                      rocblas_operation transa, rocblas_operation transb,
                      rocblas_int m, rocblas_int n, rocblas_int k,
                      const float* alpha,
                      const float* A, rocblas_int ls_a, rocblas_int ld_a, rocblas_int bs_a,
                      const float* B, rocblas_int ls_b, rocblas_int ld_b, rocblas_int bs_b,
                      const float* beta,
                      float* C, rocblas_int ls_c, rocblas_int ld_c, rocblas_int bs_c,
                      rocblas_int batch_count )
```

rocBLAS assumes matrices A and vectors x, y are allocated in GPU memory space filled with data. Users are responsible for copying data from/to the host and device memory. HIP provides memcpy style API’s to facilitate data management.
2.9.2.7 Example

```c
#include <stdlib.h>
#include <stdio.h>
#include <vector>
#include <math.h>
#include "rocblas.h"

using namespace std;

int main()
{
    rocblas_int N = 10240;
    float alpha = 10.0;

    vector<float> hx(N);
    vector<float> hz(N);
    float* dx;
    float tolerance = 0, error;

    rocblas_handle handle;
    rocblas_create_handle(&handle);

    // allocate memory on device
    hipMalloc(&dx, N * sizeof(float));

    // Initial Data on CPU,
    srand(1);
    for ( int i = 0; i < N; ++i )
    {
        hx[i] = rand() % 10 + 1; //generate a integer number between [1, 10]
    }

    // save a copy in hz
    hz = hx;

    hipMemcpy(dx, hx.data(), sizeof(float) * N, hipMemcpyHostToDevice);
    rocblas_sscal(handle, N, &alpha, dx, 1);

    // copy output from device memory to host memory
    hipMemcpy(hx.data(), dx, sizeof(float) * N, hipMemcpyDeviceToHost);

    // verify rocblas_scal result
    for(rocblas_int i=0;i<N;i++)
    {
        error = fabs(hz[i] * alpha - hx[i]);
        if(error > tolerance)
        {
            printf("error in element %d: CPU=%f, GPU=%f ", i, hz[i] * alpha, hx[i]);
            break;
        }
    }
    if(error > tolerance)
    {
        printf("SCAL Failed !\n");
    }
}
```

(continues on next page)
Paste the above code into the file rocblas_sscal_example.cpp

Use hipcc Compiler:

The recommend host compiler is hipcc. To use hipcc you will need to add /opt/rocm/bin to your path with the following:

```bash
export PATH=$PATH:/opt/rocm/bin
```

The following makefile can be used to build the executable.

The Makefile assumes that rocBLAS is installed in the default location /opt/rocm/rocblas. If you have rocBLAS installed in your home directory in ~/rocBLAS/build/release/rocblas-install/rocblas then edit Makefile and change /opt/rocm/rocblas to ~/rocBLAS/build/release/rocblas-install/rocblas.

You may need to give the location of the library with

```bash
export LD_LIBRARY_PATH=/opt/rocm/rocblas/lib$LD_LIBRARY_PATH:+:$LD_LIBRARY_PATH
```

Run the executable with the command

```bash
./rocblas_sscal_example
```

Use g++ Compiler:

2.9. ROCm Libraries
Use the Makefile below:

```makefile
ROCBLAS_INSTALL_DIR=/opt/rocm/rocblas
ROCBLAS_INCLUDE=$(ROCBLAS_INSTALL_DIR)/include
ROCBLAS_LIB_PATH=$(ROCBLAS_INSTALL_DIR)/lib
ROCBLAS_LIB=rocblas
ROCM_INCLUDE=/opt/rocm/include
LDFLAGS=-L$(ROCBLAS_LIB_PATH) -l$(ROCBLAS_LIB) -L/opt/rocm/lib -lhip_hcc
LD=g++
CFLAGS=-I$(ROCBLAS_INCLUDE) -I$(ROCM_INCLUDE) -D__HIP_PLATFORM_HCC__
CPP=g++
OBJ=rocblas_sscal_example.o
EXE=rocblas_sscal_example

%.o: %.cpp
  $(CPP) -c -o $@ $< $(CFLAGS)

$(EXE) : $(OBJ)
  $(LD) $(OBJ) $(LDFLAGS) -o $@

clean:
  rm -f $(EXE) $(OBJ)
```

### 2.9.2.8 Build

#### 2.9.2.8.1 Download rocBLAS

Download the master branch of rocBLAS from github using:

```bash
git clone -b master https://github.com/ROCmSoftwarePlatform/rocBLAS.git
cd rocBLAS
```

Note if you want to contribute to rocBLAS, you will need the develop branch, not the master branch, and you will need to read .github/CONTRIBUTING.md.

Below are steps to build either (dependencies + library) or (dependencies + library + client). You only need (dependencies + library) if you call rocBLAS from your code, or if you need to install rocBLAS for other users. The client contains the test code and examples.

It is recommended that the script install.sh be used to build rocBLAS. If you need individual commands, they are also given.

#### 2.9.2.8.2 Use install.sh to build (library dependencies + library)

Common uses of install.sh to build (library dependencies + library) are in the table below.

#### 2.9.2.8.3 Use install.sh to build (library dependencies + client dependencies + library + client)

The client contains executables in the table below.

<table>
<thead>
<tr>
<th>executable name</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rocblas-test</td>
<td>runs Google Tests to test the library</td>
</tr>
<tr>
<td>rocblas-bench</td>
<td>executable to benchmark or test individual functions</td>
</tr>
<tr>
<td>example-sscal</td>
<td>example C code calling rocblas_sscal function</td>
</tr>
</tbody>
</table>
Common uses of install.sh to build (dependencies + library + client) are in the table below.

<table>
<thead>
<tr>
<th>install.sh</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>./install.sh -h</td>
<td>Help information.</td>
</tr>
<tr>
<td>./install.sh -dc</td>
<td>Build library dependencies, client dependencies, library, and client in your local directory. The -d flag only needs to be used once. For subsequent invocations of install.sh it is not necessary to rebuild the dependencies.</td>
</tr>
<tr>
<td>./install.sh -c</td>
<td>Build library and client in your local directory. It is assumed the dependencies have been built.</td>
</tr>
<tr>
<td>./install.sh -idc</td>
<td>Build library dependencies, client dependencies, library, client, then build and install the rocBLAS package. You will be prompted for sudo access. It is expected that if you want to install for all users you use the -i flag. If you want to keep rocBLAS in your local directory, you do not need the -i flag.</td>
</tr>
<tr>
<td>./install.sh -ic</td>
<td>Build and install rocBLAS package, and build the client. You will be prompted for sudo access. This will install for all users. If you want to keep rocBLAS in your local directory, you do not need the -i flag.</td>
</tr>
</tbody>
</table>

2.9.2.8.4 Build (library dependencies + library) Using Individual Commands

Before building the library please install the library dependencies CMake, Python 2.7, and Python-yaml.

CMake 3.5 or later

The build infrastructure for rocBLAS is based on Cmake v3.5. This is the version of cmake available on ROCm supported platforms. If you are on a headless machine without the x-windows system, we recommend using ccmake; if you have access to X-windows, we recommend using cmake-gui.

Install one-liners cmake:

- Ubuntu: sudo apt install cmake-qt-gui
- Fedora: sudo dnf install cmake-gui

Python 2.7

By default both python2 and python3 are on Ubuntu. You can check the installation with python -V. Python is used in Tensile, and Tensile is part of rocBLAS. To build rocBLAS the default version of Python must be Python 2.7, not Python 3.

Python-yaml

PyYAML files contain training information from Tensile that is used to build gemm kernels in rocBLAS.

Install one-liners PyYAML:

- Ubuntu: sudo apt install python2.7 python-yaml
- Fedora: sudo dnf install python PyYAML

Build library

The rocBLAS library contains both host and device code, so the HCC compiler must be specified during cmake configuration to properly initialize build tools. Example steps to build rocBLAS:
# after downloading and changing to rocblas directory:
mkdir -p build/release
cd build/release
# Default install path is in /opt/rocm, use -DCMAKE_INSTALL_PREFIX=<path> to specify
˓→other install path
# Default build config is 'Release', define -DCMAKE_BUILD_TYPE=Debug to specify Debug
˓→configuration
CXX=/opt/rocm/bin/hcc cmake ../..
make -j$(nproc)
#if you want to install in /opt/rocm or the directory set in cmake with -DCMAKE_ 
˓→INSTALL_PREFIX
sudo make install # sudo required if installing into system directory such as /opt/ 
˓→rocm

2.9.2.8.5 Build (library dependencies + client dependencies + library + client) using Individual Commands

Additional dependencies for the rocBLAS clients

The unit tests and benchmarking applications in the client introduce the following dependencies:

1. boost
2. fortran
3. lapack
   - lapack itself brings a dependency on a fortran compiler
4. googletest

boost

Linux distros typically have an easy installation mechanism for boost through the native package manager.

Ubuntu: sudo apt install libboost-program-options-dev
Fedora: sudo dnf install boost-program-options

Unfortunately, googletest and lapack are not as easy to install. Many distros do not provide a googletest package with pre-compiled libraries, and the lapack packages do not have the necessary cmake config files for cmake to configure linking the cblas library. rocBLAS provide a cmake script that builds the above dependencies from source. This is an optional step; users can provide their own builds of these dependencies and help cmake find them by setting the CMAKE_PREFIX_PATH definition. The following is a sequence of steps to build dependencies and install them to the cmake default /usr/local.

gfortran and lapack

LAPACK is used in the client to test rocBLAS. LAPACK is a Fortran Library, so gfortran is required for building the client.

Ubuntu apt-get update
  apt-get install gfortran
Fedora yum install gcc-gfortran
mkdir -p build/release/deps
cd build/release/deps

(continues on next page)
2.9.2.8.6 Build Library and Client Using Individual Commands

Once dependencies are available on the system, it is possible to configure the clients to build. This requires a few extra cmake flags to the library cmake configure script. If the dependencies are not installed into system defaults (like /usr/local), you should pass the CMAKE_PREFIX_PATH to cmake to help find them.

```
-DCMAKE_PREFIX_PATH="<semicolon separated paths>"
```

# after downloading and changing to rocblas directory:
mkdir -p build/release
cd build/release
# Default install location is in /opt/rocm, use -DCMAKE_INSTALL_PREFIX=<path> to specify other
CXX=/opt/rocm/bin/hcc cmake -DBUILD_CLIENTS_TESTS=ON -DBUILD_CLIENTS_BENCHMARKS=ON -
-DBUILD_CLIENTS_SAMPLES=ON ../..
make -j$(nproc)
sudo make install # sudo required if installing into system directory such as /opt/

2.9.2.8.7 Use of Tensile

The rocBLAS library uses Tensile, which supplies the high-performance implementation of xGEMM. Tensile is downloaded by cmake during library configuration and automatically configured as part of the build, so no further action is required by the user to set it up.

2.9.2.8.8 CUDA build errata

rocBLAS is written with HiP kernels, so it should build and run on CUDA platforms. However, currently the cmake infrastructure is broken with a CUDA backend. However, a BLAS marshalling library that presents a common interface for both ROCm and CUDA backends can be found with hipBLAS.

2.9.2.8.9 Common build problems

- **Issue:** “Tensile could not be found because dependency Python Interp could not be found”.
  
  **Solution:** Due to a bug in Tensile, you may need cmake-gui 3.5 and above, though in the cmakefiles it requires 2.8.

- **Issue:** HIP (/opt/rocm/hcc/hip) was built using hcc 1.0.xxx-xxx-xxx-xxx, but you are using /opt/rocm/hcc/hcc with version 1.0.yyy-yyy-yyy-yyy from hipcc. (version does not match). Please rebuild HIP including cmake or update HCC_HOME variable.
  
  **Solution:** Download HIP from github and use hcc to build from source and then use the build HIP instead of /opt/rocm/hip one or singly overwrite the new build HIP to this location.

- **Issue:** For Carrizo - HCC RUNTIME ERROR: Fail to find compatible kernel
Solution: Add the following to the cmake command when configuring:

```
DCMAKE_CXX_FLAGS="-amdgpu-target=gfx801"
```

- **Issue:** For MI25 (Vega10 Server) - HCC RUNTIME ERROR: Fail to find compatible kernel

  **Solution:** export HCC_AMDGPU_TARGET=gfx900

- **Issue:** Could not find a package configuration file provided by “ROCM” with any of the following names:
  - ROCMConfig.cmake
  - rocm-config.cmake

  **Solution:** Install ROCm cmake module.

---

### 2.9.2.9 Running

#### 2.9.2.9.1 Notice

This wiki describes running the examples, tests, and benchmarks in the client. Before reading this Wiki, it is assumed rocBLAS (dependencies + library + client) has been built as described in Build

#### 2.9.2.9.2 Examples

The default for [BUILD_DIR] is ~/rocblas/build.

```
cd [BUILD_DIR]/release/clients/staging
./example-sscal
./example-scal-template
./example-sgemm
./example-sgemm-strided-batched
```

Code for the examples is at: samples

In addition see Example

#### 2.9.2.9.3 Unit tests

Run tests with the following:

```
cd [BUILD_DIR]/release/clients/staging ./rocblas-test
```

To run specific tests, use `-gtest_filter=match` where match is a `:`-separated list of wildcard patterns (called the positive patterns) optionally followed by a `:`- and another `:`-separated pattern list (called the negative patterns). For example, run gemv tests with the following:

```
cd [BUILD_DIR]/release/clients/staging ./rocblas-test -gtest_filter=*checkin*gemm*float*-batched:NaN
```

#### 2.9.2.9.4 Benchmarks

Run benchmarks with the following:

```
cd [BUILD_DIR]/release/clients/staging ./rocblas-bench -h
```

The following are examples for running particular gemm and gemv benchmark:
2.9.2.10 Asynchronous API

Except a few routines (like TRSM) having memory allocation inside preventing asynchronicity, most of the library routines (like BLAS-1 SCAL, BLAS-2 GEMV, BLAS-3 GEMM) are configured to operate in asynchronous fashion with respect to CPU, meaning these library functions return immediately.

For more information regarding rocBLAS library and corresponding API documentation, refer rocBLAS

2.9.2.11 API

This section provides details of the library API

2.9.2.11.1 Types

2.9.2.11.1.1 Definitions

2.9.2.11.1.2 rocblas_int

```c
typedef int32_t rocblas_int
```

To specify whether int32 or int64 is used.

2.9.2.11.1.3 rocblas_long

```c
typedef int64_t rocblas_long
```

2.9.2.11.1.4 rocblas_float_complex

```c
typedef float2 rocblas_float_complex
```

2.9.2.11.1.5 rocblas_double_complex

```c
typedef double2 rocblas_double_complex
```

2.9.2.11.1.6 rocblas_half

```c
typedef uint16_t rocblas_half
```

2.9.2.11.1.7 rocblas_half_complex

```c
typedef float2 rocblas_half_complex
```
2.9.2.11.8 rocblas_handle

typedef struct _rocblas_handle *rocblas_handle

2.9.2.11.9 Enums

Enumeration constants have numbering that is consistent with CBLAS, ACML and most standard C BLAS libraries.

2.9.2.11.10 rocblas_operation

enum rocblas_operation
    Used to specify whether the matrix is to be transposed or not.
    parameter constants. numbering is consistent with CBLAS, ACML and most standard C BLAS libraries
    Values:
        rocblas_operation_none = 111
            Operate with the matrix.
        rocblas_operation_transpose = 112
            Operate with the transpose of the matrix.
        rocblas_operation_conjugate_transpose = 113
            Operate with the conjugate transpose of the matrix.

2.9.2.11.11 rocblas_fill

enum rocblas_fill
    Used by the Hermitian, symmetric and triangular matrix routines to specify whether the upper or lower triangle is being referenced.
    Values:
        rocblas_fill_upper = 121
            Upper triangle.
        rocblas_fill_lower = 122
            Lower triangle.
        rocblas_fill_full = 123

2.9.2.11.12 rocblas_diagonal

enum rocblas_diagonal
    It is used by the triangular matrix routines to specify whether the matrix is unit triangular.
    Values:
        rocblas_diagonal_non_unit = 131
            Non-unit triangular.
        rocblas_diagonal_unit = 132
            Unit triangular.
2.9.2.11.13 rocblas_side

define rocblas_side

Indicates the side matrix A is located relative to matrix B during multiplication.

Values:

rocblas_side_left = 141
Multiply general matrix by symmetric, Hermitian or triangular matrix on the left.

rocblas_side_right = 142
Multiply general matrix by symmetric, Hermitian or triangular matrix on the right.

rocblas_side_both = 143

2.9.2.11.14 rocblas_status

define rocblas_status

rocblas status codes definition

Values:

rocblas_status_success = 0
success

rocblas_status_invalid_handle = 1
handle not initialized, invalid or null

rocblas_status_not_implemented = 2
function is not implemented

rocblas_status_invalid_pointer = 3
invalid pointer parameter

rocblas_status_invalid_size = 4
invalid size parameter

rocblas_status_memory_error = 5
failed internal memory allocation, copy or dealloc

rocblas_status_internal_error = 6
other internal library failure

2.9.2.11.15 rocblas_datatype

define rocblas_datatype

Indicates the precision width of data stored in a blas type.

Values:

rocblas_datatype_f16_r = 150
rocblas_datatype_f32_r = 151
rocblas_datatype_f64_r = 152
rocblas_datatype_f16_c = 153
rocblas_datatype_f32_c = 154
rocblas_datatype_f64_c = 155
rocblas_datatype_i8_r = 160
rocblas_datatype_u8_r = 161
rocblas_datatype_i32_r = 162
rocblas_datatype_u32_r = 163
rocblas_datatype_i8_c = 164
rocblas_datatype_u8_c = 165
rocblas_datatype_i32_c = 166
rocblas_datatype_u32_c = 167

2.9.2.11.1.16 rocblas_pointer_mode

enum rocblas_pointer_mode
  Indicates the pointer is device pointer or host pointer.
  Values:
  rocblas_pointer_mode_host = 0
  rocblas_pointer_mode_device = 1

2.9.2.11.1.17 rocblas_layer_mode

enum rocblas_layer_mode
  Indicates if layer is active with bitmask.
  Values:
  rocblas_layer_mode_none = 0b0000000000
  rocblas_layer_mode_log_trace = 0b0000000001
  rocblas_layer_mode_log_bench = 0b0000000010
  rocblas_layer_mode_log_profile = 0b0000000100

2.9.2.11.1.18 rocblas_gemm_algo

enum rocblas_gemm_algo
  Indicates if layer is active with bitmask.
  Values:
  rocblas_gemm_algo_standard = 0b0000000000
2.9.2.11.2 Functions

2.9.2.11.2.1 Level 1 BLAS

2.9.2.11.2.2 rocblas_<type>scal()

rocblas_status rocblas_dscal (rocblas_handle handle, rocblas_int n, const double *alpha, double *x, rocblas_int incx)

rocblas_status rocblas_sscal (rocblas_handle handle, rocblas_int n, const float *alpha, float *x, rocblas_int incx)

BLAS Level 1 API.

scal scales the vector x[i] with scalar alpha, for i = 1, ..., n

\[ x := \alpha \cdot x, \]

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] alpha: specifies the scalar alpha.
- [inout] x: pointer storing vector x on the GPU.
- [in] incx: specifies the increment for the elements of x.

2.9.2.11.2.3 rocblas_<type>copy()

rocblas_status rocblas_dcopy (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, double *y, rocblas_int incy)

rocblas_status rocblas_scopy (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, float *y, rocblas_int incy)

BLAS Level 1 API.

copy copies the vector x into the vector y, for i = 1, ..., n

\[ y := x, \]

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] x: pointer storing vector x on the GPU.
- [in] incx: specifies the increment for the elements of x.
- [out] y: pointer storing vector y on the GPU.
- [in] incy: rocblas_int specifies the increment for the elements of y.
2.9.2.11.2.4 rocblas_<type>dot()

rocblas_status rocblas_ddot (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, const double *y, rocblas_int incy, double *result)

rocblas_status rocblas_sdot (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, const float *y, rocblas_int incy, float *result)

BLAS Level 1 API.
dot(u) perform dot product of vector x and y

\[ \text{result} = x \times y; \]
dotc perform dot product of complex vector x and complex y

\[ \text{result} = \text{conjugate} (x) \times y; \]

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] x: pointer storing vector x on the GPU.
- [in] incx: rocblas_int specifies the increment for the elements of y.
- [inout] result: store the dot product. either on the host CPU or device GPU. return is 0.0 if n <= 0.

2.9.2.11.2.5 rocblas_<type>swap()

rocblas_status rocblas_sswap (rocblas_handle handle, rocblas_int n, float *x, rocblas_int incx, float *y, rocblas_int incy)

BlAS Level 1 API.
swap interchange vector x[i] and y[i], for i = 1, . . . , n

\[ y := x; \ x := y \]

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [inout] x: pointer storing vector x on the GPU.
- [in] incx: specifies the increment for the elements of x.
- [inout] y: pointer storing vector y on the GPU.
- [in] incy: rocblas_int specifies the increment for the elements of y.
2.9.2.11.2.6 rocblas_<type>axpy()

rocblas_status rocblas_daxpy (rocblas_handle handle, rocblas_int n, const double *alpha, const double *x, rocblas_int incx, double *y, rocblas_int incy)
rocblas_status rocblas_saxpy (rocblas_handle handle, rocblas_int n, const float *alpha, const float *x, rocblas_int incx, float *y, rocblas_int incy)
rocblas_status rocblas_haxpy (rocblas_handle handle, rocblas_int n, const rocblas_half *alpha, const rocblas_half *x, rocblas_int incx, rocblas_half *y, rocblas_int incy)

BLAS Level 1 API.

axpy compute y := alpha * x + y

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] alpha: specifies the scalar alpha.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of x.
• [out] y: pointer storing vector y on the GPU.
• [inout] incy: rocblas_int specifies the increment for the elements of y.

2.9.2.11.2.7 rocblas_<type>asum()

rocblas_status rocblas_dasum (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, double *result)
rocblas_status rocblas_sasum (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, float *result)

BLAS Level 1 API.

asum computes the sum of the magnitudes of elements of a real vector x, or the sum of magnitudes of the real and imaginary parts of elements if x is a complex vector

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of y.
• [inout] result: store the asum product. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

2.9.2.11.2.8 rocblas_<type>nrm2()

rocblas_status rocblas_dnrm2 (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, double *result)

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rocblas_status rocblas_snrm2 (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, float *result)

BLAS Level 1 API.

nrm2 computes the euclidean norm of a real or complex vector := sqrt( x'*x ) for real vector := sqrt( x**H*x ) for complex vector

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of y.
• [inout] result: store the nrm2 product. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

2.9.2.11.2.9 rocblas_i<type>amax()

rocblas_status rocblas_idamax (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, rocblas_int *result)

rocblas_status rocblas_isamax (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, rocblas_int *result)

BLAS Level 1 API.

amax finds the first index of the element of maximum magnitude of real vector x or the sum of magnitude of the real and imaginary parts of elements if x is a complex vector

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of y.
• [inout] result: store the amax index. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

2.9.2.11.2.10 rocblas_i<type>amin()

rocblas_status rocblas_idamin (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, rocblas_int *result)

rocblas_status rocblas_isamin (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, rocblas_int *result)

BLAS Level 1 API.

amin finds the first index of the element of minimum magnitude of real vector x or the sum of magnitude of the real and imaginary parts of elements if x is a complex vector

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of y.
• [inout] result: store the amin index. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

2.9.2.11.2.11 Level 2 BLAS

2.9.2.11.2.12 rocblas_<type>gemv()

rocblas_status rocblas_dgemv (rocblas_handle handle, rocblas_operation trans, rocblas_int m, rocblas_int n, const double *alpha, const double *A, rocblas_int lda, const double *x, rocblas_int incx, const double *beta, double *y, rocblas_int incy)
rocblas_status rocblas_sgemv (rocblas_handle handle, rocblas_operation trans, rocblas_int m, rocblas_int n, const float *alpha, const float *A, rocblas_int lda, const float *x, rocblas_int incx, const float *beta, float *y, rocblas_int incy)

BLAS Level 2 API.

xGEMV performs one of the matrix-vector operations

\[
\begin{align*}
y & := \alpha A x + \beta y, \\
\text{or} \\
y & := \alpha A^T x + \beta y, \\
\text{or} \\
y & := \alpha A^H x + \beta y,
\end{align*}
\]

where alpha and beta are scalars, x and y are vectors and A is an m by n matrix.

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] trans: rocblas_operation
• [in] m: rocblas_int
• [in] n: rocblas_int
• [in] alpha: specifies the scalar alpha.
• [in] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: specifies the increment for the elements of x.
• [in] beta: specifies the scalar beta.
• [out] y: pointer storing vector y on the GPU.
• [in] incy: rocblas_int specifies the increment for the elements of y.

2.9.2.11.2.13 rocblas_<type>trsv()

rocblas_status rocblas_dtrsv (rocblas_handle handle, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, const double *A, rocblas_int lda, double *x, rocblas_int incx)
rocblas_status rocblas_strsv(rocblas_handle handle, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, const float *A, rocblas_int lda, float *x, rocblas_int incx)

BLAS Level 2 API.

trsv solves

\[ A \times x = \alpha \times b \]  
\[ \text{or} \quad A^T \times x = \alpha \times b, \]

where \( x \) and \( b \) are vectors and \( A \) is a triangular matrix.

The vector \( x \) is overwritten on \( b \).

**Parameters**

- **[in]** handle: rocblas_handle, handle to the rocblas library context queue.
- **[in]** uplo: rocblas_fill, rocblas_fill_upper: \( A \) is an upper triangular matrix. rocblas_fill_lower: \( A \) is a lower triangular matrix.
- **[in]** transA: rocblas_operation
- **[in]** diag: rocblas_diagonal, rocblas_diagonal_unit: \( A \) is assumed to be unit triangular. rocblas_diagonal_non_unit: \( A \) is not assumed to be unit triangular.
- **[in]** m: rocblas_int, \( m \) specifies the number of rows of \( b \). \( m \geq 0 \).
- **[in]** alpha: specifies the scalar \( \alpha \).
- **[in]** A: pointer storing matrix \( A \) on the GPU, of dimension ( \( \text{lda} \), \( m \) )
- **[in]** lda: rocblas_int, specifies the leading dimension of \( A \). \( \text{lda} = \max(1, m) \).
- **[in]** x: pointer storing vector \( x \) on the GPU.
- **[in]** incx: specifies the increment for the elements of \( x \).

### 2.9.2.11.2.14 rocblas_<type>ger()

rocblas_status rocblas_dger(rocblas_handle handle, rocblas_int m, rocblas_int n, const double *alpha, const double *x, rocblas_int incx, const double *y, rocblas_int incy, double *A, rocblas_int lda)

rocblas_status rocblas_sger(rocblas_handle handle, rocblas_int m, rocblas_int n, const float *alpha, const float *x, rocblas_int incx, const float *y, rocblas_int incy, float *A, rocblas_int lda)

BLAS Level 2 API.

xHE(SY)MV performs the matrix-vector operation:

\[ y := \alpha \times A \times x + \beta \times y, \]

where \( \alpha \) and \( \beta \) are scalars, \( x \) and \( y \) are \( n \) element vectors and \( A \) is an \( n \) by \( n \) Hermitian(Symmetric) matrix.

**Parameters**

- **[in]** handle: rocblas_handle, handle to the rocblas library context queue.
- **[in]** uplo: rocblas_fill, specifies whether the upper or lower
- **[in]** n: rocblas_int,
• [in] alpha: specifies the scalar alpha.
• [in] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: specifies the increment for the elements of x.
• [in] beta: specifies the scalar beta.
• [out] y: pointer storing vector y on the GPU.
• [in] incy: rocblas_int specifies the increment for the elements of y.

xGER performs the matrix-vector operations

\[ A := A + \alpha \cdot x \cdot y^T \]

where alpha is a scalar, x and y are vectors, and A is an m by n matrix.

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] m: rocblas_int
• [in] n: rocblas_int
• [in] alpha: specifies the scalar alpha.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of x.
• [in] y: pointer storing vector y on the GPU.
• [in] incy: rocblas_int specifies the increment for the elements of y.
• [inout] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.

2.9.2.11.2.15 rocblas_<type>syr()

roblas_status rocblas_dsy_r(rocblas_handle handle, rocblas_fill uplo, rocblas_int n, const double *alpha, const double *x, rocblas_int incx, double *A, rocblas_int lda)

roblas_status rocblas_ssy_r(rocblas_handle handle, rocblas_fill uplo, rocblas_int n, const float *alpha, const float *x, rocblas_int incx, float *A, rocblas_int lda)

BLAS Level 2 API.

xSYR performs the matrix-vector operations

\[ A := A + \alpha \cdot x \cdot x^T \]

where alpha is a scalar, x is a vector, and A is an n by n symmetric matrix.

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] n: rocblas_int
• [in] alpha: specifies the scalar alpha.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of x.
• [inout] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.

2.9.2.11.2.16 Level 3 BLAS

2.9.2.11.2.17 rocblas_<type>trtri.batched()

rocblas_status rocblas_dtrtri_batched(rocblas_handle handle, rocblas_fill uplo, rocblas_diagonal diag, rocblas_int n, const double *A, rocblas_int lda, rocblas_int stride_a, double *invA, rocblas_int ldinvA, rocblas_int bsinvA, rocblas_int batch_count)

rocblas_status rocblas_strtri_batched(rocblas_handle handle, rocblas_fill uplo, rocblas_diagonal diag, rocblas_int n, const float *A, rocblas_int lda, rocblas_int stride_a, float *invA, rocblas_int ldinvA, rocblas_int bsinvA, rocblas_int batch_count)

BLAS Level 3 API.

trtri compute the inverse of a matrix A

\[
\text{inv}(A);
\]

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] uplo: rocblas_fill. specifies whether the upper ‘rocblas_fill_upper’ or lower ‘rocblas_fill_lower’
• [in] diag: rocblas_diagonal. = ‘rocblas_diagonal_non_unit’, A is non-unit triangular; = ‘rocblas_diagonal_unit’, A is unit triangular;
• [in] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.
• [in] stride_a: rocblas_int “batch stride a”: stride from the start of one “A” matrix to the next

2.9.2.11.2.18 rocblas_<type>trsm()

rocblas_status rocblas_dtrsm(rocblas_handle handle, rocblas_side side, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, rocblas_int n, const double *alpha, const double *A, rocblas_int lda, double *B, rocblas_int ldb)
rocblas_status rocblas_strsm(rocblas_handle handle, rocblas_side side, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, rocblas_int n, const float *alpha, const float *A, rocblas_int lda, float *B, rocblas_int ldb)

BLAS Level 3 API.

trsm solves

\[ \text{op}(A) \times X = \alpha \times B \] 
\[ \text{or} \quad X \times \text{op}(A) = \alpha \times B, \]

where alpha is a scalar, X and B are m by n matrices, A is triangular matrix and op(A) is one of

\[ \text{op}(A) = A \quad \text{or} \quad \text{op}(A) = A^T \quad \text{or} \quad \text{op}(A) = A^H. \]

The matrix X is overwritten on B.

Parameters

- \([\text{in}]\) handle: rocblas_handle. handle to the rocblas library context queue.
- \([\text{in}]\) side: rocblas_side. rocblas_side_left: \(\text{op}(A) \times X = \alpha \times B\). rocblas_side_right: \(X \times \text{op}(A) = \alpha \times B\).
- \([\text{in}]\) uplo: rocblas_fill. rocblas_fill_upper: A is an upper triangular matrix. rocblas_fill_lower: A is a lower triangular matrix.
- \([\text{in}]\) transA: rocblas_operation. transB: \(\text{op}(A) = A\). rocblas_operation_transpose: \(\text{op}(A) = A^T\). rocblas_operation_conjugate_transpose: \(\text{op}(A) = A^H\).
- \([\text{in}]\) diag: rocblas_diagonal. rocblas_diagonal_unit: A is assumed to be unit triangular. rocblas_diagonal_non_unit: A is not assumed to be unit triangular.
- \([\text{in}]\) m: rocblas_int. m specifies the number of rows of B. \(m \geq 0\).
- \([\text{in}]\) n: rocblas_int. n specifies the number of columns of B. \(n \geq 0\).
- \([\text{in}]\) alpha: alpha specifies the scalar alpha. When alpha is &zero then A is not referenced and B need not be set before entry.
- \([\text{in}]\) A: pointer storing matrix A on the GPU. of dimension ( lda, k ), where k is m when rocblas_side_left and is n when rocblas_side_right only the upper/lower triangular part is accessed.
- \([\text{in}]\) lda: rocblas_int. lda specifies the first dimension of A. if side = rocblas_side_left, lda >= max( 1, m ), if side = rocblas_side_right, lda >= max( 1, n ).

2.9.2.11.2.19 rocblas_<type>gemm()

rocblas_status rocblas_dgemm(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const double *alpha, const double *A, rocblas_int lda, const double *B, rocblas_int ldb, const double *beta, double *C, rocblas_int ldc)

rocblas_status rocblas_sgemm(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const float *alpha, const float *A, rocblas_int lda, const float *B, rocblas_int ldb, const float *beta, float *C, rocblas_int ldc)
rocblas_status rocblas_hgemm(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const rocblas_half *alpha, const rocblas_half *A, rocblas_int lda, const rocblas_half *B, rocblas_int ldb, const rocblas_half *beta, rocblas_half *C, rocblas_int ldc)

BLAS Level 3 API.

xGEMM performs one of the matrix-matrix operations

\[ C = \alpha \cdot \text{op}(A) \cdot \text{op}(B) + \beta \cdot C, \]

where \( \text{op}(X) \) is one of

\[
\begin{align*}
\text{op}(X) & = X \\
\text{op}(X) & = X^{\ast} \cdot X \\
\text{op}(X) & = X^{\ast} \cdot H,
\end{align*}
\]

alpha and beta are scalars, and A, B and C are matrices, with \( \text{op}(A) \) an m by k matrix, \( \text{op}(B) \) a k by n matrix and C an m by n matrix.

Parameters

- [in] handle: rocblas_handle, handle to the rocblas library context queue.
- [in] transA: rocblas_operation, specifies the form of \( \text{op}(A) \)
- [in] transB: rocblas_operation, specifies the form of \( \text{op}(B) \)
- [in] m: rocblas_int, number or rows of matrices \( \text{op}(A) \) and C
- [in] n: rocblas_int, number of columns of matrices \( \text{op}(B) \) and C
- [in] k: rocblas_int, number of columns of matrix \( \text{op}(A) \) and number of rows of matrix \( \text{op}(B) \)
- [in] alpha: specifies the scalar alpha.
- [in] A: pointer storing matrix A on the GPU.
- [in] lda: rocblas_int, specifies the leading dimension of A.
- [in] B: pointer storing matrix B on the GPU.
- [in] ldb: rocblas_int, specifies the leading dimension of B.
- [inout] C: pointer storing matrix C on the GPU.
- [in] ldc: rocblas_int, specifies the leading dimension of C.

2.9.2.11.2.20 rocblas_<type>gemm_strided_batched()

rocblas_status rocblas_dgemm_strided_batched(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const double *alpha, const double *A, rocblas_int lda, rocblas_int stride_a, const double *B, rocblas_int ldb, rocblas_int stride_b, const double *beta, double *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)
rocblas_status rocblas_sgemm_strided_batched (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const float *alpha, const float *A, rocblas_int lda, rocblas_int stride_a, const float *B, rocblas_int ldb, rocblas_int stride_b, const float *beta, float *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_hgemm_strided_batched (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const rocblas_half *alpha, const rocblas_half *A, rocblas_int lda, rocblas_int stride_a, const rocblas_half *B, rocblas_int ldb, rocblas_int stride_b, const rocblas_half *beta, rocblas_half *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

BLAS Level 3 API.

xGEMM_STRIDED_BATCHED performs one of the strided batched matrix-matrix operations

\[ C[i\ast \text{stride}_c] = \alpha \ast \text{op}(A[i\ast \text{stride}_a]) \ast \text{op}(B[i\ast \text{stride}_b]) + \beta \ast C[i\ast \text{stride}_c], \text{ for } i \in [0, \text{batch\_count}-1] \]

where op( X ) is one of

\[
\begin{align*}
\text{op}(X) & = X & \text{or} \\
\text{op}(X) & = X^T & \text{or} \\
\text{op}(X) & = X^H,
\end{align*}
\]

alpha and beta are scalars, and A, B and C are strided batched matrices, with op( A ) an m by k by batch_count strided_batched matrix, op( B ) an k by n by batch_count strided_batched matrix and C an m by n by batch_count strided_batched matrix.

Parameters

- [in] handle: rocblas_handle, handle to the rocblas library context queue.
- [in] transA: rocblas_operation specifies the form of op( A )
- [in] transB: rocblas_operation specifies the form of op( B )
- [in] m: rocblas_int, matrix dimension m.
- [in] n: rocblas_int, matrix dimension n.
- [in] k: rocblas_int, matrix dimension k.
- [in] alpha: specifies the scalar alpha.
- [in] A: pointer storing strided batched matrix A on the GPU.
- [in] lda: rocblas_int specifies the leading dimension of “A”.
- [in] stride_a: rocblas_int stride from the start of one “A” matrix to the next
- [in] B: pointer storing strided batched matrix B on the GPU.
- [in] ldb: rocblas_int specifies the leading dimension of “B”.
- [in] stride_b: rocblas_int stride from the start of one “B” matrix to the next
• [in] beta: specifies the scalar beta.
• [inout] C: pointer storing strided batched matrix C on the GPU.
• [in] ldc: rocblas_int specifies the leading dimension of “C”.
• [in] stride_c: rocblas_int stride from the start of one “C” matrix to the next
• [in] batch_count: rocblas_int number of gemm operatons in the batch

2.9.2.11.2.21 rocblas_<type>gemm_kernel_name()

rocblas_status rocblas_dgemm_kernel_name (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const double *alpha, const double *A, rocblas_int lda, rocblas_int stride_a, const double *B, rocblas_int ldb, rocblas_int stride_b, const double *beta, double *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_sgemm_kernel_name (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const float *alpha, const float *A, rocblas_int lda, rocblas_int stride_a, const float *B, rocblas_int ldb, rocblas_int stride_b, const float *beta, float *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_hgemm_kernel_name (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const rocblas_half *alpha, const rocblas_half *A, rocblas_int lda, rocblas_int stride_a, const rocblas_half *B, rocblas_int ldb, rocblas_int stride_b, const rocblas_half *beta, rocblas_half *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

2.9.2.11.2.22 rocblas_<type>geam()

rocblas_status rocblas_dgeam (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, const double *alpha, const double *A, rocblas_int lda, rocblas_int stride_a, const double *B, rocblas_int ldb, double *C, rocblas_int ldc)

rocblas_status rocblas_sgeam (rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, const float *alpha, const float *A, rocblas_int lda, const float *B, rocblas_int ldb, float *C, rocblas_int ldc)

BLAS Level 3 API.

xGEAM performs one of the matrix-matrix operations

\[ C = \alpha \cdot \text{op}( A ) + \beta \cdot \text{op}( B ), \]

where \text{op}( X ) is one of
\[ \text{op}(X) = X \quad \text{or} \quad \text{op}(X) = X^T \quad \text{or} \quad \text{op}(X) = X^H, \]

alpha and beta are scalars, and A, B and C are matrices, with \( \text{op}(A) \) an \( m \) by \( n \) matrix, \( \text{op}(B) \) an \( m \) by \( n \) matrix, and \( C \) an \( m \) by \( n \) matrix.

**Parameters**

- [in] handle: rocblas_handle, handle to the rocblas library context queue.
- [in] transA: rocblas_operation specifies the form of \( \text{op}(A) \)
- [in] transB: rocblas_operation specifies the form of \( \text{op}(B) \)
- [in] m: rocblas_int.
- [in] alpha: specifies the scalar alpha.
- [in] A: pointer storing matrix A on the GPU.
- [in] lda: rocblas_int specifies the leading dimension of A.
- [in] B: pointer storing matrix B on the GPU.
- [in] ldb: rocblas_int specifies the leading dimension of B.
- [inout] C: pointer storing matrix C on the GPU.
- [in] ldc: rocblas_int specifies the leading dimension of C.

### 2.9.2.11.23 BLAS Extensions

#### 2.9.2.11.24 rocblas_gemm_ex()

```c
rocblas_status rocblas_gemm_ex(rocblas_handle handle, rocblas_operation trans_a, rocblas_operation trans_b, rocblas_int m, rocblas_int n, rocblas_int k, const void *alpha, const void *a, rocblas_datatype a_type, rocblas_int lda, const void *b, rocblas_datatype b_type, rocblas_int ldb, const void *beta, const void *c, rocblas_datatype c_type, rocblas_int ldc, void *d, rocblas_datatype d_type, rocblas_int ldd, rocblas_datatype compute_type, rocblas_gemm_algo algo, int32_t solution_index, uint32_t flags, size_t *workspace_size, void *workspace)
```

2.9. ROCm Libraries
2.9.2.11.2.25 rocblas_gemm_strided_batched_ex()

rocblas_status rocblas_gemm_strided_batched_ex(rocblas_handle handle, rocblas_operation trans_a, rocblas_operation trans_b, rocblas_int m, rocblas_int n, rocblas_int k, const void *alpha, const void *a, rocblas_datatype a_type, rocblas_int lda, rocblas_long stride_a, const void *b, rocblas_datatype b_type, rocblas_int ldb, rocblas_long stride_b, const void *beta, const void *c, rocblas_datatype c_type, rocblas_int ldc, rocblas_long stride_c, void *d, rocblas_datatype d_type, rocblas_int ldd, rocblas_long stride_d, rocblas_int batch_count, rocblas_datatype compute_type, rocblas_gemm_algo algo, int32_t solution_index, uint32_t flags, size_t *workspace_size, void *workspace)

BLAS EX API.

GEMM_EX performs one of the matrix-matrix operations

\[ D = \alpha \cdot \text{op}(A) \cdot \text{op}(B) + \beta \cdot C, \]

where \( \text{op}(X) \) is one of

\[
\text{op}(X) = X \quad \text{or} \\
\text{op}(X) = X^{\ast T} \quad \text{or} \\
\text{op}(X) = X^{\ast H},
\]

alpha and beta are scalars, and A, B, C, and D are matrices, with \( \text{op}(A) \) an m by k matrix, \( \text{op}(B) \) a k by n matrix and C and D are m by n matrices.

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] transA: rocblas_operation specifies the form of \( \text{op}(A) \)
- [in] transB: rocblas_operation specifies the form of \( \text{op}(B) \)
- [in] m: rocblas_int. matrix dimension m
- [in] n: rocblas_int. matrix dimension n
- [in] k: rocblas_int. matrix dimension k
- [in] alpha: const void * specifies the scalar alpha. Same datatype as compute_type.
- [in] a: void * pointer storing matrix A on the GPU.
- [in] a_type: rocblas_datatype specifies the datatype of matrix A
- [in] lda: rocblas_int specifies the leading dimension of A.
- [in] b: void * pointer storing matrix B on the GPU.
- [in] b_type: rocblas_datatype specifies the datatype of matrix B
- [in] ldb: rocblas_int specifies the leading dimension of B.
- [in] beta: const void * specifies the scalar beta. Same datatype as compute_type.
• [in] c: void * pointer storing matrix C on the GPU.
• [in] c_type: rocblas_datatype specifies the datatype of matrix C
• [in] ldc: rocblas_int specifies the leading dimension of C.
• [out] d: void * pointer storing matrix D on the GPU.
• [in] d_type: rocblas_datatype specifies the datatype of matrix D
• [in] ldD: rocblas_int specifies the leading dimension of D.
• [in] compute_type: rocblas_datatype specifies the datatype of computation
• [in] algo: rocblas_gemm_algo enumerant specifying the algorithm type.
• [in] solution_index: int32_t reserved for future use
• [in] flags: uint32_t reserved for future use

2.9.2.11.2.26 Build Information

2.9.2.11.2.27 rocblas_get_version_string()

rocblas_status rocblas_get_version_string(char *buf, size_t len)

BLAS EX API.

GEMM_STRIDED_BATCHED_EX performs one of the strided_batched matrix-matrix operations

\[ D[i \times \text{stride}_d] = \alpha \cdot \text{op}(A[i \times \text{stride}_a]) \cdot \text{op}(B[i \times \text{stride}_b]) + \beta \cdot C[i \times \text{stride}_c], \]

\[ \text{for } i \text{ in } [0, \text{batch_count}-1] \]

where \( \text{op}(X) \) is one of

\[ \text{op}(X) = X \quad \text{or} \]
\[ \text{op}(X) = X^T \quad \text{or} \]
\[ \text{op}(X) = X^H, \]

alpha and beta are scalars, and A, B, C, and D are strided_batched matrices, with \( \text{op}(A) \) an \( m \) by \( k \) by \( \text{batch_count} \) strided_batched matrix, \( \text{op}(B) \) a \( k \) by \( n \) by \( \text{batch_count} \) strided_batched matrix and C and D are \( m \) by \( n \) by \( \text{batch_count} \) strided_batched matrices.

The strided_batched matrices are multiple matrices separated by a constant stride. The number of matrices is \( \text{batch_count} \).

Parameters

• [in] handle: rocblas_handle. handle to the rocs library context queue.
• [in] transA: rocblas_operation specifies the form of \( \text{op}(A) \)
• [in] transB: rocblas_operation specifies the form of \( \text{op}(B) \)
• [in] m: rocblas_int. matrix dimension \( m \)
• [in] n: rocblas_int. matrix dimension \( n \)
• [in] k: rocblas_int. matrix dimension \( k \)
• **[in]** alpha: const void * specifies the scalar alpha. Same datatype as compute_type.
• **[in]** a: void * pointer storing matrix A on the GPU.
• **[in]** a_type: rocblas_datatype specifies the datatype of matrix A
• **[in]** lda: rocblas_int specifies the leading dimension of A.
• **[in]** stride_a: rocblas_long specifies stride from start of one “A” matrix to the next
• **[in]** b: void * pointer storing matrix B on the GPU.
• **[in]** b_type: rocblas_datatype specifies the datatype of matrix B
• **[in]** ldb: rocblas_int specifies the leading dimension of B.
• **[in]** stride_b: rocblas_long specifies stride from start of one “B” matrix to the next
• **[in]** beta: const void * specifies the scalar beta. Same datatype as compute_type.
• **[in]** c: void * pointer storing matrix C on the GPU.
• **[in]** c_type: rocblas_datatype specifies the datatype of matrix C
• **[in]** ldc: rocblas_int specifies the leading dimension of C.
• **[in]** stride_c: rocblas_long specifies stride from start of one “C” matrix to the next
• **[out]** d: void * pointer storing matrix D on the GPU.
• **[in]** d_type: rocblas_datatype specifies the datatype of matrix D
• **[in]** ldd: rocblas_int specifies the leading dimension of D.
• **[in]** stride_d: rocblas_long specifies stride from start of one “D” matrix to the next
• **[in]** batch_count: rocblas_int number of gemm operations in the batch
• **[in]** compute_type: rocblas_datatype specifies the datatype of computation
• **[in]** algo: rocblas_gemm_algo enumerant specifying the algorithm type.
• **[in]** solution_index: int32_t reserved for future use
• **[in]** flags: uint32_t reserved for future use

2.9.2.11.2.28 Auxiliary

2.9.2.11.2.29 rocblas_pointer_to_mode()

rocblas_pointer_mode rocblas_pointer_to_mode(void *ptr)

indicates whether the pointer is on the host or device. Currently HIP API can only recognize the input ptr on
device or not can not recognize it is on host or not

2.9.2.11.2.30 rocblas_create_handle()

rocblas_status rocblas_create_handle(rocblas_handle *handle)
2.9.2.11.2.31 rocblas_destroy_handle()

rocblas_status rocblas_destroy_handle (rocblas_handle handle)

2.9.2.11.2.32 rocblas_add_stream()

rocblas_status rocblas_add_stream (rocblas_handle handle, hipStream_t stream)

2.9.2.11.2.33 rocblas_set_stream()

rocblas_status rocblas_set_stream (rocblas_handle handle, hipStream_t stream)

2.9.2.11.2.34 rocblas_get_stream()

rocblas_status rocblas_get_stream (rocblas_handle handle, hipStream_t *stream)

2.9.2.11.2.35 rocblas_set_pointer_mode()

rocblas_status rocblas_set_pointer_mode (rocblas_handle handle, rocblas_pointer_mode pointer_mode)

2.9.2.11.2.36 rocblas_get_pointer_mode()

rocblas_status rocblas_get_pointer_mode (rocblas_handle handle, rocblas_pointer_mode *pointer_mode)

2.9.2.11.2.37 rocblas_set_vector()

rocblas_status rocblas_set_vector (rocblas_int n, rocblas_int elem_size, const void *x, rocblas_int incx, void *y, rocblas_int incy)

2.9.2.11.2.38 rocblas_get_vector()

rocblas_status rocblas_get_vector (rocblas_int n, rocblas_int elem_size, const void *x, rocblas_int incx, void *y, rocblas_int incy)

2.9.2.11.2.39 rocblas_set_matrix()

rocblas_status rocblas_set_matrix (rocblas_int rows, rocblas_int cols, rocblas_int elem_size, const void *a, rocblas_int lda, void *b, rocblas_int ldb)

2.9.2.11.2.40 rocblas_get_matrix()

rocblas_status rocblas_get_matrix (rocblas_int rows, rocblas_int cols, rocblas_int elem_size, const void *a, rocblas_int lda, void *b, rocblas_int ldb)
namespace rocblas

Functions

void reinit_logs()

file rocblas-auxiliary.h
#include <hip/hip_runtime_api.h>
#include "rocblas-types.h"

rocblas-auxiliary.h provides auxiliary functions in rocblas

Defines

#define _ROCBLAS_AUXILIARY_H_

Functions

rocblas_pointer_mode rocblas_pointer_to_mode (void *ptr)

indicates whether the pointer is on the host or device. currently HIP API can only recognize the input ptr
on device or not can not recognize it is on host or not

rocblas_status rocblas_create_handle (rocblas_handle *handle)
rocblas_status rocblas_destroy_handle (rocblas_handle handle)
rocblas_status rocblas_add_stream (rocblas_handle handle, hipStream_t stream)
rocblas_status rocblas_set_stream (rocblas_handle handle, hipStream_t stream)
rocblas_status rocblas_get_stream (rocblas_handle handle, hipStream_t *stream)
rocblas_status rocblas_set_pointer_mode (rocblas_handle handle, rocblas_pointer_mode pointer_mode)
rocblas_status rocblas_get_pointer_mode (rocblas_handle handle, rocblas_pointer_mode *pointer_mode)
rocblas_status rocblas_set_vector (rocblas_int n, rocblas_int elem_size, const void *x, rocblas_int incx, void *y, rocblas_int incy)
rocblas_status rocblas_get_vector (rocblas_int n, rocblas_int elem_size, const void *x, rocblas_int incx, void *y, rocblas_int incy)
rocblas_status rocblas_set_matrix (rocblas_int rows, rocblas_int cols, rocblas_int elem_size, const void *a, rocblas_int lda, void *b, rocblas_int ldb)
rocblas_status rocblas_get_matrix (rocblas_int rows, rocblas_int cols, rocblas_int elem_size, const void *a, rocblas_int lda, void *b, rocblas_int ldb)

file rocblas-functions.h
#include "rocblas-types.h"

rocblas-functions.h provides Basic Linear Algebra Subprograms of Level 1, 2 and 3, using HIP optimized for AMD HCC-based GPU hardware. This library can also run on CUDA-based NVIDIA GPUs. This file exposes C89 BLAS interface

Defines

#define _ROCBLAS_FUNCTIONS_H_
**Functions**

**rocblas_status rocblas_sscal** *(rocblas_handle handle, rocblas_int n, const float *alpha, float *x, rocblas_int incx)*

BLAS Level 1 API.

scal scale the vector x[i] with scalar alpha, for i = 1, ..., n

\[ x := \alpha \cdot x, \]

**Parameters**

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] alpha: specifies the scalar alpha.
- [inout] x: pointer storing vector x on the GPU.
- [in] incx: specifies the increment for the elements of x.

**rocblas_status rocblas_dscal** *(rocblas_handle handle, rocblas_int n, const double *alpha, double *x, rocblas_int incx)*

**rocblas_status rocblas_scopy** *(rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, float *y, rocblas_int incy)*

BLAS Level 1 API.

copy copies the vector x into the vector y, for i = 1, ..., n

\[ y := x, \]

**Parameters**

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] x: pointer storing vector x on the GPU.
- [in] incx: specifies the increment for the elements of x.
- [out] y: pointer storing vector y on the GPU.
- [in] incy: rocblas_int specifies the increment for the elements of y.

**rocblas_status rocblas_dcopy** *(rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, double *y, rocblas_int incy)*

**rocblas_status rocblas_sdot** *(rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, const float *y, rocblas_int incy, float *result)*

BLAS Level 1 API.

dot perform dot product of vector x and y

\[ result = x \cdot y; \]

dotc perform dot product of complex vector x and complex y

\[ result = \text{conjugate}(x) \cdot y; \]
• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of y.
• [inout] result: store the dot product. either on the host CPU or device GPU. return is 0.0 if n <= 0.

rocblas_status rocblas_ddot (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, const double *y, rocblas_int incy, double *result)

rocblas_status rocblas_sswap (rocblas_handle handle, rocblas_int n, float *x, rocblas_int incx, float *y, rocblas_int incy)

BLAS Level 1 API.
swap interchange vector x[i] and y[i], for i = 1, ..., n

\[ y := x; \ x := y \]

Parameters
• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] incx: specifies the increment for the elements of x.
• [inout] y: pointer storing vector y on the GPU.
• [in] incy: rocblas_int specifies the increment for the elements of y.

rocblas_status rocblas_dswap (rocblas_handle handle, rocblas_int n, double *x, rocblas_int incx, double *y, rocblas_int incy)

rocblas_status rocblas_haxpy (rocblas_handle handle, rocblas_int n, const rocblas_half *alpha, const rocblas_half *x, rocblas_int incx, rocblas_half *y, rocblas_int incy)

BLAS Level 1 API.
axpy compute \( y := \alpha \times x + y \)

Parameters
• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of x.
• [out] y: pointer storing vector y on the GPU.
• [inout] incy: rocblas_int specifies the increment for the elements of y.

rocblas_status rocblas_saxpy (rocblas_handle handle, rocblas_int n, const float *alpha, const float *x, rocblas_int incx, float *y, rocblas_int incy)
rocblas_status rocblas_daxpy (rocblas_handle handle, rocblas_int n, const double *alpha, const double *x, rocblas_int incx, double *y, rocblas_int incy)

rocblas_status rocblas_sasum (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, float *result)

BLAS Level 1 API.

asum computes the sum of the magnitudes of elements of a real vector x, or the sum of magnitudes of the real and imaginary parts of elements if x is a complex vector

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] x: pointer storing vector x on the GPU.
- [in] incx: rocblas_int specifies the increment for the elements of y.
- [inout] result: store the asum product. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

rocblas_status rocblas_dasum (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, double *result)

rocblas_status rocblas_snrm2 (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, float *result)

BLAS Level 1 API.

nrm2 computes the euclidean norm of a real or complex vector := sqrt( x'*x ) for real vector := sqrt( x**H*x ) for complex vector

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] x: pointer storing vector x on the GPU.
- [in] incx: rocblas_int specifies the increment for the elements of y.
- [inout] result: store the nrm2 product. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

rocblas_status rocblas_dnrm2 (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, double *result)

rocblas_status rocblas_isamax (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, rocblas_int *result)

BLAS Level 1 API.

amax finds the first index of the element of maximum magnitude of real vector x or the sum of magnitude of the real and imaginary parts of elements if x is a complex vector

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] x: pointer storing vector x on the GPU.
- [in] incx: rocblas_int specifies the increment for the elements of y.
rocblas_status rocblas_idamax (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, rocblas_int *result)

rocblas_status rocblas_isamin (rocblas_handle handle, rocblas_int n, const float *x, rocblas_int incx, rocblas_int *result)

BLAS Level 1 API.

amin finds the first index of the element of minimum magnitude of real vector x or the sum of magnitude of the real and imaginary parts of elements if x is a complex vector

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of y.
• [inout] result: store the amin index. either on the host CPU or device GPU. return is 0.0 if n, incx<=0.

rocblas_status rocblas_idamin (rocblas_handle handle, rocblas_int n, const double *x, rocblas_int incx, rocblas_int *result)

rocblas_status rocblas_sgemv (rocblas_handle handle, rocblas_operation trans, rocblas_int m, rocblas_int n, const float *alpha, const float *A, rocblas_int lda, const float *x, rocblas_int incx, const float *beta, float *y, rocblas_int incy)

BLAS Level 2 API.

xGEMV performs one of the matrix-vector operations

\[
\begin{align*}
y &= \alpha A x + \beta y, & \text{or} \\
y &= \alpha A^T x + \beta y, & \text{or} \\
y &= \alpha A^H x + \beta y,
\end{align*}
\]

where alpha and beta are scalars, x and y are vectors and A is an m by n matrix.

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] trans: rocblas_operation
• [in] m: rocblas_int
• [in] n: rocblas_int
• [in] alpha: specifies the scalar alpha.
• [in] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: specifies the increment for the elements of x.
• [in] beta: specifies the scalar beta.
• [out] y: pointer storing vector y on the GPU.
• [in] incy: rocblas_int specifies the increment for the elements of y.

rocblas_status rocblas_dgemv (rocblas_handle handle, rocblas_operation trans, rocblas_int m, rocblas_int n, const double *alpha, const double *A, rocblas_int lda, const double *x, rocblas_int incx, const double *beta, double *y, rocblas_int incy)

rocblas_status rocblas_strsv (rocblas_handle handle, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, const float *A, rocblas_int lda, float *x, rocblas_int incx)

BLAS Level 2 API.

trsv solves

$$A \cdot x = \alpha b \text{ or } A^T \cdot x = \alpha b,$$

where x and b are vectors and A is a triangular matrix.

The vector x is overwritten on b.

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] uplo: rocblas_fill. rocblas_fill_upper: A is an upper triangular matrix. rocblas_fill_lower: A is a lower triangular matrix.
• [in] transA: rocblas_operation
• [in] diag: rocblas_diagonal. rocblas_diagonal_unit: A is assumed to be unit triangular. rocblas_diagonal_non_unit: A is not assumed to be unit triangular.
• [in] m: rocblas_int m specifies the number of rows of b. m >= 0.
• [in] alpha: specifies the scalar alpha.
• [in] A: pointer storing matrix A on the GPU, of dimension ( lda, m )
• [in] lda: rocblas_int specifies the leading dimension of A. lda = max( 1, m ).
• [in] x: pointer storing vector x on the GPU.
• [in] incx: specifies the increment for the elements of x.

rocblas_status rocblas_dtrsv (rocblas_handle handle, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, const double *A, rocblas_int lda, double *x, rocblas_int incx)

rocblas_status rocblas_sger (rocblas_handle handle, rocblas_int m, rocblas_int n, const float *alpha, const float *x, rocblas_int incx, const float *y, rocblas_int incy, float *A, rocblas_int lda)

BLAS Level 2 API.

xHE(SY)MV performs the matrix-vector operation:

$$y := \alpha A \cdot x + \beta y,$$

where alpha and beta are scalars, x and y are n element vectors and A is an n by n Hermitian(Symmetric) matrix.

BLAS Level 2 API
Parameters

- **[in]** `handle`: rocblas_handle. handle to the rocblas library context queue.
- **[in]** `uplo`: rocblas_fill. specifies whether the upper or lower
- **[in]** `n`: rocblas_int.
- **[in]** `alpha`: specifies the scalar alpha.
- **[in]** `A`: pointer storing matrix A on the GPU.
- **[in]** `lda`: rocblas_int specifies the leading dimension of A.
- **[in]** `x`: pointer storing vector x on the GPU.
- **[in]** `incx`: specifies the increment for the elements of x.
- **[in]** `beta`: specifies the scalar beta.
- **[out]** `y`: pointer storing vector y on the GPU.
- **[in]** `incy`: rocblas_int specifies the increment for the elements of y.

\[
\text{xGER performs the matrix-vector operations} \\
A := A + \alpha x y^T
\]

where alpha is a scalars, x and y are vectors, and A is an m by n matrix.

Parameters

- **[in]** `handle`: rocblas_handle. handle to the rocblas library context queue.
- **[in]** `m`: rocblas_int
- **[in]** `n`: rocblas_int
- **[in]** `alpha`: specifies the scalar alpha.
- **[in]** `x`: pointer storing vector x on the GPU.
- **[in]** `incx`: specifies the increment for the elements of x.
- **[in]** `y`: pointer storing vector y on the GPU.
- **[in]** `incy`: rocblas_int specifies the increment for the elements of y.
- **[inout]** `A`: pointer storing matrix A on the GPU.
- **[in]** `lda`: rocblas_int specifies the leading dimension of A.

\[
\text{rocblas_status rocblas_dger} (\text{rocblas_handle handle, rocblas_int m, rocblas_int n, const double *alpha, const double *x, rocblas_int incx, const double *y, rocblas_int lda})
\]

\[
\text{rocblas_status rocblas_ssyr} (\text{rocblas_handle handle, rocblas_fill uplo, rocblas_int n, const float *alpha, const float *x, rocblas_int incx, float *A, rocblas_int lda})
\]

BLAS Level 2 API.

\[
\text{xSYR performs the matrix-vector operations} \\
A := A + \alpha x x^T
\]

where alpha is a scalars, x is a vector, and A is an n by n symmetric matrix.

Parameters
• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] n: rocblas_int
• [in] alpha: specifies the scalar alpha.
• [in] x: pointer storing vector x on the GPU.
• [in] incx: rocblas_int specifies the increment for the elements of x.
• [inout] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.

rocblas_status rocblas_dsyr (rocblas_handle handle, rocblas_fill uplo, rocblas_int n, const double *alpha, const double *x, rocblas_int incx, double *A, rocblas_int lda)

rocblas_status rocblas_strtri (rocblas_handle handle, rocblas_fill uplo, rocblas_diagonal diag, rocblas_int n, const float *A, rocblas_int lda, float *invA, rocblas_int ldinvA)

BLAS Level 3 API.

trtri compute the inverse of a matrix A, namely, invA

and write the result into invA;

Parameters

• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] uplo: rocblas_fill. specifies whether the upper 'rocblas_fill_upper' or lower 'rocblas_fill_lower' if rocblas_fill_upper, the lower part of A is not referenced if rocblas_fill_lower, the upper part of A is not referenced
• [in] diag: rocblas_diagonal. = 'rocblas_diagonal_non_unit', A is non-unit triangular; = 'rocblas_diagonal_unit', A is unit triangular;
• [in] n: rocblas_int. size of matrix A and invA
• [in] A: pointer storing matrix A on the GPU.
• [in] lda: rocblas_int specifies the leading dimension of A.

rocblas_status rocblas_dtrtri (rocblas_handle handle, rocblas_fill uplo, rocblas_diagonal diag, rocblas_int n, const double *A, rocblas_int lda, double *invA, rocblas_int ldinvA)

rocblas_status rocblas_strtri_batched (rocblas_handle handle, rocblas_fill uplo, rocblas_diagonal diag, rocblas_int n, const float *A, rocblas_int lda, rocblas_int stride_a, float *invA, rocblas_int ldinvA, rocblas_int bsinvA, rocblas_int batch_count)

BLAS Level 3 API.

trtri compute the inverse of a matrix A

inv(A);

Parameters
rocblas_status rocblas_dtrtri_batched(
    rocblas_handle handle,
    rocblas_fill uplo,
    rocblas_diagonal diag,
    rocblas_int n,
    const double *A,
    rocblas_int lda,
    rocblas_int stride_a,
    double *invA,
    rocblas_int ldinvA,
    rocblas_int bsinvA,
    rocblas_int batch_count)

rocblas_status rocblas_strsm(
    rocblas_handle handle,
    rocblas_side side,
    rocblas_fill uplo,
    rocblas_operation transA,
    rocblas_diagonal diag,
    rocblas_int m,
    rocblas_int n,
    const float *alpha,
    const float *A,
    rocblas_int lda,
    float *B,
    rocblas_int ldb)

BLAS Level 3 API.

trsm solves
\[
\text{op}(A) \cdot X = \alpha \cdot B \text{ or } X \cdot \text{op}(A) = \alpha \cdot B,
\]

where alpha is a scalar, X and B are m by n matrices, A is triangular matrix and op(A) is one of
\[
\text{op}(A) = A \text{ or } \text{op}(A) = A^T \text{ or } \text{op}(A) = A^H.
\]

The matrix X is overwritten on B.

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] side: rocblas_side. rocblas_side_left: \( \text{op}(A) \cdot X = \alpha \cdot B \). rocblas_side_right: \( X \cdot \text{op}(A) = \alpha \cdot B \).
- [in] uplo: rocblas_fill. rocblas_fill_upper: A is an upper triangular matrix. rocblas_fill_lower: A is a lower triangular matrix.
- [in] diag: rocblas_diagonal. rocblas_diagonal_unit: A is assumed to be unit triangular. rocblas_diagonal_non_unit: A is not assumed to be unit triangular.
- [in] m: rocblas_int. m specifies the number of rows of B. m \( \geq 0 \).
- [in] n: rocblas_int. n specifies the number of columns of B. n \( \geq 0 \).
- [in] alpha: alpha specifies the scalar alpha. When alpha is \&zero then A is not referenced and B need not be set before entry.
• [in] A: pointer storing matrix A on the GPU. of dimension ( lda, k ), where k is m when rocblas_side_left and is n when rocblas_side_right only the upper/lower triangular part is accessed.

• [in] lda: rocblas_int. lda specifies the first dimension of A. if side = rocblas_side_left, lda >= max( 1, m ), if side = rocblas_side_right, lda >= max( 1, n ).

```
rocblas_status rocblas_dtrsm(rocblas_handle handle, rocblas_side side, rocblas_fill uplo, rocblas_operation transA, rocblas_diagonal diag, rocblas_int m, rocblas_int n, const double *alpha, const double *A, rocblas_int lda, double *B, rocblas_int ldb)

rocblas_status rocblas_hgemm(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const rocblas_half *alpha, const rocblas_half *A, rocblas_int lda, const rocblas_half *B, rocblas_int ldb, const rocblas_half *beta, rocblas_half *C, rocblas_int ldc)
```

BLAS Level 3 API.

xGEMM performs one of the matrix-matrix operations

\[
C = \alpha \cdot \text{op}( A ) \cdot \text{op}( B ) + \beta \cdot C,
\]

where \( \text{op}( X ) \) is one of

\[
\begin{align*}
\text{op}( X ) &= X & \text{or} \\
\text{op}( X ) &= X^T & \text{or} \\
\text{op}( X ) &= X^H 
\end{align*}
\]

alpha and beta are scalars, and A, B and C are matrices, with \( \text{op}( A ) \) an m by k matrix, \( \text{op}( B ) \) a k by n matrix and C an m by n matrix.

Parameters

• [in] handle: rocblas_handle, handle to the rocblas library context queue.

• [in] transA: rocblas_operation, specifies the form of \( \text{op}( A ) \)

• [in] transB: rocblas_operation, specifies the form of \( \text{op}( B ) \)

• [in] m: rocblas_int, number or rows of matrices \( \text{op}( A ) \) and C

• [in] n: rocblas_int, number of columns of matrices \( \text{op}( B ) \) and C

• [in] k: rocblas_int, number of columns of matrix \( \text{op}( A ) \) and number of rows of matrix \( \text{op}( B ) \)

• [in] alpha: specifies the scalar alpha.

• [in] A: pointer storing matrix A on the GPU.

• [in] lda: rocblas_int, specifies the leading dimension of A.

• [in] B: pointer storing matrix B on the GPU.

• [in] ldb: rocblas_int, specifies the leading dimension of B.

• [in] beta: specifies the scalar beta.

• [inout] C: pointer storing matrix C on the GPU.

• [in] ldc: rocblas_int, specifies the leading dimension of C.
\textbf{rocblas\_status rocblas\_sgemm}\,(rocblas\_handle handle, rocblas\_operation transa, rocblas\_operation transb, rocblas\_int m, rocblas\_int n, rocblas\_int k, const float *alpha, const float *A, rocblas\_int lda, const float *B, rocblas\_int ldb, const float *beta, float *C, rocblas\_int ldc)

\textbf{rocblas\_status rocblas\_dgemm}\,(rocblas\_handle handle, rocblas\_operation transa, rocblas\_operation transb, rocblas\_int m, rocblas\_int n, rocblas\_int k, const double *alpha, const double *A, rocblas\_int lda, const double *B, rocblas\_int ldb, const double *beta, double *C, rocblas\_int ldc)

\textbf{rocblas\_status rocblas\_hgemm\_strided\_batched}\,(rocblas\_handle handle, rocblas\_operation transa, rocblas\_operation transb, rocblas\_int m, rocblas\_int n, rocblas\_int k, const rocblas\_half *alpha, const rocblas\_half *A, rocblas\_int lda, rocblas\_int stride\_a, const rocblas\_half *B, rocblas\_int ldb, rocblas\_int stride\_b, const rocblas\_half *beta, rocblas\_half *C, rocblas\_int ldc, rocblas\_int stride\_c, rocblas\_int batch\_count)

BLAS Level 3 API.

\texttt{xGEMM\_STRIDED\_BATCHED}\ performs one of the strided batched matrix-matrix operations

\begin{verbatim}
C[i\times\text{stride}\_c] = alpha\times\text{op}( A[i\times\text{stride}\_a]\times\text{op}( B[i\times\text{stride}\_b] ) + \beta\times C[i\times\text{stride}\_c], \text{for } i \text{ in } [0,\text{batch\_count}-1])
\end{verbatim}

where \text{op}( X ) is one of

\begin{verbatim}
\text{op}( X ) = X \quad \text{or} \\
\text{op}( X ) = X^\text{T} \quad \text{or} \\
\text{op}( X ) = X^\text{H},
\end{verbatim}

alpha and beta are scalars, and A, B and C are strided batched matrices, with \text{op}( A ) an m by k by batch\_count strided\_batched matrix, \text{op}( B ) an k by n by batch\_count strided\_batched matrix and C an m by n by batch\_count strided\_batched matrix.

\textbf{Parameters}

- [in] handle: rocblas\_handle. handle to the rocblas library context queue.
- [in] transA: rocblas\_operation specifies the form of \text{op}( A )
- [in] transB: rocblas\_operation specifies the form of \text{op}( B )
- [in] m: rocblas\_int. matrix dimension m.
- [in] k: rocblas\_int. matrix dimension k.
- [in] alpha: specifies the scalar alpha.
- [in] A: pointer storing strided batched matrix A on the GPU.
- [in] lda: rocblas\_int specifies the leading dimension of “A”.
- [in] stride\_a: rocblas\_int stride from the start of one “A” matrix to the next
- [in] B: pointer storing strided batched matrix B on the GPU.
in ldb: rocblas_int specifies the leading dimension of “B”.

in stride_b: rocblas_int stride from the start of one “B” matrix to the next

in beta: specifies the scalar beta.

inout C: pointer storing strided batched matrix C on the GPU.

in ldc: rocblas_int specifies the leading dimension of “C”.

in stride_c: rocblas_int stride from the start of one “C” matrix to the next

in batch count: rocblas_int number of gemm operations in the batch

rocblas_status rocblas_sgemm_strided_batched(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const float *alpha, const float *A, rocblas_int lda, rocblas_int stride_a, const float *B, rocblas_int ldb, rocblas_int stride_b, const float *beta, float *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_dgemm_strided_batched(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const double *alpha, const double *A, rocblas_int lda, rocblas_int stride_a, const double *B, rocblas_int ldb, rocblas_int stride_b, const double *beta, double *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_hgemm_kernel_name(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const rocblas_half *alpha, const rocblas_half *A, rocblas_int lda, rocblas_int stride_a, const rocblas_half *B, rocblas_int ldb, rocblas_int stride_b, const rocblas_half *beta, rocblas_half *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_sgemm_kernel_name(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const float *alpha, const float *A, rocblas_int lda, rocblas_int stride_a, const float *B, rocblas_int ldb, rocblas_int stride_b, const float *beta, float *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)

rocblas_status rocblas_dgemm_kernel_name(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, rocblas_int k, const double *alpha, const double *A, rocblas_int lda, rocblas_int stride_a, const double *B, rocblas_int ldb, rocblas_int stride_b, const double *beta, double *C, rocblas_int ldc, rocblas_int stride_c, rocblas_int batch_count)
rocblas_status rocblas_sgeam(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, const float *alpha, const float *A, rocblas_int lda, const float *beta, const float *B, rocblas_int ldb, float *C, rocblas_int ldc)

BLAS Level 3 API.

xGEAM performs one of the matrix-matrix operations

\[ C = \alpha \cdot \text{op}(A) + \beta \cdot \text{op}(B), \]

where \( \text{op}(X) \) is one of

\[
\begin{align*}
\text{op}(X) &= X \\
\text{op}(X) &= X^T \\
\text{op}(X) &= X^H,
\end{align*}
\]

alpha and beta are scalars, and A, B and C are matrices, with \( \text{op}(A) \) an \( m \times n \) matrix, \( \text{op}(B) \) an \( m \times n \) matrix, and \( C \) an \( m \times n \) matrix.

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] transA: rocblas_operation specifies the form of \( \text{op}(A) \)
- [in] transB: rocblas_operation specifies the form of \( \text{op}(B) \)
- [in] m: rocblas_int.
- [in] alpha: specifies the scalar alpha.
- [in] A: pointer storing matrix A on the GPU.
- [in] lda: rocblas_int specifies the leading dimension of A.
- [in] B: pointer storing matrix B on the GPU.
- [in] ldb: rocblas_int specifies the leading dimension of B.
- [inout] C: pointer storing matrix C on the GPU.
- [in] ldc: rocblas_int specifies the leading dimension of C.

rocblas_status rocblas_dgeam(rocblas_handle handle, rocblas_operation transa, rocblas_operation transb, rocblas_int m, rocblas_int n, const double *alpha, const double *A, rocblas_int lda, const double *beta, const double *B, rocblas_int ldb, double *C, rocblas_int ldc)

rocblas_status rocblas_gemm_ex(rocblas_handle handle, rocblas_operation trans_a, rocblas_operation trans_b, rocblas_int m, rocblas_int n, rocblas_int k, const void *alpha, const void *a, rocblas_datatype a_type, rocblas_int lda, const void *b, rocblas_datatype b_type, rocblas_int ldb, const void *beta, const void *c, rocblas_datatype c_type, rocblas_int ldc, void *d, rocblas_datatype d_type, rocblas_int ldd, rocblas_datatype compute_type, rocblas_gemm_algo algo, int32_t solution_index, uint32_t flags, size_t *workspace_size, void *workspace)
rocblas_status rocblas_gemm_strided_batched_ex (rocblas_handle handle, rocblas_operation trans_a, rocblas_operation trans_b, rocblas_int m, rocblas_int n, rocblas_int k, const void *alpha, const void *a, rocblas_datatype a_type, rocblas_int lda, rocblas_long stride_a, const void *b, rocblas_datatype b_type, rocblas_int ldb, rocblas_long stride_b, const void *beta, const void *c, rocblas_datatype c_type, rocblas_int ldc, rocblas_long stride_c, void *d, rocblas_datatype d_type, rocblas_int ldd, rocblas_long stride_d, rocblas_int batch_count, rocblas_datatype compute_type, rocblas_gemm_algo algo, int32_t solution_index, uint32_t flags, size_t *workspace_size, void *workspace)

BLAS EX API.

GEMM_EX performs one of the matrix-matrix operations

\[ D = \alpha \cdot \text{op}(A) \cdot \text{op}(B) + \beta \cdot C, \]

where \( \text{op}(X) \) is one of

\[
\text{op}(X) = X \\
\text{op}(X) = X^{\text{T}} \\
\text{op}(X) = X^{\text{H}},
\]

alpha and beta are scalars, and A, B, C, and D are matrices, with \( \text{op}(A) \) an m by k matrix, \( \text{op}(B) \) a k by n matrix and C and D are m by n matrices.

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] transA: rocblas_operation specifies the form of \( \text{op}(A) \)
- [in] transB: rocblas_operation specifies the form of \( \text{op}(B) \)
- [in] m: rocblas_int. matrix dimension m
- [in] n: rocblas_int. matrix dimension n
- [in] k: rocblas_int. matrix dimension k
- [in] alpha: const void * specifies the scalar alpha. Same datatype as compute_type.
- [in] a: void * pointer storing matrix A on the GPU.
- [in] a_type: rocblas_datatype specifies the datatype of matrix A
- [in] lda: rocblas_int specifies the leading dimension of A.
- [in] b: void * pointer storing matrix B on the GPU.
- [in] b_type: rocblas_datatype specifies the datatype of matrix B
- [in] ldb: rocblas_int specifies the leading dimension of B.
- [in] beta: const void * specifies the scalar beta. Same datatype as compute_type.
- [in] c: void * pointer storing matrix C on the GPU.
rocblas_status rocblas_get_version_string(char *buf, size_t len)

BLAS EX API.

GEMM_STRIDED_BATCHED_EX performs one of the strided_batched matrix-matrix operations

\[
D[i \ast stride_d] = alpha \ast op(A[i \ast stride_a]) \ast op(B[i \ast stride_b]) + beta \ast C[i \ast stride_c], \quad \text{for } i \in [0, \text{batch_count}-1]
\]

where \( op(X) \) is one of

\[
\begin{align*}
\text{op}(X) &= X \\
\text{op}(X) &= X^{*T} \\
\text{op}(X) &= X^{*H},
\end{align*}
\]

alpha and beta are scalars, and A, B, C, and D are strided_batched matrices, with \( op(A) \) an \( m \) by \( k \) by \( \text{batch_count} \) strided_batched matrix, \( op(B) \) a \( k \) by \( n \) by \( \text{batch_count} \) strided_batched matrix and C and D are \( m \) by \( n \) by \( \text{batch_count} \) strided_batched matrices.

The strided_batched matrices are multiple matrices separated by a constant stride. The number of matrices is \( \text{batch_count} \).

Parameters

- [in] handle: rocblas_handle. handle to the rocblas library context queue.
- [in] transA: rocblas_operation specifies the form of \( op(A) \)
- [in] transB: rocblas_operation specifies the form of \( op(B) \)
- [in] m: rocblas_int. matrix dimension \( m \)
- [in] n: rocblas_int. matrix dimension \( n \)
- [in] k: rocblas_int. matrix dimension \( k \)
- [in] alpha: const void * specifies the scalar alpha. Same datatype as compute_type.
- [in] a: void * pointer storing matrix A on the GPU.
- [in] a_type: rocblas_datatype specifies the datatype of matrix A
- [in] lda: rocblas_int specifies the leading dimension of A.
- [in] stride_a: rocblas_long specifies stride from start of one “A” matrix to the next
• [in] b: void * pointer storing matrix B on the GPU.
• [in] b_type: rocblas_datatype specifies the datatype of matrix B
• [in] ldb: rocblas_int specifies the leading dimension of B.
• [in] stride_b: rocblas_long specifies stride from start of one “B” matrix to the next
• [in] beta: const void * specifies the scalar beta. Same datatype as compute_type.
• [in] c: void * pointer storing matrix C on the GPU.
• [in] c_type: rocblas_datatype specifies the datatype of matrix C
• [in] ldc: rocblas_int specifies the leading dimension of C.
• [in] stride_c: rocblas_long specifies stride from start of one “C” matrix to the next
• [out] d: void * pointer storing matrix D on the GPU.
• [in] d_type: rocblas_datatype specifies the datatype of matrix D
• [in] ldd: rocblas_int specifies the leading dimension of D.
• [in] stride_d: rocblas_long specifies stride from start of one “D” matrix to the next
• [in] batch_count: rocblas_int number of gemm operations in the batch
• [in] compute_type: rocblas_datatype specifies the datatype of computation
• [in] algo: rocblas_gemm_algo enumerant specifying the algorithm type.
• [in] solution_index: int32_t reserved for future use
• [in] flags: uint32_t reserved for future use

file rocblas-types.h
#include <stddef.h> #include <stdint.h> #include <hip/hip_vector_types.h> rocblas-types.h defines data types used by rocblas

Defines

_ROCBLAS_TYPES_H_

Typedefs

typedef int32_t rocblas_int

To specify whether int32 or int64 is used.

typedef int64_t rocblas_long

typedef float2 rocblas_float_complex

typedef double2 rocblas_double_complex

typedef uint16_t rocblas_half

typedef float2 rocblas_half_complex

typedef struct _rocblas_handle *rocblas_handle
Enums

**enum rocblas_operation**
Used to specify whether the matrix is to be transposed or not.

Parameter constants. Numbering is consistent with CBLAS, ACML, and most standard C BLAS libraries.

Values:

- **rocblas_operation_none** = 111
  Operate with the matrix.

- **rocblas_operation_transpose** = 112
  Operate with the transpose of the matrix.

- **rocblas_operation_conjugate_transpose** = 113
  Operate with the conjugate transpose of the matrix.

**enum rocblas_fill**
Used by the Hermitian, symmetric, and triangular matrix routines to specify whether the upper or lower triangle is being referenced.

Values:

- **rocblas_fill_upper** = 121
  Upper triangle.

- **rocblas_fill_lower** = 122
  Lower triangle.

- **rocblas_fill_full** = 123

**enum rocblas_diagonal**
It is used by the triangular matrix routines to specify whether the matrix is unit triangular.

Values:

- **rocblas_diagonal_non_unit** = 131
  Non-unit triangular.

- **rocblas_diagonal_unit** = 132
  Unit triangular.

**enum rocblas_side**
Indicates the side matrix A is located relative to matrix B during multiplication.

Values:

- **rocblas_side_left** = 141
  Multiply general matrix by symmetric, Hermitian, or triangular matrix on the left.

- **rocblas_side_right** = 142
  Multiply general matrix by symmetric, Hermitian, or triangular matrix on the right.

- **rocblas_side_both** = 143

**enum rocblas_status**
Rocblas status codes definition

Values:

- **rocblas_status_success** = 0
  Success
rocblas_status_invalid_handle = 1
handle not initialized, invalid or null

rocblas_status_not_implemented = 2
function is not implemented

rocblas_status_invalid_pointer = 3
invalid pointer parameter

rocblas_status_invalid_size = 4
invalid size parameter

rocblas_status_memory_error = 5
failed internal memory allocation, copy or dealloc

rocblas_status_internal_error = 6
other internal library failure

defined rocblas_datatype
Indicates the precision width of data stored in a blas type.

Values:
rocblas_datatype_f16_r = 150
rocblas_datatype_f32_r = 151
rocblas_datatype_f64_r = 152
rocblas_datatype_f16_c = 153
rocblas_datatype_f32_c = 154
rocblas_datatype_f64_c = 155
rocblas_datatype_i8_r = 160
rocblas_datatype_u8_r = 161
rocblas_datatype_i32_r = 162
rocblas_datatype_u32_r = 163
rocblas_datatype_i8_c = 164
rocblas_datatype_u8_c = 165
rocblas_datatype_i32_c = 166
rocblas_datatype_u32_c = 167

defined rocblas_pointer_mode
Indicates the pointer is device pointer or host pointer.

Values:
rocblas_pointer_mode_host = 0
rocblas_pointer_mode_device = 1

defined rocblas_layer_mode
Indicates if layer is active with bitmask.

Values:
rocblas_layer_mode_none = 0b0000000000
rocblas_layer_mode_log_trace = 0b0000000001

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rocblas_layer_mode_log_bench = 0b0000000010
rocblas_layer_mode_log_profile = 0b00000000100

enum rocblas_gemm_algo
Indicates if layer is active with bitmask.
Values:
rocblas_gemm_algo_standard = 0b0000000000

file rocblas.h
#include <stdbool.h>
#include "rocblas-export.h"
#include "rocblas-version.h"
#include "rocblas-types.h"
#include "rocblas-auxiliary.h"
#include "rocblas-functions.h" rocblas.h includes other *.h and exposes a common interface

Defines

#define _ROCBLAS_H_

file buildinfo.cpp
#include <stdio.h>
#include <sstream>
#include <string.h>
#include "definitions.h"
#include "rocblas-types.h"
#include "rocblas-functions.h"
#include "rocblas-version.h"

Defines

TO_STR2(x)
TO_STR(x)
VERSION_STRING

Functions

rocblas_status rocblas_get_version_string(char *buf, size_t len)

BLAS EX API.
GEMM_STRIDED_BATCHED_EX performs one of the strided_batched matrix-matrix operations

\[ D[i \times \text{stride}_d] = \alpha \cdot \text{op}(A[i \times \text{stride}_a]) \cdot \text{op}(B[i \times \text{stride}_b]) + \beta \cdot C[i \times \text{stride}_c], \text{ for } i \in [0, \text{batch_count}-1] \]

where \( \text{op}(X) \) is one of

\[
\begin{align*}
\text{op}(X) &= X & \text{or} \\
\text{op}(X) &= X^T & \text{or} \\
\text{op}(X) &= X^H,
\end{align*}
\]

alpha and beta are scalars, and A, B, C, and D are strided_batched matrices, with \( \text{op}(A) \) an \( m \times k \) by \( k \times n \) strided_batched matrix, \( \text{op}(B) \) a \( k \times n \) by \( \text{batch_count} \times \text{strided_batched_matrix} \) and \( C \) and \( D \) are \( m \times n \) by \( \text{batch_count} \times \text{strided_batched_matrix} \).

The strided_batched matrices are multiple matrices separated by a constant stride. The number of matrices is \( \text{batch_count} \).

Parameters
• [in] handle: rocblas_handle. handle to the rocblas library context queue.
• [in] transA: rocblas_operation specifies the form of \( \text{op}(A) \)
• [in] transB: rocblas_operation specifies the form of \( \text{op}(B) \)
• [in] m: rocblas_int. matrix dimension \( m \)
• [in] n: rocblas_int. matrix dimension \( n \)
• [in] k: rocblas_int. matrix dimension \( k \)
• [in] alpha: const void * specifies the scalar \( \alpha \). Same datatype as compute_type.
• [in] a: void * pointer storing matrix \( A \) on the GPU.
• [in] a_type: rocblas_datatype specifies the datatype of matrix \( A \)
• [in] lda: rocblas_int specifies the leading dimension of \( A \).
• [in] stride_a: rocblas_long specifies stride from start of one “\( A \)” matrix to the next
• [in] b: void * pointer storing matrix \( B \) on the GPU.
• [in] b_type: rocblas_datatype specifies the datatype of matrix \( B \)
• [in] ldb: rocblas_int specifies the leading dimension of \( B \).
• [in] stride_b: rocblas_long specifies stride from start of one “\( B \)” matrix to the next
• [in] beta: const void * specifies the scalar \( \beta \). Same datatype as compute_type.
• [in] c: void * pointer storing matrix \( C \) on the GPU.
• [in] c_type: rocblas_datatype specifies the datatype of matrix \( C \)
• [in] ldc: rocblas_int specifies the leading dimension of \( C \).
• [in] stride_c: rocblas_long specifies stride from start of one “\( C \)” matrix to the next
• [out] d: void * pointer storing matrix \( D \) on the GPU.
• [in] d_type: rocblas_datatype specifies the datatype of matrix \( D \)
• [in] ldd: rocblas_int specifies the leading dimension of \( D \).
• [in] stride_d: rocblas_long specifies stride from start of one “\( D \)” matrix to the next
• [in] batch_count: rocblas_int number of gemm operations in the batch
• [in] compute_type: rocblas_datatype specifies the datatype of computation
• [in] algo: rocblas_gemm_algo enumerant specifying the algorithm type.
• [in] solution_index: int32_t reserved for future use
• [in] flags: uint32_t reserved for future use

file handle.cpp
#include “handle.h”#include <cstdlib>

Functions

static void open_log_stream(const char *environment_variable_name, std::ostream *log_os,
                          std::ofstream &log_ofs)
Logging function.

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open_log_stream Open stream log_os for logging. If the environment variable with name environment_variable_name is not set, then stream log_os to std::cerr. Else open a file at the full logfile path contained in the environment variable. If opening the file succeeds, stream to the file else stream to std::cerr.

[out] log_os std::ostream* Output stream. Stream to std::cerr if environment_variable_name is not set, else set to stream to log_ofs

Parameters

• [in] environment_variable_name: const char* Name of environment variable that contains the full logfile path.

[out] log_ofs std::ofstream& Output file stream. If log_ofs->is_open()==true, then log_os will stream to log_ofs. Else it will stream to std::cerr.

file rocblas_auxiliary.cpp
#include <stdio.h>
#include <hip/hip_runtime.h>
#include "definitions.h"
#include "rocblas-types.h"
#include "handle.h"
#include "logging.h"
#include "utility.h"
#include "rocblas_unique_ptr.hpp"
#include "rocblas-auxiliary.h"

Functions

rocblas_pointer_mode rocblas_pointer_to_mode (void *ptr)
indicates whether the pointer is on the host or device. currently HIP API can only recognize the input ptr on deive or not can not recognize it is on host or not

rocblas_status rocblas_get_pointer_mode (rocblas_handle handle, rocblas_pointer_mode *mode)
rocblas_status rocblas_set_pointer_mode (rocblas_handle handle, rocblas_pointer_mode mode)
rocblas_status rocblas_create_handle (rocblas_handle *handle)
rocblas_status rocblas_destroy_handle (rocblas_handle handle)
rocblas_status rocblas_set_stream (rocblas_handle handle, hipStream_t stream_id)
rocblas_status rocblas_get_stream (rocblas_handle handle, hipStream_t *stream_id)

__global__ void copy_void_ptr_vector_kernel(rocblas_int n, rocblas_int elem_size, const void * x, rocblas_int incx, void * y, rocblas_int incy)
rocblas_status rocblas_set_vector (rocblas_int n, rocblas_int elem_size, const void *x_h, rocblas_int incx, void *y_d, rocblas_int incy)
rocblas_status rocblas_get_vector (rocblas_int n, rocblas_int elem_size, const void *x_d, rocblas_int incx, void *y_h, rocblas_int incy)

__global__ void copy_void_ptr_matrix_kernel (rocblas_int rows, rocblas_int cols, size_t elem_size, const void * a, rocblas_int lda, void * b, rocblas_int ldb)
rocblas_status rocblas_set_matrix (rocblas_int rows, rocblas_int cols, rocblas_int elem_size, const void *a_h, rocblas_int lda, void *b_d, rocblas_int ldb)
rocblas_status rocblas_get_matrix (rocblas_int rows, rocblas_int cols, rocblas_int elem_size, const void *a_d, rocblas_int lda, void *b_h, rocblas_int ldb)

Variables

constexpr size_t VEC_BUFF_MAX_BYTES = 1048576
constexpr rocblas_int NB_X = 256
constexpr size_t MAT_BUFF_MAX_BYTES = 1048576
constexpr rocblas_int MATRIX_DIM_X = 128
constexpr rocblas_int MATRIX_DIM_Y = 8

#include <hip/hip_runtime_api.h>
#include "rocblas.h"
#include "status.h"

Functions

rocblas_status get_rocblas_status_for_hip_status(hipError_t status)

2.9.3 hipBLAS

2.9.3.1 Introduction

Please Refer here for Github link hipBLAS

hipBLAS is a BLAS marshalling library, with multiple supported backends. It sits between the application and a ‘worker’ BLAS library, marshalling inputs into the backend library and marshalling results back to the application. hipBLAS exports an interface that does not require the client to change, regardless of the chosen backend. Currently, hipBLAS supports rocblas and cuBLAS as backends.

2.9.3.1.1 Installing pre-built packages

Download pre-built packages either from ROCm’s package servers or by clicking the github releases tab and manually downloading, which could be newer. Release notes are available for each release on the releases tab.

```
sudo apt update && sudo apt install hipblas
```

2.9.3.1.2 Quickstart hipBLAS build

Bash helper build script (Ubuntu only)

The root of this repository has a helper bash script install.sh to build and install hipBLAS on Ubuntu with a single command. It does not take a lot of options and hard-codes configuration that can be specified through invoking cmake directly, but it's a great way to get started quickly and can serve as an example of how to build/install. A few commands in the script need sudo access, so it may prompt you for a password.

```
./install -h -- shows help
./install -id -- build library, build dependencies and install (-d flag only needs to be passed once on a system)
```
Manual build (all supported platforms)

If you use a distro other than Ubuntu, or would like more control over the build process, the hipblas build has helpful information on how to configure cmake and manually build.

Functions supported
A list of exported functions from hipblas can be found on the wiki

2.9.3.1.3 hipBLAS interface examples

The hipBLAS interface is compatible with rocBLAS and cuBLAS-v2 APIs. Porting a CUDA application which originally calls the cuBLAS API to an application calling hipBLAS API should be relatively straightforward. For example, the hipBLAS SGEMV interface is

2.9.3.1.4 GEMV API

```c
hipblasStatus_t
hipblasSgemv( hipblasHandle_t handle,
             hipblasOperation_t trans,
             int m, int n, const float *alpha,
             const float *A, int lda,
             const float *x, int incx, const float *beta,
             float *y, int incy );
```

2.9.3.1.5 Batched and strided GEMM API

hipBLAS GEMM can process matrices in batches with regular strides. There are several permutations of these API’s, the following is an example that takes everything

```c
hipblasStatus_t
hipblasSgemmStridedBatched( hipblasHandle_t handle,
                          hipblasOperation_t transa, hipblasOperation_t transb,
                          int m, int n, int k, const float *alpha,
                          const float *A, int lda, long long bsa,
                          const float *B, int ldb, long long bsb, const float *beta,
                          float *C, int ldc, long long bsc,
                          int batchCount);
```

hipBLAS assumes matrices A and vectors x, y are allocated in GPU memory space filled with data. Users are responsible for copying data from/to the host and device memory.

2.9.3.2 Build

2.9.3.2.1 Dependencies For Building Library

CMake 3.5 or later
The build infrastructure for hipBLAS is based on Cmake v3.5. This is the version of cmake available on ROCm supported platforms. If you are on a headless machine without the x-windows system, we recommend using ccmake; if you have access to X-windows, we recommend using cmake-gui.

Install one-liners cmake:
Ubuntu: `sudo apt install cmake-qt-gui`
Fedora: `sudo dnf install cmake-gui`

2.9.3.2.2 Build Library Using Script (Ubuntu only)

The root of this repository has a helper bash script `install.sh` to build and install hipBLAS on Ubuntu with a single command. It does not take a lot of options and hard-codes configuration that can be specified through invoking cmake directly, but it’s a great way to get started quickly and can serve as an example of how to build/install. A few commands in the script need sudo access, so it may prompt you for a password.

```
./install.sh -h -- shows help
./install.sh -id -- build library, build dependencies and install (-d flag only needs to be passed once on a system)
```

2.9.3.2.3 Build Library Using Individual Commands

```
mkdir -p [HIPBLAS_BUILD_DIR]/release
cd [HIPBLAS_BUILD_DIR]/release
# Default install location is in /opt/rocm, define -DCMAKE_INSTALL_PREFIX=<path> to specify other
# Default build config is 'Release', define -DCMAKE_BUILD_TYPE=<config> to specify other
CXX=/opt/rocm/bin/hcc ccmake [HIPBLAS_SOURCE]
make -j$(nproc)
sudo make install # sudo required if installing into system directory such as /opt/rocm
```

2.9.3.2.4 Build Library + Tests + Benchmarks + Samples Using Individual Commands

The repository contains source for clients that serve as samples, tests and benchmarks. Clients source can be found in the clients subdir.

**Dependencies (only necessary for hipBLAS clients)**

The hipBLAS samples have no external dependencies, but our unit test and benchmarking applications do. These clients introduce the following dependencies:

1. boost
2. lapack
   - lapack itself brings a dependency on a fortran compiler
3. googletest

Linux distros typically have an easy installation mechanism for boost through the native package manager.

```
Ubuntu: `sudo apt install libboost-program-options-dev`
Fedora: `sudo dnf install boost-program-options`
```

Unfortunately, googletest and lapack are not as easy to install. Many distros do not provide a googletest package with pre-compiled libraries, and the lapack packages do not have the necessary cmake config files for cmake to configure linking the cblas library. hipBLAS provide a cmake script that builds the above dependencies from source. This is an optional step; users can provide their own builds of these dependencies and help cmake find them by setting the
CMAKE_PREFIX_PATH definition. The following is a sequence of steps to build dependencies and install them to the cmake default /usr/local.

**(optional, one time only)**

```
mkdir -p [HIPBLAS_BUILD_DIR]/release/deps
cd [HIPBLAS_BUILD_DIR]/release/deps
ccmake -DBUILD_BOOST=OFF [HIPBLAS_SOURCE]/deps  # assuming boost is installed,
       --through package manager as above
make -j$(nproc) install
```

Once dependencies are available on the system, it is possible to configure the clients to build. This requires a few extra cmake flags to the library cmake configure script. If the dependencies are not installed into system defaults (like /usr/local ), you should pass the CMAKE_PREFIX_PATH to cmake to help find them.

```
-DCMAKE_PREFIX_PATH="<semicolon separated paths>"
```

### 2.9.3.2.5 Common build problems

- **Issue:** HIP (/opt/rocm/hip) was built using hcc 1.0.xxx-xxx-xxx-xxx, but you are using /opt/rocm/hcc/hcc with version 1.0.yyy-yyyy-yyyy from hipcc. (version does not match) . Please rebuild HIP including cmake or update HCC_HOME variable.

**Solution:** Download HIP from github and use hcc to build from source and then use the build HIP instead of /opt/rocm/hip one or singly overwrite the new build HIP to this location.

- **Issue:** For Carrizo - HCC RUNTIME ERROR: Fail to find compatible kernel

**Solution:** Add the following to the cmake command when configuring: 
-DCMAKE_CXX_FLAGS="-amdgpu-target=gfx801"

- **Issue:** For MI25 (Vega10 Server) - HCC RUNTIME ERROR: Fail to find compatible kernel

**Solution:** export HCC_AMDGPU_TARGET=gfx900

### 2.9.3.3 Running

#### 2.9.3.3.1 Notice

Before reading this Wiki, it is assumed hipBLAS with the client applications has been successfully built as described in Build hipBLAS libraries and verification code

**Samples**

```
cd [BUILD_DIR]/clients/staging
./example-sscal
```

Example code that calls hipBLAS you can also see the following blog on the right side Example C code calling hipBLAS routine.
Unit tests

Run tests with the following:

```bash
cd [BUILD_DIR]/clients/staging
./hipblas-test
```

To run specific tests, use `--gtest_filter=match` where `match` is a `:`-separated list of wildcard patterns (called the positive patterns) optionally followed by a `:` and another `:`-separated pattern list (called the negative patterns). For example, run gemv tests with the following:

```bash
cd [BUILD_DIR]/clients/staging
./hipblas-test --gtest_filter=*gemv*
```

### 2.9.4 hcRNG

#### 2.9.4.1 hCRNG has been deprecated and has been replaced by rocRAND

#### 2.9.4.2 Introduction

The hcRNG library is an implementation of uniform random number generators targeting the AMD heterogeneous hardware via HCC compiler runtime. The computational resources of underlying AMD heterogeneous compute gets exposed and exploited through the HCC C++ frontend. Refer [here](#) for more details on HCC compiler.

The following list enumerates the current set of RNG generators that are supported so far.

- MRG31k3p
- MRG32k3a
- LFSR113
- Philox-4x32-10

#### 2.9.4.3 Examples

Random number generator Mrg31k3p example:

File: Randomarray.cpp

```c++
#!/c++

// This example is a simple random array generation and it compares host output with device output

// Random number generator Mrg31k3p
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <cstdint.h>
#include <assert.h>
#include <hcRNG/mrg31k3p.h>
#include <hcRNG/hcRNG.h>
#include <hc.hpp>
#include <hc_am.hpp>
using namespace hc;

int main()
```

(continues on next page)
```c
hcrngStatus status = HCRNG_SUCCESS;
bool ispassed = 1;
size_t streamBufferSize;
// Number of streams
size_t streamCount = 10;
// Number of random numbers to be generated
// numberCount must be a multiple of streamCount
size_t numberCount = 100;
// Enumerate the list of accelerators
std::vector<hc::accelerator>acc = hc::accelerator::get_all();
accelerator_view accl_view = (acc[1].create_view());
// Allocate memory for host pointers
float *Random1 = (float*) malloc(sizeof(float) * numberCount);
float *Random2 = (float*) malloc(sizeof(float) * numberCount);
float *outBufferDevice = hc::am_alloc(sizeof(float) * numberCount, acc[1], 0);

// Create streams
hcrngMrg31k3pStream *streams = hcrngMrg31k3pCreateStreams(NULL, streamCount, &
streamBufferSize, NULL);
    hcrngMrg31k3pStream *streams_buffer = hc::am_alloc(sizeof(hcrngMrg31k3pStream)
      * streamCount, acc[1], 0);
    accl_view.copy(streams, streams_buffer, streamCount*);

// Invoke random number generators in device (here stream_length and streams_per_ 
// thread arguments are default)
status = hcrngMrg31k3pDeviceRandomU01Array_single(accl_view, streamCount, 
    streams_buffer, numberCount, outBufferDevice);

if(status) std::cout << "TEST FAILED" << std::endl;
    accl_view.copy(outBufferDevice, Random1, numberCount * sizeof(float));

// Invoke random number generators in host
for (size_t i = 0; i < numberCount; i++)
    Random2[i] = hcrngMrg31k3pRandomU01(&streams[i % streamCount]);
    // Compare host and device outputs
for(int i =0; i < numberCount; i++) {
    if (Random1[i] != Random2[i]) {
        ispassed = 0;
        std::cout <<" RANDDEVICE[" << i << "] " << Random1[i] << "and RANDHOST[" 
<< i <<"] mismatches"" << Random2[i] << std::endl;
        break;
    } 
    else 
        continue;
}
if(!ispassed) std::cout << "TEST FAILED" << std::endl;

// Free host resources
free(Random1);
free(Random2);
// Release device resources
hc::am_free(outBufferDevice);
hc::am_free(streams_buffer);
return 0;
```
• Compiling the example code:

`/opt/hcc/bin/clang++ /opt/hcc/bin/hcc-config --cflags --ldflags -lhcrng Randomarray.cpp`

### 2.9.4.4 Installation

#### Installation steps

The following are the steps to use the library

- ROCM 2.6 Kernel, Driver and Compiler Installation (if not done until now)
- Library installation.

#### ROCM 2.6 Installation

To Know more about ROCM refer [here](#)

**a. Installing Debian ROCM repositories**

Before proceeding, make sure to completely uninstall any pre-release ROCm packages.

Refer [Here](#) for instructions to remove pre-release ROCM packages

Follow Steps to install rocm package

```bash
wget -qO- http://packages.amd.com/rocm/apt/debian/rocm.gpg.key | sudo apt-key add -
sudo sh -c \\
"echo deb [arch=amd64] http://packages.amd.com/rocm/apt/debian/ xenial \nmain > /etc/apt/sources.list.d/rocm.list"
sudo apt-get update
sudo apt-get install rocm
```

Then, make the ROCm kernel your default kernel. If using grub2 as your bootloader, you can edit the GRUB_DEFAULT variable in the following file:

```bash
sudo vi /etc/default/grub
sudo update-grub
```

and Reboot the system

**b. Verifying the Installation**

Once Reboot, to verify that the ROCm stack completed successfully you can execute HSA vector_copy sample application:

```bash
cd /opt/rocm/hsa/sample
make
./vector_copy
```

#### Library Installation

**a. Install using Prebuilt debian**

```bash
wget https://github.com/ROCMSoftwarePlatform/hcRNG/blob/master/pre-builds/hcrng-
---master-184472e-Linux.deb
sudo dpkg -i hcrng-master-184472e-Linux.deb
```

**b. Build debian from source**

```bash
git clone https://github.com/ROCMSoftwarePlatform/hcRNG.git && cd hcRNG
chmod +x build.sh && ./build.sh
```

### 2.9. ROCm Libraries
build.sh execution builds the library and generates a debian under build directory.

2.9.4.5 Key Features

- Support for 4 commonly used uniform random number generators.
- Single and Double precision.
- Multiple streams, created on the host and generates random numbers either on the host or on computing devices.

Prerequisites

This section lists the known set of hardware and software requirements to build this library

Hardware

- CPU: mainstream brand, Better if with >=4 Cores Intel Haswell based CPU
- System Memory >= 4GB (Better if >10GB for NN application over multiple GPUs)
- Hard Drive > 200GB (Better if SSD or NVMe driver for NN application over multiple GPUs)
- Minimum GPU Memory (Global) > 2GB

GPU cards supported

- dGPU: AMD R9 Fury X, R9 Fury, R9 Nano
- APU: AMD Kaveri or Carrizo

AMD Driver and Runtime

- Radeon Open Compute Kernel (ROCK) driver: https://github.com/RadeonOpenCompute/ROCK-Kernel-Driver
- HSA runtime API and runtime for Boltzmann: https://github.com/RadeonOpenCompute/ROCR-Runtime

System software

- Ubuntu 14.04 trusty and later
- GCC 4.6 and later
- CPP 4.6 and later (come with GCC package)
- python 2.7 and later
- python-pip
- BeautifulSoup4 (installed using python-pip)
- HCC 0.9 from here

Tools and Misc

- git 1.9 and later
- cmake 2.6 and later (2.6 and 2.8 are tested)
- firewall off
- root privilege or user account in sudo group

Ubuntu Packages

- libc6-dev-i386
- liblapack-dev
• graphicmagick
• libblas-dev

2.9.4.6 Tested Environments

Driver versions

• Boltzmann Early Release Driver + dGPU
  – Radeon Open Compute Kernel (ROCK) driver: https://github.com/RadeonOpenCompute/ROCK-Kernel-Driver
  – HSA runtime API and runtime for Boltzmann: https://github.com/RadeonOpenCompute/ROCR/Runtime

• Traditional HSA driver + APU (Kaveri)

GPU Cards

• Radeon R9 Nano
• Radeon R9 FuryX
• Radeon R9 Fury
• Kaveri and Carizo APU

Server System

• Supermicro SYS 2028GR-THT 6 R9 NANO
• Supermicro SYS-1028GQ-TRT 4 R9 NANO
• Supermicro SYS-7048GR-TR Tower 4 R9 NANO

2.9.4.7 Unit testing

a) Automated testing:
Follow these steps to start automated testing:

```
cd ~/hcRNG/
./build.sh --test=on
```

b) Manual testing:

(i) Google testing (GTEST) with Functionality check
```
cd ~/hcRNG/build/test/unit/bin/
```

All functions are tested against google test.

2.9.5 hipeigen

Eigen is a C++ template library for linear algebra: matrices, vectors, numerical solvers, and related algorithms.
For more information go to http://eigen.tuxfamily.org/.

2.9. ROCm Libraries
2.9.5.1 Installation instructions for ROCm

The ROCm Platform brings a rich foundation to advanced computing by seamlessly integrating the CPU and GPU with the goal of solving real-world problems.

To install ROCm, please follow:

2.9.5.2 Installing from AMD ROCm repositories

AMD is hosting both Debian and RPM repositories for the ROCm 2.6 packages. The packages in both repositories have been signed to ensure package integrity. Directions for each repository are given below:

- Debian repository - apt-get
- Add the ROCm apt repository

Complete installation steps of ROCm can be found [Here](#) or

For Debian based systems, like Ubuntu, configure the Debian ROCm repository as follows:

```
wget -qO - http://packages.amd.com/rocm/apt/debian/rocm.gpg.key | sudo apt-key add -
sudo sh -c 'echo deb [arch=amd64] http://packages.amd.com/rocm/apt/debian/ xenial main > /etc/apt/sources.list.d/rocm.list'
```

The gpg key might change, so it may need to be updated when installing a new release.

**Install or Update**

Next, update the apt-get repository list and install/update the rocm package:

```
Warning: Before proceeding, make sure to completely uninstall any pre-release ROCm packages
```

```
sudo apt-get update
sudo apt-get install rocm
```

Then, make the ROCm kernel your default kernel. If using grub2 as your bootloader, you can edit the GRUB_DEFAULT variable in the following file:

```
sudo vi /etc/default/grub
sudo update-grub
```

Once complete, **reboot your system.**

We recommend you verify your installation to make sure everything completed successfully.

2.9.5.3 Installation instructions for Eigen

**Explanation before starting**

Eigen consists only of header files, hence there is nothing to compile before you can use it. Moreover, these header files do not depend on your platform, they are the same for everybody.

**Method 1. Installing without using CMake**

You can use right away the headers in the Eigen/ subdirectory. In order to install, just copy this Eigen/ subdirectory to your favorite location. If you also want the unsupported features, copy the unsupported/ subdirectory too.
Method 2. Installing using CMake

Let’s call this directory ‘source_dir’ (where this INSTALL file is). Before starting, create another directory which we will call ‘build_dir’.

Do:

```bash
cd build_dir
cmake source_dir
make install
```

The make install step may require administrator privileges.

You can adjust the installation destination (the “prefix”) by passing the -DCMAKE_INSTALL_PREFIX=myprefix option to cmake, as is explained in the message that cmake prints at the end.

2.9.5.4 Build and Run hipeigen direct tests

To build the direct tests for hipeigen:

```bash
cd build_dir
make check -j $(nproc)
```

Note: All direct tests should pass with ROCm 2.6

2.9.6 clFFT

For Github Repository clFFT

clFFT is a software library containing FFT functions written in OpenCL. In addition to GPU devices, the library also supports running on CPU devices to facilitate debugging and heterogeneous programming.

Pre-built binaries are available here.

2.9.6.1 What’s New

- Support for powers of 11&13 size transforms
- Support for 1D large size transforms with no extra memory allocation requirement with environment flag
  CLFFT_REQUEST_LIB_NOMEMALLOC=1 for complex FFTs of powers of 2,3,5,10 sizes

2.9.6.1.1 Note

- clFFT requires platform/runtime that supports OpenCL 1.2

2.9.6.2 Introduction to clFFT

The FFT is an implementation of the Discrete Fourier Transform (DFT) that makes use of symmetries in the FFT definition to reduce the mathematical intensity required from O(N^2) to O(N log2(N)) when the sequence length N is the product of small prime factors. Currently, there is no standard API for FFT routines. Hardware vendors usually provide a set of high-performance FFTs optimized for their systems: no two vendors employ the same interfaces for their FFT routines. clFFT provides a set of FFT routines that are optimized for AMD graphics processors, but also are functional across CPU and other compute devices.

The clFFT library is an open source OpenCL library implementation of discrete Fast Fourier Transforms. The library:
• provides a fast and accurate platform for calculating discrete FFTs.
• works on CPU or GPU backends.
• supports in-place or out-of-place transforms.
• supports 1D, 2D, and 3D transforms with a batch size that can be greater than 1.
• supports planar (real and complex components in separate arrays) and interleaved (real and complex components as a pair contiguous in memory) formats.
• supports dimension lengths that can be any combination of powers of 2, 3, 5, 7, 11 and 13.
• Supports single and double precision floating point formats.

2.9.6.3 clFFT library user documentation

Library and API documentation for developers is available online as a GitHub Pages website

2.9.6.4 API semantic versioning

Good software is typically the result of the loop of feedback and iteration; software interfaces no less so. clFFT follows the semantic versioning guidelines. The version number used is of the form MAJOR.MINOR.PATCH.

2.9.6.5 clFFT Wiki

The project wiki contains helpful documentation, including a build primer

2.9.6.6 Contributing code

Please refer to and read the Contributing document for guidelines on how to contribute code to this open source project. The code in the /master branch is considered to be stable, and all pull-requests must be made against the /develop branch.

2.9.6.7 License

The source for clFFT is licensed under the Apache License, Version 2.0

2.9.6.8 Example

The following simple example shows how to use clFFT to compute a simple 1D forward transform

```c
#include <stdlib.h>
/* No need to explicitly include the OpenCL headers */
#include <clFFT.h>

int main( void )
{
    cl_int err;
    cl_platform_id platform = 0;
    cl_device_id device = 0;
    cl_context_properties props[3] = { CL_CONTEXT_PLATFORM, 0, 0 };
cl_context ctx = 0;
cl_command_queue queue = 0;
cl_mem bufX;
float *X;
cl_event event = NULL;
int ret = 0;
size_t N = 16;

/* FFT library realted declarations */
clfftPlanHandle planHandle;
clfftDim dim = CLFFT_1D;
size_t clLengths[1] = {N};

/* Setup OpenCL environment. */
err = clGetPlatformIDs( 1, &platform, NULL );
err = clGetDeviceIDs( platform, CL_DEVICE_TYPE_GPU, 1, &device, NULL );

props[1] = (cl_context_properties)platform;
ctx = clCreateContext( props, 1, &device, NULL, NULL, &err );
queue = clCreateCommandQueue( ctx, device, 0, &err );

/* Setup clFFT. */
clfftSetupData fftSetup;
err = clfftInitSetupData(&fftSetup);
err = clfftSetup(&fftSetup);

/* Allocate host & initialize data. */
/* Only allocation shown for simplicity. */
X = (float *)malloc(N * 2 * sizeof(*X));

/* Prepare OpenCL memory objects and place data inside them. */
bufX = clCreateBuffer( ctx, CL_MEM_READ_WRITE, N * 2 * sizeof(*X), NULL, &err );

err = clEnqueueWriteBuffer( queue, bufX, CL_TRUE, 0,
N * 2 * sizeof( *X ), X, 0, NULL, NULL );

/* Create a default plan for a complex FFT. */
err = clfftCreateDefaultPlan(&planHandle, ctx, dim, clLengths);

/* Set plan parameters. */
err = clfftSetPlanPrecision(planHandle, CLFFT_SINGLE);
err = clfftSetLayout(planHandle, CLFFT_COMPLEX_INTERLEAVED, CLFFT_COMPLEX_INPLACE);

err = clfftSetResultLocation(planHandle, CLFFT_INPLACE);

/* Bake the plan. */
err = clfftBakePlan(planHandle, 1, &queue, NULL, NULL);

/* Execute the plan. */
err = clfftEnqueueTransform(planHandle, CLFFT_FORWARD, 1, &queue, 0, NULL,
bufX, NULL, NULL);

/* Wait for calculations to be finished. */
err = clFinish(queue);

/* Fetch results of calculations. */
err = clEnqueueReadBuffer( queue, bufX, CL_TRUE, 0, N * 2 * sizeof( *X ), X, 0,
NULL, NULL );

(continues on next page)


/* Release OpenCL memory objects. */
clReleaseMemObject( bufX );

free(X);

/* Release the plan. */
err = clfftDestroyPlan( &planHandle );

/* Release clFFT library. */
clfftTeardown( );

/* Release OpenCL working objects. */
clReleaseCommandQueue( queue );
clReleaseContext( ctx );

return ret;

2.9.6.9 Build dependencies

Library for Windows
To develop the clFFT library code on a Windows operating system, ensure to install the following packages on your system:

- Windows® 7/8.1
- Visual Studio 2012 or later
- Latest CMake
- An OpenCL SDK, such as APP SDK 3.0

Library for Linux
To develop the clFFT library code on a Linux operating system, ensure to install the following packages on your system:

- GCC 4.6 and onwards
- Latest CMake
- An OpenCL SDK, such as APP SDK 3.0

Library for Mac OSX
To develop the clFFT library code on a Mac OS X, it is recommended to generate Unix makefiles with cmake.

Test infrastructure
To test the developed clFFT library code, ensure to install the following packages on your system:

- Googletest v1.6
- Latest FFTW
- Latest Boost
2.9.6.10 Performance infrastructure

To measure the performance of the clFFT library code, ensure that the Python package is installed on your system.

2.9.7 clBLAS

For Github repository clBLAS

This repository houses the code for the OpenCL™ BLAS portion of clMath. The complete set of BLAS level 1, 2 & 3 routines is implemented. Please see Netlib BLAS for the list of supported routines. In addition to GPU devices, the library also supports running on CPU devices to facilitate debugging and multicore programming. APPML 1.12 is the most current generally available pre-packaged binary version of the library available for download for both Linux and Windows platforms.

The primary goal of clBLAS is to make it easier for developers to utilize the inherent performance and power efficiency benefits of heterogeneous computing. clBLAS interfaces do not hide nor wrap OpenCL interfaces, but rather leaves OpenCL state management to the control of the user to allow for maximum performance and flexibility. The clBLAS library does generate and enqueue optimized OpenCL kernels, relieving the user from the task of writing, optimizing and maintaining kernel code themselves.

cBLAS update notes 01/2017

v2.12 is a bugfix release as a rollup of all fixes in /develop branch Thanks to @pavanky, @iotamudelta, @shahsan10, @psyhtest, @haahh, @hughperkins, @tfauck @abhiShandy, @IvanVergiliev, @zouglob, @mgates3 for contributions to clBLAS v2.12 Summary of fixes available to read on the releases tab

2.9.7.1 clBLAS library user documentation

Library and API documentation for developers is available online as a GitHub Pages website

cBLAS Wiki

The project wiki contains helpful documentation, including a build primer

Contributing code

Please refer to and read the Contributing document for guidelines on how to contribute code to this open source project. The code in the /master branch is considered to be stable, and all pull-requests should be made against the /develop branch.

2.9.7.2 License

The source for clBLAS is licensed under the Apache License, Version 2.0

2.9.7.3 Example

The simple example below shows how to use clBLAS to compute an OpenCL accelerated SGEMM

```c
#include <sys/types.h>
#include <stdio.h>

/* Include the clBLAS header. It includes the appropriate OpenCL headers */
#include <cBLAS.h>

/* This example uses predefined matrices and their characteristics for
 */ (continues on next page)```
* simplicity purpose.
*/

#define M 4
#define N 3
#define K 5

static const cl_float alpha = 10;

static const cl_float A[M*K] = {
    11, 12, 13, 14, 15,
    21, 22, 23, 24, 25,
    31, 32, 33, 34, 35,
    41, 42, 43, 44, 45,
};
static const size_t lda = K; /* i.e. lda = K */

static const cl_float B[K*N] = {
    11, 12, 13,
    21, 22, 23,
    31, 32, 33,
    41, 42, 43,
    51, 52, 53,
};
static const size_t ldb = N; /* i.e. ldb = N */

static const cl_float beta = 20;

static cl_float C[M*N] = {
    11, 12, 13,
    21, 22, 23,
    31, 32, 33,
    41, 42, 43,
};
static const size_t ldc = N; /* i.e. ldc = N */

static cl_float result[M*N];

int main( void )
{
    cl_int err;
    cl_platform_id platform = 0;
    cl_device_id device = 0;
    cl_context_properties props[3] = { CL_CONTEXT_PLATFORM, 0, 0 };
    cl_context ctx = 0;
    cl_command_queue queue = 0;
    cl_mem bufA, bufB, bufC;
    cl_event event = NULL;
    int ret = 0;

    /* Setup OpenCL environment. */
    err = clGetPlatformIDs( 1, &platform, NULL );
    err = clGetDeviceIDs( platform, CL_DEVICE_TYPE_GPU, 1, &device, NULL );
    props[1] = (cl_context_properties)platform;
    ctx = clCreateContext( props, 1, &device, NULL, NULL, &err );
    queue = clCreateCommandQueue( ctx, device, 0, &err );
/* Setup clBLAS */
err = clblasSetup();

/* Prepare OpenCL memory objects and place matrices inside them. */
bufA = clCreateBuffer( ctx, CL_MEM_READ_ONLY, M * K * sizeof(*A),
                      NULL, &err );
bufB = clCreateBuffer( ctx, CL_MEM_READ_ONLY, K * N * sizeof(*B),
                      NULL, &err );
bufC = clCreateBuffer( ctx, CL_MEM_READ_WRITE, M * N * sizeof(*C),
                      NULL, &err );

err = clEnqueueWriteBuffer( queue, bufA, CL_TRUE, 0,
                            M * K * sizeof( *A ), A, 0, NULL, NULL );
err = clEnqueueWriteBuffer( queue, bufB, CL_TRUE, 0,
                            K * N * sizeof( *B ), B, 0, NULL, NULL );
err = clEnqueueWriteBuffer( queue, bufC, CL_TRUE, 0,
                            M * N * sizeof( *C ), C, 0, NULL, NULL );

/* Call clBLAS extended function. Perform gemm for the lower right sub-matrices */
err = clblasSgemm( clblasRowMajor, clblasNoTrans, clblasNoTrans,
                 M, N, K,
                 alpha, bufA, 0, lda,
                 buffb, 0, ldb, beta,
                 buffC, 0, ldc,
                 1, &queue, 0, NULL, &event );

/* Wait for calculations to be finished. */
err = clWaitForEvents( 1, &event );

/* Fetch results of calculations from GPU memory. */
err = clEnqueueReadBuffer( queue, bufC, CL_TRUE, 0,
                            M * N * sizeof(*result),
                            result, 0, NULL, NULL );

/* Release OpenCL memory objects. */
clReleaseMemObject( bufC );
clReleaseMemObject( bufB );
clReleaseMemObject( bufA );

/* Finalize work with clBLAS */
clblasTeardown();

/* Release OpenCL working objects. */
clReleaseCommandQueue( queue );
clReleaseContext( ctx );
return ret;
}

2.9.7.4 Build dependencies

Library for Windows

- Windows® 7/8
- Visual Studio 2010 SP1, 2012
• An OpenCL SDK, such as APP SDK 2.8
• Latest CMake

**Library for Linux**

• GCC 4.6 and onwards
• An OpenCL SDK, such as APP SDK 2.9
• Latest CMake

**Library for Mac OSX**

• Recommended to generate Unix makefiles with cmake

**Test infrastructure**

• Googletest v1.6
• Latest Boost
• CPU BLAS
• Netlib CBLAS (recommended) Ubuntu: install by “apt-get install libblas-dev” Windows: download & install lapack-3.6.0 which comes with CBLAS
• or ACML on windows/linux; Accelerate on Mac OSX

### 2.9.7.5 Performance infrastructure

Python

### 2.9.8 clSPARSE

For Github repository clSPARSE

an OpenCL™ library implementing Sparse linear algebra routines. This project is a result of a collaboration between AMD Inc. and Vratis Ltd..

#### 2.9.8.1 What’s new in clSPARSE v0.10.1

• **bug fix release**
  – Fixes for travis builds
  – Fix to the matrix market reader in the cuSPARSE benchmark to synchronize with the regular MM reader
  – Replace cl.hpp with cl2.hpp (thanks to arrayfire)
  – **Fixes for the Nvidia platform; tested 352.79**
    * Fixed buffer overruns in CSR-Adaptive kernels
    * Fix invalid memory access on Nvidia GPUs in CSR-Adaptive SpMV kernel

#### 2.9.8.2 Build Status

Pre-built binaries are available on our [releases page](#)
2.9.8.3 clSPARSE features

- Sparse Matrix - dense Vector multiply (SpM-dV)
- Sparse Matrix - dense Matrix multiply (SpM-dM)
- Sparse Matrix - Sparse Matrix multiply Sparse Matrix Multiply (SpGEMM) - Single Precision
- Iterative conjugate gradient solver (CG)
- Iterative biconjugate gradient stabilized solver (BiCGStab)
- Dense to CSR conversions (& converse)
- COO to CSR conversions (& converse)
- Functions to read matrix market files in COO or CSR format

True in spirit with the other clMath libraries, clSPARSE exports a “C” interface to allow projects to build wrappers around clSPARSE in any language they need. A great deal of thought and effort went into designing the API’s to make them less ‘cluttered’ compared to the older clMath libraries. OpenCL state is not explicitly passed through the API, which enables the library to be forward compatible when users are ready to switch from OpenCL 1.2 to OpenCL 2.0.

2.9.8.4 API semantic versioning

Good software is typically the result of iteration and feedback. clSPARSE follows the semantic versioning guidelines, and while the major version number remains ‘0’, the public API should not be considered stable. We release clSPARSE as beta software (0.y.z) early to the community to elicit feedback and comment. This comes with the expectation that with feedback, we may incorporate breaking changes to the API that might require early users to recompile, or rewrite portions of their code as we iterate on the design.

clSPARSE Wiki

The project wiki contains helpful documentation. A build primer is available, which describes how to use cmake to generate platforms specific build files

Samples

clSPARSE contains a directory of simple OpenCL samples that demonstrate the use of the API in both C and C++. The superbuild script for clSPARSE also builds the samples as an external project, to demonstrate how an application would find and link to clSPARSE with cmake.

clSPARSE library documentation

API documentation is available at http://clmathlibraries.github.io/clSPARSE/. The samples give an excellent starting point to basic library operations.

Contributing code

Please refer to and read the Contributing document for guidelines on how to contribute code to this open source project. Code in the /master branch is considered to be stable and new library releases are made when commits are merged into /master. Active development and pull-requests should be made to the develop branch.

2.9.8.5 License

clSPARSE is licensed under the Apache License, Version 2.0

Compiling for Windows

- Windows® 7/8
- Visual Studio 2013 and above
• CMake 2.8.12 (download from Kitware)
• Solution (.sln) or
• Nmake makefiles
• An OpenCL SDK, such as APP SDK 3.0

Compiling for Linux
• GCC 4.8 and above
• CMake 2.8.12 (install with distro package manager)
• Unix makefiles or
  – KDevelop or
  – QT Creator
  – An OpenCL SDK, such as APP SDK 3.0

Compiling for Mac OSX
• CMake 2.8.12 (install via brew)
• Unix makefiles or
• XCode
• An OpenCL SDK (installed via xcode-select –install)

Bench & Test infrastructure dependencies
• Googletest v1.7
• Boost v1.58
• Footnotes

[1]: Changed to reflect CppCoreGuidelines: F.21
[2]: Changed to reflect CppCoreGuidelines: NL.8
[3]: OpenCL 2.0 support is not yet fully implemented; only the interfaces have been designed

2.9.9 clRNG

For Github repository clRNG

A library for uniform random number generation in OpenCL.

Streams of random numbers act as virtual random number generators. They can be created on the host computer in unlimited numbers, and then used either on the host or on computing devices by work items to generate random numbers. Each stream also has equally-spaced substreams, which are occasionally useful. The API is currently implemented for four different RNGs, namely the MRG31k3p, MRG32k3a, LFSR113 and Philox-4×32-10 generators.

2.9.9.1 What’s New

Libraries related to clRNG, for probability distributions and quasi-Monte Carlo methods, are available:

• clProbDist
• clQMC
Releases

The first public version of clRNG is v1.0.0 beta. Please go to releases for downloads.

2.9.9.2 Building

1. Install the runtime dependency:
   - An OpenCL SDK, such as APP SDK.

2. Install the build dependencies:
   - The CMake cross-platform build system. Visual Studio users can use CMake Tools for Visual Studio.
   - A recent C compiler, such as GCC 4.9, or Visual Studio 2013.

3. Get the clRNG source code.

4. Configure the project using CMake (to generate standard makefiles) or CMake Tools for Visual Studio (to generate solution and project files).

5. Build the project.

6. Install the project (by default, the library will be installed in the package directory under the build directory).

7. Point the environment variable CLRNG_ROOT to the installation directory, i.e., the directory under which include/clRNG can be found. This step is optional if the library is installed under /usr, which is the default.

8. In order to execute the example programs (under the bin subdirectory of the installation directory) or to link clRNG into other software, the dynamic linker must be informed where to find the clRNG shared library. The name and location of the shared library generally depend on the platform.

9. Optionally run the tests.

2.9.9.3 Example Instructions for Linux

On a 64-bit Linux platform, steps 3 through 9 from above, executed in a Bash-compatible shell, could consist of:

```
git clone https://github.com/clMathLibraries/clRNG.git
mkdir clRNG.build; cd clRNG.build; cmake ../clRNG/src
make
make install
export CLRNG_ROOT=$PWD/package
export LD_LIBRARY_PATH=$CLRNG_ROOT/lib64:$LD_LIBRARY_PATH
$CLRNG_ROOT/bin/CTest
```

Examples

Examples can be found in src/client. The compiled client program examples can be found under the bin subdirectory of the installation package ($CLRNG_ROOT/bin under Linux). Note that the examples expect an OpenCL GPU device to be available.

Simple example

The simple example below shows how to use clRNG to generate random numbers by directly using device side headers (.clh) in your OpenCL kernel.

```
#include <stdlib.h>
#include <string.h>
```

(continues on next page)
#include "clRNG/clRNG.h"
#include "clRNG/mrg31k3p.h"

int main( void )
{
    cl_int err;
    cl_platform_id platform = 0;
    cl_device_id device = 0;
    cl_context_properties props[3] = { CL_CONTEXT_PLATFORM, 0, 0 };
    cl_context ctx = 0;
    cl_command_queue queue = 0;
    cl_program program = 0;
    cl_kernel kernel = 0;
    cl_event event = 0;
    cl_mem bufIn, bufOut;
    float *out;
    char *clrng_root;
    char include_str[1024];
    char build_log[4096];
    size_t i = 0;
    size_t numWorkItems = 64;
    clrngMrg31k3pStream *streams = 0;
    size_t streamBufferSize = 0;
    size_t kernelLines = 0;

    /* Sample kernel that calls clRNG device-side interfaces to generate random
     numbers */
    const char *kernelSrc[] = {
        " #define CLRNG_SINGLE_PRECISION
        " #include <clRNG/mrg31k3p.clh>
        "__kernel void example(__global clrngMrg31k3pHostStream *streams,
        " __global float *out)
        "{
            int gid = get_global_id(0);
            clrngMrg31k3pStream workItemStream;
           clrngMrg31k3pCopyOverStreamsFromGlobal(1, &workItemStream,
                &streams[gid]);
            out[gid] = clrngMrg31k3pRandomU01(&workItemStream);
        }
    };
    /* Setup OpenCL environment. */
    err = clGetPlatformIDs( 1, &platform, NULL );
    err = clGetDeviceIDs( platform, CL_DEVICE_TYPE_GPU, 1, &device, NULL );

    props[1] = (cl_context_properties)platform;
    ctx = clCreateContext( props, 1, &device, NULL, NULL, &err );
    queue = clCreateCommandQueue( ctx, device, 0, &err );

    /* Make sure CLRNG_ROOT is specified to get library path */
    clrng_root = getenv("CLRNG_ROOT");
    if(clrng_root == NULL) printf("Specify environment variable CLRNG_ROOT as described\n");
strcpy(include_str, "-I ");
strcat(include_str, clrng_root);
strcat(include_str, "/include");

/* Create sample kernel */
kernelLines = sizeof(kernelSrc) / sizeof(kernelSrc[0]);
program = clCreateProgramWithSource(ctx, kernelLines, kernelSrc, NULL, &err);
err = clBuildProgram(program, 1, &device, include_str, NULL, NULL);
if (err != CL_SUCCESS)
{
    printf("\nclBuildProgram has failed\n");
    clGetProgramBuildInfo(program, device, CL_PROGRAM_BUILD_LOG, 4096, build_log, NULL);
    printf("%s", build_log);
}
kern = clCreateKernel(program, "example", &err);

/* Create streams */
streams = clrngMrg31k3pCreateStreams(NULL, numWorkItems, &streamBufferSize, &err);

/* Create buffers for the kernel */
bufIn = clCreateBuffer(ctx, CL_MEM_READ_ONLY | CL_MEM_COPY_HOST_PTR, streamBufferSize, streams, &err);
bufOut = clCreateBuffer(ctx, CL_MEM_WRITE_ONLY | CL_MEM_HOST_READ_ONLY, numWorkItems * sizeof(cl_float), NULL, &err);

/* Setup the kernel */
err = clSetKernelArg(kernel, 0, sizeof(bufIn), &bufIn);
err = clSetKernelArg(kernel, 1, sizeof(bufOut), &bufOut);

/* Execute the kernel and read back results */
err = clEnqueueNDRangeKernel(queue, kernel, 1, NULL, &numWorkItems, NULL, 0, NULL, &event);
err = clWaitForEvents(1, &event);
out = (float *)malloc(numWorkItems * sizeof(out[0]));
err = clEnqueueReadBuffer(queue, bufOut, CL_TRUE, 0, numWorkItems * sizeof(out[0]), out, 0, NULL, NULL);

/* Release allocated resources */
clReleaseEvent(event);
free(out);
clReleaseMemObject(bufIn);
clReleaseMemObject(bufOut);
clReleaseKernel(kernel);
clReleaseProgram(program);
cReleaseCommandQueue(queue);
cReleaseContext(ctx);

return 0;
2.9.4 Building the documentation manually

The documentation can be generated by running make from within the doc directory. This requires Doxygen to be installed.

2.9.10 hcFFT

2.9.10.1 hcFFT has been deprecated and has been replaced by rocFFT

2.9.10.2 Installation

The following are the steps to use the library

- ROCM 2.6 Kernel, Driver and Compiler Installation (if not done until now)
- Library installation.

ROCM 2.6 Installation

To Know more about ROCM refer https://github.com/RadeonOpenCompute/ROCm/blob/master/README.md

a. Installing Debian ROCM repositories

Before proceeding, make sure to completely uninstall any pre-release ROCm packages.

Refer https://github.com/RadeonOpenCompute/ROCm#removing-pre-release-packages for instructions to remove pre-release ROCM packages.

Steps to install rocm package are,

```
wget -qO - http://packages.amd.com/rocm/apt/debian/rocm.gpg.key | sudo apt-key add -
sudo sh -c 'echo deb [arch=amd64] http://packages.amd.com/rocm/apt/debian/ xenial-main > /etc/apt/sources.list.d/rocm.list'
sudo apt-get update
sudo apt-get install rocm
```

Then, make the ROCm kernel your default kernel. If using grub2 as your bootloader, you can edit the GRUB_DEFAULT variable in the following file:

```
sudo vi /etc/default/grub
sudo update-grub
```

and Reboot the system

b. Verifying the Installation

Once Reboot, to verify that the ROCm stack completed successfully you can execute HSA vector_copy sample application:

- cd /opt/rocm/hsa/sample
- make
- ./vector_copy

Library Installation

a. Install using Prebuilt debian
wget https://github.com/ROCmSoftwarePlatform/hcFFT/blob/master/pre-builds/hcfft-master-87a37f5-Linux.deb
sudo dpkg -i hcfft-master-87a37f5-Linux.deb

b. Build debian from source

git clone https://github.com/ROCmSoftwarePlatform/hcFFT.git && cd hcFFT
chmod +x build.sh && ./build.sh

build.sh execution builds the library and generates a debian under build directory.

c. Install CPU based FFTW3 library

sudo apt-get install fftw3 fftw3-dev pkg-config

2.9.10.3 Introduction

This repository hosts the HCC based FFT Library, that targets GPU acceleration of FFT routines on AMD devices. To know what HCC compiler features, refer here.

The following are the sub-routines that are implemented

1. R2C : Transforms Real valued input in Time domain to Complex valued output in Frequency domain.
2. C2R : Transforms Complex valued input in Frequency domain to Real valued output in Real domain.
3. C2C : Transforms Complex valued input in Frequency domain to Complex valued output in Real domain or vice versa

2.9.10.4 KeyFeature

- Support 1D, 2D and 3D Fast Fourier Transforms
- Supports R2C, C2R, C2C, D2Z, Z2D and Z2Z Transforms
- Support Out-Of-Place data storage
- Ability to Choose desired target accelerator
- Single and Double precision

Prerequisites

This section lists the known set of hardware and software requirements to build this library

Hardware

- CPU: mainstream brand, Better if with >=4 Cores Intel Haswell based CPU
- System Memory >= 4GB (Better if >10GB for NN application over multiple GPUs)
- Hard Drive > 200GB (Better if SSD or NVMe driver for NN application over multiple GPUs)
- Minimum GPU Memory (Global) > 2GB

GPU cards supported

- dGPU: AMD R9 Fury X, R9 Fury, R9 Nano
- APU: AMD Kaveri or Carrizo

2.9. ROCm Libraries
AMD Driver and Runtime

- Radeon Open Compute Kernel (ROCK) driver: https://github.com/RadeonOpenCompute/ROCK-Kernel-Driver
- HSA runtime API and runtime for Boltzmann: https://github.com/RadeonOpenCompute/ROCR-Runtime

System software

- Ubuntu 14.04 trusty and later
- GCC 4.6 and later
- CPP 4.6 and later (come with GCC package)
- python 2.7 and later
- python-pip
- BeautifulSoup4 (installed using python-pip)
- HCC 0.9 from here

Tools and Misc

- git 1.9 and later
- cmake 2.6 and later (2.6 and 2.8 are tested)
- firewall off
- root privilege or user account in sudo group

Ubuntu Packages

- libc6-dev-i386
- liblapack-dev
- graphicsmagick
- libblas-dev

2.9.10.5 Examples

FFT 1D R2C example:

file: hcfft_1D_R2C.cpp

```c++
#include <iostream>
#include <cstdlib>
#include "hcfft.h"
#include "hc_am.hpp"
#include "hcfftlib.h"

int main(int argc, char* argv[]) {
    int N = argc > 1 ? atoi(argv[1]) : 1024;
    // HCFFT work flow
    hcfftHandle plan;
    hcfftResult status = hcfftPlan1d(&plan, N, HCFFT_R2C);
    assert(status == HCFFT_SUCCESS);
    int Rsize = N;
}
```

(continues on next page)
```
int Csize = (N / 2) + 1;
hcfftReal* input = (hcfftReal*)calloc(Rsize, sizeof(hcfftReal));
int seed = 123456789;
srand(seed);

// Populate the input
for(int i = 0; i < Rsize ; i++) {
    input[i] = rand();
}

hcfftComplex* output = (hcfftComplex*)calloc(Csize, sizeof(hcfftComplex));

std::vector<hc::accelerator> accs = hc::accelerator::get_all();
assert(accs.size() && "Number of Accelerators == 0!");
hc::accelerator_view accl_view = accs[1].get_default_view();

hcfftReal* idata = hc::am_alloc(Rsize * sizeof(hcfftReal), accs[1], 0);
accl_view.copy(input, idata, sizeof(hcfftReal) * Rsize);
hcfftComplex* odata = hc::am_alloc(Csize * sizeof(hcfftComplex), accs[1], 0);
accl_view.copy(output, odata, sizeof(hcfftComplex) * Csize);
status = hcfftExecR2C(plan, idata, odata);
assert(status == HCFFT_SUCCESS);
accl_view.copy(odata, output, sizeof(hcfftComplex) * Csize);
status = hcfftDestroy(plan);
assert(status == HCFFT_SUCCESS);
free(input);
free(output);
hc::am_free(idata);
hc::am_free(odata);
```

- Compiling the example code:

Assuming the library and compiler installation is followed as in installation.

```
/opt/rocm/hcc/bin/clang++ /opt/rocm/hcc/bin/hcc-config -cxxflags -ldflags -lhcc_am -lhcfft -L/../lib/include -L/../build/lib/src hcfft_1D_R2C.cpp
```

### 2.9.10.6 Tested Environments

This sections enumerates the list of tested combinations of Hardware and system softwares.

**Driver versions**

- **Boltzmann Early Release Driver + dGPU**
  - Radeon Open Compute Kernel (ROCK) driver: [https://github.com/RadeonOpenCompute/ROCK-Kernel-Driver](https://github.com/RadeonOpenCompute/ROCK-Kernel-Driver)
  - HSA runtime API and runtime for Boltzmann: [https://github.com/RadeonOpenCompute/ROCR-Runtime](https://github.com/RadeonOpenCompute/ROCR-Runtime)

- **Traditional HSA driver + APU (Kaveri)**

**GPU Cards**

- Radeon R9 Nano
- Radeon R9 FuryX

### 2.9. ROCm Libraries

---

[175]
• Radeon R9 Fury
• Kaveri and Carizo APU

Server System
• Supermicro SYS 2028GR-THT 6 R9 NANO
• Supermicro SYS-1028GQ-TRT 4 R9 NANO
• Supermicro SYS-7048GR-TR Tower 4 R9 NANO

2.9.11 Tensile

2.9.11.1 Introduction

Tensile is a tool for creating a benchmark-driven backend library for GEMMs, GEMM-like problems (such as batched GEMM), N-dimensional tensor contractions, and anything else that multiplies two multi-dimensional objects together on an AMD GPU.

Overview for creating a custom TensileLib backend library for your application:

1. Install the PyYAML and cmake dependency (mandatory), git clone and cd Tensile
2. Create a benchmark config.yaml file in ./Tensile/Configs/
3. Run the benchmark. After the benchmark is finished, Tensile will dump 4 directories: 1 & 2 is about benchmarking. 3 & 4 is the summarized results from your library (like rocBLAS) viewpoints.
   - 1_BenchmarkProblems: has all the problems descriptions and executables generated during benchmarking, where you can re-launch exe to reproduce results.
   - 2_BenchmarkData: has the raw performance results.
   - 3_LibraryLogic: has optimal kernel configurations yaml file and Winner*.csv. Usually rocBLAS takes the yaml files from this folder.
   - 4_LibraryClient: has a client exe, so you can launch from a library viewpoint.
4. Add the Tensile library to your application’s CMake target. The Tensile library will be written, compiled and linked to your application at application-compile-time.
   • GPU kernels, written in HIP, OpenCL, or AMD GCN assembly.
   • Solution classes which enqueue the kernels.
   • APIs which call the fastest solution for a problem.

2.9.11.1.1 Quick Example (Ubuntu):

```
sudo apt-get install python-yaml
mkdir Tensile
cd Tensile
git clone https://github.com/ROCmSoftwarePlatform/Tensile repo
cd repo
git checkout master
mkdir build
cd build
python ../Tensile/Tensile.py ../Tensile/Configs/test_sgemm.yaml ./
```

After about 10 minutes of benchmarking, Tensile will print out the path to the client you can run.
2.9.11.2 Benchmark Config example

Tensile uses an incremental and “programmable” benchmarking protocol.

2.9.11.2.1 Example Benchmark config.yaml as input file to Tensile

```yaml
GlobalParameters:
  PrintLevel: 1
  ForceRedoBenchmarkProblems: False
  ForceRedoLibraryLogic: True
  ForceRedoLibraryClient: True
  CMakeBuildType: Release
  EnqueuesPerSync: 1
  SyncsPerBenchmark: 1
  LibraryPrintDebug: False
  NumElementsToValidate: 128
  ValidationMaxToPrint: 16
  ValidationPrintValids: False
  ShortNames: False
  MergeFiles: True
  PlatformIdx: 0
  DeviceIdx: 0
  DataInitTypeAB: 0

BenchmarkProblems:
  - # sgemm NN
    - # ProblemType
      OperationType: GEMM
      DataType: s
      TransposeA: False
      TransposeB: False
      UseBeta: True
      Batched: True
    - # BenchmarkProblemSizeGroup
      InitialSolutionParameters:
      BenchmarkCommonParameters:
        - ProblemSizes:
          - Range: [ [5760], 0, [1], 0 ]
          - LoopDoWhile: [False]
          - NumLoadsCoalescedA: [-1]
          - NumLoadsCoalescedB: [1]
          - WorkGroupMapping: [1]
      ForkParameters:
        - ThreadTile:
          - [ 8, 8 ]
          - [ 4, 8 ]
          - [ 4, 4 ]
        - WorkGroup:
          - [ 8, 16, 1 ]
          - [ 16, 16, 1 ]
```

(continues on next page)
- LoopTail: [False, True]
- EdgeType: ["None", "Branch", "ShiftPtr"]
- DepthU: [8, 16]
- VectorWidth: [1, 2, 4]

BenchmarkForkParameters:
JoinParameters:
- MacroTile
BenchmarkJoinParameters:
BenchmarkFinalParameters:
- ProblemSizes:
  - Range: [5760], 0, [1], 0]

LibraryLogic:
LibraryClient:

2.9.11.2.2 Structure of config.yaml

Top level data structure whose keys are Parameters, BenchmarkProblems, LibraryLogic and LibraryClient.

- **Parameters** contains a dictionary storing global parameters used for all parts of the benchmarking.
- **BenchmarkProblems** contains a list of dictionaries representing the benchmarks to conduct; each element, i.e. dictionary, in the list is for benchmarking a single **ProblemType**. The keys for these dictionaries are **ProblemType**, **InitialSolutionParameters**, **BenchmarkCommonParameters**, **ForkParameters**, **BenchmarkForkParameters**, **JoinParameters**, **BenchmarkJoinParameters** and **BenchmarkFinalParameters**. See Benchmark Protocol for more information on these steps.
- **LibraryLogic** contains a dictionary storing parameters for analyzing the benchmark data and designing how the backend library will select which Solution for certain ProblemSizes.
- **LibraryClient** contains a dictionary storing parameters for actually creating the library and creating a client which calls into the library.

2.9.11.2.3 Global Parameters

- **Name**: Prefix to add to API function names; typically name of device.
- **MinimumRequiredVersion**: Which version of Tensile is required to interpret this yaml file
- **RuntimeLanguage**: Use HIP or OpenCL runtime.
- **KernelLanguage**: For OpenCL runtime, kernel language must be set to OpenCL. For HIP runtime, kernel language can be set to HIP or assembly (gfx803, gfx900).
- **PrintLevel**: 0=Tensile prints nothing, 1=prints some, 2=prints a lot.
- **ForceRedoBenchmarkProblems**: False means don’t redo a benchmark phase if results for it already exist.
- **ForceRedoLibraryLogic**: False means don’t re-generate library logic if it already exist.
- **ForceRedoLibraryClient**: False means don’t re-generate library client if it already exist.
- **CMakeBuildType**: Release or Debug
- **EnqueuesPerSync**: Num enqueues before syncing the queue.
- **SyncsPerBenchmark**: Num queue syncs for each problem size.
• **LibraryPrintDebug**: True means Tensile solutions will print kernel enqueue info to stdout
• **NumElementsToValidate**: Number of elements to validate; 0 means no validation.
• **ValidationMaxToPrint**: How many invalid results to print.
• **ValidationPrintValids**: True means print validation comparisons that are valid, not just invalids.
• **ShortNames**: Convert long kernel, solution and files names to short serial ids.
• **MergeFiles**: False means write each solution and kernel to its own file.
• **PlatformIdx**: OpenCL platform id.
• **DeviceIdx**: OpenCL or HIP device id.
• **DataInitType[AB,C]**: Initialize validation data with 0=0’s, 1=1’s, 2=serial, 3=random.
• **KernelTime**: Use kernel time reported from runtime rather than api times from cpu clocks to compare kernel performance.

The exhaustive list of global parameters and their defaults is stored in Common.py.

### 2.9.11.2.4 Problem Type Parameters

• **OperationType**: GEMM or TensorContraction.
• **DataType**: s, d, c, z, h
• **UseBeta**: False means library/solutions/kernel won’t accept a beta parameter; thus beta=0.
• **UseInitialStrides**: False means data is contiguous in memory.
• **HighPrecisionAccumulate**: For tmpC += a*b, use twice the precision for tmpC as for DataType. Not yet implemented.
• **ComplexConjugateA**: True or False; ignored for real precision.
• **ComplexConjugateB**: True or False; ignored for real precision.

For OperationType=GEMM only:

• **TransposeA**: True or False.
• **TransposeB**: True or False.
• **Batched**: True (False has been deprecated). For OperationType=TensorContraction only (showing batched gemm NT: C[ijk] = Sum[l] A[ilk] * B[jlk])
• **IndexAssignmentsA**: [0, 3, 2]
• **IndexAssignmentsB**: [1, 3, 2]
• **NumDimensionsC**: 3.

### 2.9.11.2.5 Solution / Kernel Parameters

See: Kernel Parameters.
2.9.11.2.6 Defaults

Because of the flexibility / complexity of the benchmarking process and, therefore, of the config.yaml files; Tensile has a default value for every parameter. If you neglect to put LoopUnroll anywhere in your benchmark, rather than crashing or complaining, Tensile will put the default LoopUnroll options into the default phase (common, fork, join...). This guarantees ease of use and more importantly backward compatibility; every time we add a new possible solution parameter, you don’t necessarily need to update your configs; we’ll have a default figured out for you.

However, this may cause some confusion. If your config fork 2 parameters, but you see that 3 were forked during benchmarking, that’s because you didn’t specify the 3rd parameter anywhere, so Tensile stuck it in its default phase, which was forking (for example). Also, specifying ForkParameters: and leaving it empty isn’t the same as leaving JoinParameter out of your config. If you leave ForkParameters out of your config, Tensile will add a ForkParameters step and put the default parameters into it (unless you put all the parameters elsewhere), but if you specify ForkParameters and leave it empty, then you won’t work anything.

Therefore, it is safest to specify all parameters in your config.yaml files; that way you’ll guarantee the behavior you want. See /Tensile/Common.py for the current list of parameters.

2.9.11.3 Benchmark Protocol

2.9.11.3.1 Old Benchmark Architecture was Intractable

The benchmarking strategy from version 1 was vanilla flavored brute force: \( (8 \text{ WorkGroups}) \times (12 \text{ ThreadTiles}) \times (4 \text{ NumLoadsCoalescedAs}) \times (4 \text{ NumLoadsCoalescedBs}) \times (3 \text{ LoopUnrolls}) \times (5 \text{ BranchTypes}) \times \ldots \times (1024 \text{ Problem-Sizes}) = 23,592,960 \) is a multiplicative series which grows very quickly. Adding one more boolean parameter doubles the number of kernel enqueues of the benchmark.

2.9.11.3.2 Incremental Benchmark is Faster

Tensile version 2 allows the user to manually interrupt the multiplicative series with “additions” instead of “multiplies”, i.e., \( (8 \text{ WorkGroups}) \times (12 \text{ ThreadTiles}) + (4 \text{ NumLoadsCoalescedAs}) \times (4 \text{ NumLoadsCoalescedBs}) \times (3 \text{ LoopUnrolls}) + (5 \text{ BranchTypes}) + \ldots + (1024 \text{ ProblemSizes}) = 1,151 \) is a dramatically smaller number of enqueues. Now, adding one more boolean parameter may only add on 2 more enqueues.

2.9.11.3.3 Phases of Benchmark

To make the Tensile’s programability more manageable for the user and developer, the benchmarking protocol has been split up into several steps encoded in a config.yaml file. The below sections reference the following config.yaml. Note that this config.yaml has been created to be a simple illustration and doesn’t not represent an actual good benchmark protocol. See the configs included in the repository (/Tensile/Configs) for examples of good benchmarking configs.

```
BenchmarkProblems:
  - # sgemm
    # Problem Type
    OperationType: GEMM
    Batched: True
  - # Benchmark Size-Group
    InitialSolutionParameters:
      - WorkGroup: [ [ 16, 16, 1 ] ]
      - NumLoadsCoalescedA: [ 1 ]
      - NumLoadsCoalescedB: [ 1 ]
      - ThreadTile: [ [ 4, 4 ] ]
```
BenchmarkCommonParameters:
- ProblemSizes:
  - Range: [ [512], [512], [1], [512] ]
- EdgeType: ["Branch", "ShiftPtr"]
- PrefetchGlobalRead: [False, True]

ForkParameters:
- WorkGroup: [ [8, 32, 1], [16, 16, 1], [32, 8, 1] ]
- ThreadTile: [ [2, 8], [4, 4], [8, 2] ]

BenchmarkForkParameters:
- ProblemSizes:
  - Exact: [2880, 2880, 1, 2880]
  - NumLoadsCoalescedA: [1, 2, 4, 8]
  - NumLoadsCoalescedB: [1, 2, 4, 8]

JoinParameters:
- MacroTile

BenchmarkJoinParameters:
- LoopUnroll: [8, 16]

BenchmarkFinalParameters:
- ProblemSizes:
  - Range: [ [16, 128], [16, 128], [1], [256] ]

### 2.9.11.3.4 Initial Solution Parameters

A Solution is comprised of ~20 parameters, and all are needed to create a kernel. Therefore, during the first benchmark which determines which WorkGroupShape is fastest, what are the other 19 solution parameters which are used to describe the kernels that we benchmark? That’s what InitialSolutionParameters are for. The solution used for benchmarking WorkGroupShape will use the parameters from InitialSolutionParameters. The user must choose good default solution parameters in order to correctly identify subsequent optimal parameters.

### 2.9.11.3.5 Problem Sizes

Each step of the benchmark can override what problem sizes will be benchmarked. A ProblemSizes entry of type Range is a list whose length is the number of indices in the ProblemType. A GEMM ProblemSizes must have 3 elements while a batched-GEMM ProblemSizes must have 4 elements. So, for a ProblemType of $C_{ij} = \sum_k A_{ik} B_{jk}$, the ProblemSizes elements represent $[\text{SizeI}, \text{SizeJ}, \text{SizeK}]$. For each index, there are 5 ways of specifying the sizes of that index:

1. [1968]
   - Benchmark only size 1968; $n = 1$.
2. [16, 1920]
   - Benchmark sizes 16 to 1968 using the default step size (=16); $n = 123$.
3. [16, 32, 1968]
   - Benchmark sizes 16 to 1968 using a step size of 32; $n = 61$.
4. [64, 32, 16, 1968]

### 2.9. ROCm Libraries
• Benchmark sizes from 64 to 1968 with a step size of 32. Also, increase the step size by 16 each iteration.
• This causes fewer sizes to be benchmarked when the sizes are large, and more benchmarks where the sizes are small; this is typically desired behavior.
• \( n = 16 \) (64, 96, 144, 208, 288, 384, 496, 624, 768, 928, 1104, 1296, 1504, 1728, 1968). The stride at the beginning is 32, but the stride at the end is 256.

5. 0
• The size of this index is just whatever size index 0 is. For a 3-dimensional ProblemType, this allows benchmarking only a 2-dimensional or 1-dimensional slice of problem sizes.

Here are a few examples of valid ProblemSizes for 3D GEMMs:

<table>
<thead>
<tr>
<th>Range:</th>
<th>([16, 128], [16, 128], [16, 128])</th>
<th>(# n = 512)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range:</td>
<td>([16, 128], 0, 0)</td>
<td>(# n = 8)</td>
</tr>
<tr>
<td>Range:</td>
<td>([16, 16, 16, 5760], 0, [1024, 1024, 4096])</td>
<td>(# n = 108)</td>
</tr>
</tbody>
</table>

### 2.9.11.3.6 Benchmark Common Parameters

During this first phase of benchmarking, we examine parameters which will be the same for all solutions for this ProblemType. During each step of benchmarking, there is only 1 winner. In the above example we are benchmarking the dictionary \{EdgeType: [Branch, ShiftPtr], PrefetchGlobalRead: [False, True]\}; therefore, this benchmark step generates 4 solution candidates, and the winner will be the fastest EdgeType/PrefetchGlobalRead combination. Assuming the winner is ET=SP and PGR=T, then all solutions for this ProblemType will have ET=SP and PGR=T. Also, once a parameter has been determined, all subsequent benchmarking steps will use this determined parameter rather than pulling values from InitialSolutionParameters. Because the common parameters will apply to all kernels, they are typically the parameters which are compiler-dependent or hardware-dependent rather than being tile-dependent.

### 2.9.11.3.7 Fork Parameters

If we continued to determine every parameter in the above manner, we’d end up with a single fastest solution for the specified ProblemSizes; we usually desire multiple different solutions with varying parameters which may be fastest for different groups of ProblemSizes. One simple example of this is small tiles sizes are fastest for small problem sizes, and large tiles are fastest for large tile sizes.

Therefore, we allow “forking” parameters; this means keeping multiple winners after each benchmark steps. In the above example we fork \{WorkGroup: […], ThreadTile: […]\}. This means that in subsequent benchmarking steps, rather than having one winning parameter, we’ll have one winning parameter per fork permutation; we’ll have 9 winners.

### 2.9.11.3.8 Benchmark Fork Parameters

When we benchmark the fork parameters, we retain one winner per permutation. Therefore, we first determine the fastest NumLoadsCoalescedA for each of the WG,TT permutations, then we determine the fastest NumLoadsCoalescedB for each permutation.

### 2.9.11.3.9 Join Parameters

After determining fastest parameters for all the forked solution permutations, we have the option of reducing the number of winning solutions. When a parameter is listed in the JoinParameters section, that means that of the kept
winning solutions, each will have a different value for that parameter. Listing more parameters to join results in more
winners being kept, while having a JoinParameters section with no parameters listed results on only 1 fastest solution.
In our example we join over the MacroTile (work-group x thread-tile). After forking tiles, there were 9 solutions that
we kept. After joining MacroTile, we’ll only keep six: 16x256, 32x128, 64x64, 128x32 and 256x16. The solutions
that are kept are based on their performance during the last BenchmarkForkParameters benchmark, or, if there weren’t
any, JoinParameters will conduct a benchmark of all solution candidates then choose the fastest.

2.9.11.3.10 Benchmark Join Parameters

After narrowing the list of fastest solutions through joining, you can continue to benchmark parameters, keeping one
winning parameter per solution permutation.

2.9.11.3.11 Benchmark Final Parameters

After all the parameter benchmarking has been completed and the final list of fastest solution has been assembled,
we can benchmark all the solution over a large set of ProblemSizes. This benchmark represent the final output of
benchmarking; it outputs a .csv file where the rows are all the problem sizes and the columns are all the solutions. This
is the information which gets analysed to produce the library logic.

2.9.11.4 Contributing

We’d love your help, but . . .

1. Never check in a tab (t); use 4 spaces.
2. Follow the coding style of the file you’re editing.
3. Make pull requests against develop branch.
4. Rebase your develop branch against ROCmSoftwarePlatform::Tensile::develop branch right before pull-
requesting.
5. In your pull request, state what you tested (which OS, what drivers, what devices, which config.yaml’s) so we
can ensure that your changes haven’t broken anything.

2.9.11.5 Dependencies

2.9.11.5.1 CMake

• CMake 2.8

2.9.11.5.2 Python

(One time only)

• Ubuntu: sudo apt install python2.7 python-yaml
• CentOS: sudo yum install python PyYAML
• Fedora: sudo dnf install python PyYAML
2.9.11.5.3 Compilers

- For Tensile_BACKEND = OpenCL1.2 *(untested)*
  - Visual Studio 14 (2015). (VS 2012 may also be supported; c++11 should no longer be required by Tensile. Need to verify.)
  - GCC 4.8 and above
- For Tensile_BACKEND = HIP
  - Public ROCm

2.9.11.6 Installation

Tensile can be installed via:

1. Download repo and don’t install; install PyYAML dependency manually and call python scripts manually:

   ```
   git clone https://github.com/ROCmSoftwarePlatform/Tensile.git
   python Tensile/Tensile/Tensile.py your_custom_config.yaml your_benchmark_path
   ```

2. Install develop branch directly from repo using pip:

   ```
   pip install git+https://github.com/ROCmSoftwarePlatform/Tensile.git@develop
   tensile your_custom_config.yaml your_benchmark_path
   ```

3. Download repo and install manually: (deprecated)

   ```
   git clone https://github.com/ROCmSoftwarePlatform/Tensile.git
   cd Tensile
   sudo python setup.py install
   tensile your_custom_config.yaml your_benchmark_path
   ```

2.9.11.7 Kernel Parameters

2.9.11.7.1 Solution / Kernel Parameters

- **LoopDoWhile**: True=DoWhile loop, False=While or For loop
- **LoopTail**: Additional loop with LoopUnroll=1.
- **EdgeType**: Branch, ShiftPtr or None
- **WorkGroup**: [dim0, dim1, LocalSplitU]
- **ThreadTile**: [dim0, dim1]
- **GlobalSplitU**: Split up summation among work-groups to create more concurrency. This option launches a kernel to handle the beta scaling, then a second kernel where the writes to global memory are atomic.
- **PrefetchGlobalRead**: True means outer loop should prefetch global data one iteration ahead.
- **PrefetchLocalRead**: True means inner loop should prefetch lds data one iteration ahead.
- **WorkGroupMapping**: In what order will work-groups compute C; affects caching.
- **LoopUnroll**: How many iterations to unroll inner loop; helps loading coalesced memory.
- **MacroTile**: Derived from WorkGroup*ThreadTile.
The exhaustive list of solution parameters and their defaults is stored in Common.py.

### 2.9.11.7.2 Kernel Parameters Affect Performance

The kernel parameters affect many aspects of performance. Changing a parameter may help address one performance bottleneck but worsen another. That is why searching through the parameter space is vital to discovering the fastest kernel for a given problem.

For a traditional GEMM, the 2-dimensional output, C[i,j], is mapped to launching a 2-dimensional grid of work groups, each of which has a 2-dimensional grid of work items; one dimension belongs to i and one dimension belongs to j.
The 1-dimensional summation is represented by a single loop within the kernel body.

2.9.11.7.4 Special Dimensions: D0, D1 and DU

To handle arbitrary dimensionality, Tensile begins by determining 3 special dimensions: D0, D1 and DU.

D0 and D1 are the free indices of A and B (one belongs to A and one to B) which have the shortest strides. This allows the inner-most loops to read from A and B the fastest via coalescing. In a traditional GEMM, every matrix has a dimension with a shortest stride of 1, but Tensile doesn’t make that assumption. Of these two dimensions, D0 is the dimension which has the shortest tensor C stride which allows for fast writing.

DU represents the summation index with the shortest combined stride (stride in A + stride in B); it becomes the inner most loop which gets “U”nrolled. This assignment is also meant to assure fast reading in the inner-most summation loop. There can be multiple summation indices (i.e. embedded loops) and DU will be iterated over in the inner most loop.

2.9.11.7.5 GPU Kernel Dimension

OpenCL allows for 3-dimensional grid of work-groups, and each work-group can be a 3-dimensional grid of work-items. Tensile assigns D0 to be dimension-0 of the work-group and work-item grid; it assigns D1 to be dimension-1 of the work-group and work-item grids. All other free or batch dimensions are flattened down into the final dimension-2 of the work-group and work-item grids. Within the GPU kernel, dimensions-2 is reconstituted back into whatever dimensions it represents.

2.9.11.8 Languages

2.9.11.8.1 Tensile Benchmarking is Python

The benchmarking module, Tensile.py, is written in python. The python scripts write solution, kernels, cmake files and all other C/C++ files used for benchmarking.

2.9.11.8.2 Tensile Library

The Tensile API, Tensile.h, is confined to C89 so that it will be usable by most software. The code behind the API is allowed to be c++11.

2.9.11.8.3 Device Languages

The device languages Tensile supports for the gpu kernels is

- OpenCL 1.2
- HIP
- Assembly
  - gfx803
  - gfx900
2.9.11.9 Library Logic

Running the LibraryLogic phase of benchmarking analyses the benchmark data and encodes a mapping for each problem type. For each problem type, it maps problem sizes to best solution (i.e. kernel).

When you build Tensile.lib, you point the TensileCreateLibrary function to a directory where your library logic yaml files are.

2.9.11.10 Problem Nomenclature

2.9.11.10.1 Example Problems

- Standard GEMM has 4 variants (2 free indices (i, j) and 1 summation index l)
- C[i,j,k] = Sum[l] A[i,l,k] * B[j,l,k] (batched-GEMM; 2 free indices, 1 batched index k and 1 summation index l)
  - C[i,j,k,l,m] = Sum[n] A[i,k,m,l,n] * B[j,k,l,n,m] (GEMM with 3 batched indices)
  - C[i,j,k,l,m] = Sum[n,o] A[i,k,m,o,n] * B[j,m,l,n,o] (4 free indices, 2 summation indices and 1 batched index)
  - C[i,j,k,l] = Sum[m,n] A[i,j,m,n,l] * B[m,n,k,j,l] (batched image convolution mapped to 7D tensor contraction)
  - and even crazier

2.9.11.10.2 Nomenclature

The indices describe the dimensionality of the problem being solved. A GEMM operation takes 2 2-dimensional matrices as input (totaling 4 input dimensions) and contracts them along one dimension (which cancels out 2 of the dimensions), resulting in a 2-dimensional result.

Whenever an index shows up in multiple tensors, those tensors must be the same size along that dimension but they may have different strides.

There are 3 categories of indices/dimensions that Tensile deals with: free, batch and bound.

Free Indices

Free indices are the indices of tensor C which come in pairs; one of the pair shows up in tensor A while the other shows up in tensor B. In the really crazy example above, i/j/k/l are the 4 free indices of tensor C. Indices i and k come from tensor A and indices j and l come from tensor B.

Batch Indices

Batch indices are the indices of tensor C which shows up in both tensor A and tensor B. For example, the difference between the GEMM example and the batched-GEMM example above is the additional index. In the batched-GEMM example, the index K is the batch index which is batching together multiple independent GEMMs.

Bound/Summation Indices
The final type of indices are called bound indices or summation indices. These indices do not show up in tensor C; they show up in the summation symbol (\(\text{Sum}[k]\)) and in tensors A and B. It is along these indices that we perform the inner products (pairwise multiply then sum).

### 2.9.11.10.3 Limitations

Problem supported by Tensile must meet the following conditions:

There must be at least one pair of free indices.

### 2.9.11.11 Tensile.lib

After running the benchmark and generating library config files, you’re ready to add Tensile.lib to your project. Tensile provides a `TensileCreateLibrary` function, which can be called:

```
set(Tensile_BACKEND "HIP")
set(Tensile_LOGIC_PATH "~/LibraryLogic" CACHE STRING "Path to Tensile logic.yaml files")
option( Tensile_MERGE_FILES "Tensile to merge kernels and solutions files?" OFF)
option( Tensile_SHORT_NAMES "Tensile to use short file/function names? Use if compiler complains they’re too long." OFF)
option( Tensile_PRINT_DEBUG "Tensile to print runtime debug info?" OFF)

find_package(Tensile) # use if Tensile has been installed
TensileCreateLibrary(
    ${Tensile_LOGIC_PATH}
    ${Tensile_BACKEND}
    ${Tensile_MERGE_FILES}
    ${Tensile_SHORT_NAMES}
    ${Tensile_PRINT_DEBUG}
    Tensile_ROOT ${Tensile_ROOT} # optional; use if tensile not installed
)
target_link_libraries( TARGET Tensile )
```

TODO: Where is the Tensile include directory?

### 2.9.11.12 Versioning


- **Major**: Tensile increments the major version if the public API changes, or if either the benchmark.yaml or library-config.yaml files change format in a non-backwards-compatible manner.
- **Minor**: Tensile increments the minor version when new kernel, solution or benchmarking features are introduced in a backwards-compatible manner.
- **Patch**: Bug fixes or minor improvements.

### 2.9.12 rocThrust

HIP back-end for Thrust(alpha release)
2.9.12.1 Introduction

Thrust is a parallel algorithm library. This library has been ported to HIP/ROCm platform, which uses the rocPRIM library. The HIP ported library works on HIP/ROCm platforms. Currently there is no CUDA backend in place.

2.9.12.2 Requirements

Software

- Git
- CMake (3.5.1 or later)
- AMD ROCm platform (1.8.0 or later)
  - Including HCC compiler, which must be set as C++ compiler on ROCm platform.
- rocPRIM library
  - It will be automatically downloaded and built by CMake script.

Optional:

- GTest
  - Required only for tests. Building tests is enabled by default.
  - It will be automatically downloaded and built by CMake script.

2.9.12.3 Hardware

Visit the following link for ROCm hardware requirements:

2.9.12.4 Build And Install

For build and install:

```
git clone https://github.com/ROCmSoftwarePlatform/rocThrust

cd rocThrust; mkdir build; cd build

# Go to rocThrust directory, create and go to the build directory.  
# Configure rocThrust, setup options for your system.  
# Build options:  
#   BUILD_TEST - ON by default,  
#   ! IMPORTANT !  
# On ROCm platform set C++ compiler to HCC. You can do it by adding 'CXX=<path-to-hcc>  
# before 'cmake' or setting cmake option 'CMAKE_CXX_COMPILER' with the path to the HCC compiler.  
# [CXX=hcc] cmake ../. # or cmake-gui ../.  
# Build  
make -j4  
# Optionally, run tests if they're enabled.  
ctest --output-on-failure
```

(continues on next page)
2.9.12.5 Using rocThrust In A Project

Recommended way of including rocThrust into a CMake project **is** by using its package configuration files.

```bash
# On ROCm rocThrust requires rocPRIM
find_package(rocprim REQUIRED CONFIG PATHS "/opt/rocm/rocprim")

# "/opt/rocm" - default install prefix
find_package(rocthrust REQUIRED CONFIG PATHS "/opt/rocm/rocthrust")
```

... includes rocThrust headers and roc::rocprim_hip target
target_link_libraries(<your_target> rocthrust)

2.9.12.6 Running Unit Tests

```bash
# Go to rocThrust build directory
cd rocThrust; cd build

# To run all tests
cctest

# To run unit tests for rocThrust
./test/<unit-test-name>
```

2.9.12.7 Documentation

Documentation is available [here](#).

2.9.12.8 Support

Bugs and feature requests can be reported through the [issue tracker](#).

2.9.13 hipCUB

hipCUB is a thin wrapper library on top of rocPRIM or CUB. It enables developers to port project using CUB library to the HIP layer and to run them on AMD hardware. In ROCm environment hipCUB uses rocPRIM library as the backend, however, on CUDA platforms it uses CUB instead.
2.9.13.1 Requirements

- Git
- CMake (3.5.1 or later)
- For AMD GPUs:
  - **AMD ROCm platform (1.8.0 or later)**
    - Including HCC compiler, which must be set as C++ compiler on ROCm platform.
  - **rocPRIM library**
    - It will be automatically downloaded and built by CMake script.
- For NVIDIA GPUs:
  - CUDA Toolkit
  - CUB library (automatically downloaded and by CMake script)

Optional:
- **GTest**
  - Required only for tests. Building tests is enabled by default.
  - It will be automatically downloaded and built by CMake script.

2.9.13.2 Build And Install

```
git clone https://github.com/ROCmSoftwarePlatform/hipCUB.git

# Go to hipCUB directory, create and go to the build directory.
cd hipCUB; mkdir build; cd build

# Configure hipCUB, setup options for your system.
# Build options:
# BUILD_TEST - ON by default,
# ! IMPORTANT !
# On ROCm platform set C++ compiler to HCC. You can do it by adding 'CXX=<path-to-hcc>'
# before 'cmake' or setting cmake option 'CMAKE_CXX_COMPILER' to path to the HCC compiler.
# [CXX=hcc] cmake ../. # or cmake-gui ../. 

# Build
make -j4

# Optionally, run tests if they're enabled.
cmake --output-on-failure

# Package
make package

# Install
[sudo] make install
```
2.9.13.3 Using hipCUB In A Project

Recommended way of including hipCUB into a CMake project is by using its package configuration files.

```bash
# On ROCm hipCUB requires rocPRIM
find_package(rocprim REQUIRED CONFIG PATHS "/opt/rocm/rocprim")

# "/opt/rocm" - default install prefix
find_package(hipcub REQUIRED CONFIG PATHS "/opt/rocm/hipcub")

...  
# On ROCm: includes hipCUB headers and roc::rocprim_hip target
# On CUDA: includes only hipCUB headers, user has to include CUB directory
target_link_libraries(<your_target> hip::hipcub)
```

Include only the main header file:

```bash
#include <hipcub/hipcub.hpp>
```

CUB or rocPRIM headers are included by hipCUB depending on the current HIP platform.

2.9.13.4 Running Unit Tests

```bash
# Go to hipCUB build directory
cd hipCUB; cd build

# To run all tests
ctest

# To run unit tests for hipCUB
./test/hipcub/<unit-test-name>
```

2.9.13.5 Documentation

```bash
# go to hipCUB doc directory
cd hipCUB; cd doc

# run doxygen
doxxygen Doxyfile

# open html/index.html
```

2.9.13.6 Support

Bugs and feature requests can be reported through the issue tracker.

2.9.13.7 Contributions and License

Contributions of any kind are most welcome! More details are found at CONTRIBUTING and LICENSE.
2.9.14 ROCm SMI library

The ROCm System Management Interface Library, or ROCm SMI library, is part of the Radeon Open Compute ROCm software stack. It is a C library for Linux that provides a user space interface for applications to monitor and control GPU applications.

2.9.14.1 Important note about Versioning and Backward Compatibility

The ROCm SMI library is currently under development, and therefore subject to change either at the ABI or API level. The intention is to keep the API as stable as possible even while in development, but in some cases we may need to break backwards compatibility in order to ensure future stability and usability. Following Semantic Versioning rules, while the ROCm SMI library is in high state of change, the major version will remain 0, and backward compatibility is not ensured.

Once new development has leveled off, the major version will become greater than 0, and backward compatibility will be enforced between major versions.

2.9.14.2 Building ROCm SMI

2.9.14.2.1 Additional Required software for building

In order to build the ROCm SMI library, the following components are required. Note that the software versions listed are what was used in development. Earlier versions are not guaranteed to work:

- CMake (v3.5.0)
- g++ (5.4.0)

In order to build the latest documentation, the following are required:

- DOxygen (1.8.11)
- latex (pdfTeX 3.14159265-2.6-1.40.16)

The source code for ROCm SMI is available on Github.

After the ROCm SMI library git repository has been cloned to a local Linux machine, building the library is achieved by following the typical CMake build sequence. Specifically,

```
$ mk -p build
$ cd build
$ cmake <location of root of ROCm SMI library CMakeLists.txt>
$ make
```

The built library will appear in the build folder.

2.9.14.3 Building the Documentation

The documentation PDF file can be built with the following steps (continued from the steps above):

```
$ make doc
$ cd latex
$ make
```

The reference manual, refman.pdf will be in the latex directory upon a successful build.
### 2.9.14.4 Building the Tests

In order to verify the build and capability of ROCm SMI on your system and to see an example of how ROCm SMI can be used, you may build and run the tests that are available in the repo. To build the tests, follow these steps:

```bash
# Set environment variables used in CMakeLists.txt file
$ ROCM_DIR=<location of ROCm SMI library>
$ mkdir <location for test build>
$ cd <location for test build>
$ cmake -DROCM_DIR=<location of ROCm SMI library .so> <ROCm SMI source root>/tests/rocm_smi_test
```

To run the test, execute the program rsmitst that is built from the steps above. Make sure ROCm SMI library is in your library search path when executing the test program.

### 2.9.14.5 Usage Basics

#### 2.9.14.5.1 Device Indices

Many of the functions in the library take a “device index”. The device index is a number greater than or equal to 0, and less than the number of devices detected, as determined by `rsmi_num_monitor_devices()`. The index is used to distinguish the detected devices from one another. It is important to note that a device may end up with a different index after a reboot, so an index should not be relied upon to be constant over reboots.

#### 2.9.14.5.2 Hello ROCm SMI

The only required ROCm-SMI call for any program that wants to use ROCm-SMI is the `rsmi_init()` call. This call initializes some internal data structures that will be used by subsequent ROCm-SMI calls.

When ROCm-SMI is no longer being used, `rsmi_shut_down()` should be called. This provides a way to do any releasing of resources that ROCm-SMI may have held. In many cases, this may have no effect, but may be necessary in future versions of the library.

A simple “Hello World” type program that displays the device ID of detected devices would look like this:

```c
#include <stdint.h>
#include "rocm_smi/rocm_smi.h"
int main() {
    rsmi_status_t ret;
    uint32_t num_devices;
    uint64_t dev_id;
    // We will skip return code checks for this example, but it
    // is recommended to always check this as some calls may not
    // apply for some devices or ROCm releases
    ret = rsmi_init(0);
    ret = rsmi_num_monitor_devices(&num_devices);
    for (int i=0; i < num_devices; ++i) {
        ret = rsmi_dev_id_get(i, &dev_id);
        // dev_id holds the device ID of device i, upon a
        // successful call
    }
    ret = rsmi_shut_down();
}
```

(continues on next page)
2.9.15 RCCL

ROCM Communication Collectives Library

2.9.15.1 Introduction

RCCL (pronounced “Rickle”) is a stand-alone library of standard collective communication routines for GPUs, implementing all-reduce, all-gather, reduce, broadcast, and reduce-scatter. It has been optimized to achieve high bandwidth on platforms using PCIe, xGMI as well as networking using InfiniBand Verbs or TCP/IP sockets. RCCL supports an arbitrary number of GPUs installed in a single node, and can be used in either single- or multi-process (e.g., MPI) applications. Multi node support is planned for a future release.

The collective operations are implemented using ring algorithms and have been optimized for throughput and latency. For best performance, small operations can be either batched into larger operations or aggregated through the API.

2.9.15.2 Requirements

- ROCm supported GPUs
- ROCm stack installed on the system (HIP runtime & HCC)
- For building and running the unit tests, chrpath will need to be installed on your machine first. (sudo apt-get install chrpath)

2.9.15.3 Quickstart RCCL Build

RCCL directly depends on HIP runtime & HCC C++ compiler which are part of the ROCm software stack. In addition, HC Direct Function call support needs to be present on your machine. There are binaries for hcc and HIP that need to be installed to get HC Direct Function call support. These binaries are currently packaged with roc-master, and will be included in ROCm 2.4.

The root of this repository has a helper script ‘install.sh’ to build and install RCCL on Ubuntu with a single command. It does not take a lot of options and hard-codes configuration that can be specified through invoking cmake directly, but it’s a great way to get started quickly and can serve as an example of how to build/install.

- ./install.sh – builds library including unit tests
- ./install.sh -i – builds and installs the library to /opt/rocm/rccl; installation path can be changed with --prefix argument (see below.)
- ./install.sh -h – shows help
- ./install.sh -t – builds library including unit tests
- ./install.sh -r – runs unit tests (must be already built)
- ./install.sh -p – builds RCCL package
- ./install.sh --prefix – specify custom path to install RCCL to (default:/opt/rocm)
2.9.15.4 Manual build

2.9.15.4.1 To build the library:

```bash
$ git clone https://github.com/ROCmSoftwarePlatform/rccl.git
$ cd rccl
$ mkdir build
$ cd build
$ CXX=/opt/rocm/bin/hcc cmake -DCMAKE_INSTALL_PREFIX=$PWD/rccl-install ..
$ make -j 8
```

You may substitute a path of your own choosing for CMAKE_INSTALL_PREFIX. Note: ensure rocm-cmake is installed,

```bash
apt install rocm-cmake.
```

2.9.15.5 To build the RCCL package and install package:

Assuming you have already cloned this repository and built the library as shown in the previous section:

```bash
$ cd rccl/build
$ make package
$ sudo dpkg -i *.deb
```

RCCL package install requires sudo/root access because it creates a directory called “rccl” under /opt/rocm/. This is an optional step and RCCL can be used directly by including the path containing librccl.so.

2.9.15.6 Tests

There are unit tests implemented with the Googletest framework in RCCL, which are currently a work-in-progress. To invoke the unit tests, go to the rccl-install folder, then the test/ subfolder, and execute the appropriate unit test executable(s). Several notes for running the unit tests:

- The LD_LIBRARY_PATH environment variable will need to be set to include /path/to/rccl-install/lib/ in order to run the unit tests.
- The HSA_FORCE_FINE_GRAIN_PCIE environment variable will need to be set to 1 in order to run the unit tests.

An example call to the unit tests:

```bash
$ LD_LIBRARY_PATH=rccl-install/lib/ HSA_FORCE_FINE_GRAIN_PCIE=1 rccl-install/test/
˓
→ UnitTests
```

There are also other performance and error-checking tests for RCCL. These are maintained separately here. See the rccl-tests README for more information on how to build and run those tests.

2.9.15.7 Library and API Documentation

Please refer to the Library documentation for current documentation.
2.9.16 rocALUTION

2.9.16.1 Introduction

2.9.16.2 Overview

rocALUTION is a sparse linear algebra library with focus on exploring fine-grained parallelism, targeting modern processors and accelerators including multi/many-core CPU and GPU platforms. The main goal of this package is to provide a portable library for iterative sparse methods on state of the art hardware. rocALUTION can be seen as middle-ware between different parallel backends and application specific packages.

The major features and characteristics of the library are

- **Various backends**
  - Host - fallback backend, designed for CPUs
  - GPU/HIP - accelerator backend, designed for HIP capable AMD GPUs
  - OpenMP - designed for multi-core CPUs
  - MPI - designed for multi-node and multi-GPU configurations

- **Easy to use** The syntax and structure of the library provide easy learning curves. With the help of the examples, anyone can try out the library - no knowledge in HIP, OpenMP or MPI programming required.

- **No special hardware requirements** There are no hardware requirements to install and run rocALUTION. If a GPU device and HIP is available, the library will use them.

- **Variety of iterative solvers**
  - Fixed-Point iteration - Jacobi, Gauss-Seidel, Symmetric-Gauss-Seidel, SOR and SSOR
  - Krylov subspace methods - CR, CG, BiCGStab, BiCGStab(l), GMRES, IDR, QMRCGSTAB, Flexible CG/GMRES
  - Mixed-precision defect-correction scheme
  - Chebyshev iteration
  - Multiple MultiGrid schemes, geometric and algebraic

- **Various preconditioners**
  - Matrix splitting - Jacobi, (Multi-colored) Gauss-Seidel, Symmetric Gauss-Seidel, SOR, SSOR
  - Factorization - ILU(0), ILU(p) (based on levels), ILU(p,q) (power(q)-pattern method), Multi-Elimination ILU (nested/recursive), ILUT (based on threshold) and IC(0)
  - Approximate Inverse - Chebyshev matrix-valued polynomial, SPAI, FSAI and TNS
  - Diagonal-based preconditioner for Saddle-point problems
  - Block-type of sub-preconditioners/solvers
  - Additive Schwarz and Restricted Additive Schwarz
- Variable type preconditioners

- **Generic and robust design** rocALUTION is based on a generic and robust design allowing expansion in the direction of new solvers and preconditioners and support for various hardware types. Furthermore, the design of the library allows the use of all solvers as preconditioners in other solvers. For example you can easily define a CG solver with a Multi-Elimination preconditioner, where the last-block is preconditioned with another Chebyshev iteration method which is preconditioned with a multi-colored Symmetric Gauss-Seidel scheme.

- **Portable code and results** All code based on rocALUTION is portable and independent of HIP or OpenMP. The code will compile and run everywhere. All solvers and preconditioners are based on a single source code, which delivers portable results across all supported backends (variations are possible due to different rounding modes on the hardware). The only difference which you can see for a hardware change is the performance variation.

- **Support for several sparse matrix formats** Compressed Sparse Row (CSR), Modified Compressed Sparse Row (MCSR), Dense (DENSE), Coordinate (COO), ELL, Diagonal (DIA), Hybrid format of ELL and COO (HYB).

The code is open-source under MIT license and hosted on here: https://github.com/ROCmSoftwarePlatform/rocALUTION

### 2.9.16.3 Building and Installing

### 2.9.16.4 Installing from AMD ROCm repositories

TODO, not yet available

### 2.9.16.5 Building rocALUTION from Open-Source repository

### 2.9.16.6 Download rocALUTION

The rocALUTION source code is available at the rocALUTION github page. Download the master branch using:

```bash
git clone -b master https://github.com/ROCmSoftwarePlatform/rocALUTION.git
cd rocALUTION
```

Note that if you want to contribute to rocALUTION, you will need to checkout the develop branch instead of the master branch. See rocalution_contributing for further details. Below are steps to build different packages of the library, including dependencies and clients. It is recommended to install rocALUTION using the `install.sh` script.

### 2.9.16.7 Using `install.sh` to build dependencies + library

The following table lists common uses of `install.sh` to build dependencies + library. Accelerator support via HIP and OpenMP will be enabled by default, whereas MPI is disabled.
### 2.9.16.8 Using `install.sh` to build dependencies + library + client

The client contains example code, unit tests and benchmarks. Common uses of `install.sh` to build them are listed in the table below.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>./install.sh -h</td>
<td>Print help information.</td>
</tr>
<tr>
<td>./install.sh -dc</td>
<td>Build dependencies, library and client in your local directory. The <code>-d</code> flag only needs to be used once. For subsequent invocations of <code>install.sh</code> it is not necessary to rebuild the dependencies.</td>
</tr>
<tr>
<td>./install.sh -c</td>
<td>Build library and client in your local directory. It is assumed dependencies are available.</td>
</tr>
<tr>
<td>./install.sh -idc</td>
<td>Build library, dependencies and client, then build and install rocALUTION package in <code>/opt/rocm/rocalution</code>. You will be prompted for sudo access. This will install for all users.</td>
</tr>
<tr>
<td>./install.sh -ic</td>
<td>Build library and client, then build and install rocALUTION package in <code>/opt/rocm/rocalution</code>. You will be prompted for sudo access. This will install for all users.</td>
</tr>
</tbody>
</table>

### 2.9.16.9 Using individual commands to build rocALUTION

CMake 3.5 or later is required in order to build rocALUTION.

rocALUTION can be built with cmake using the following commands:

```bash
# Create and change to build directory
mkdir -p build/release ; cd build/release
```

(continues on next page)
# Default install path is /opt/rocm, use -DCMAKE_INSTALL_PREFIX=<path> to adjust it

cmake ../.. -DSUPPORT_HIP=ON \
   -DSUPPORT_MPI=OFF \
   -DSUPPORT_OMP=ON

# Compile rocALUTION library
make -j$(nproc)

# Install rocALUTION to /opt/rocm
sudo make install

GoogleTest is required in order to build rocALUTION client.

rocALUTION with dependencies and client can be built using the following commands:

```
# Install googletest
mkdir -p build/release/deps ; cd build/release/deps
cmake ../../../deps
sudo make -j$(nproc) install

# Change to build directory
cd ..

# Default install path is /opt/rocm, use -DCMAKE_INSTALL_PREFIX=<path> to adjust it

cmake ../.. -DBUILD_CLIENTS_TESTS=ON \
   -DBUILD_CLIENTS_SAMPLES=ON

# Compile rocALUTION library
make -j$(nproc)

# Install rocALUTION to /opt/rocm
sudo make install
```

The compilation process produces a shared library file liberoalution.so and liberoalution_hip.so if HIP support is enabled. Ensure that the library objects can be found in your library path. If you do not copy the library to a specific location you can add the path under Linux in the LD_LIBRARY_PATH variable.

```
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:<path_to_rocalution>
```

## 2.9.16.10 Common build problems

1. **Issue:** HIP (/opt/rocm/hip) was built using hcc 1.0.xxx-xxx-xxx-xxx, but you are using /opt/rocm/bin/hcc with version 1.0.yyy-yyyy-yyyy-yyyy from hipcc (version mismatch). Please rebuild HIP including cmake or update HCC_HOME variable.

   **Solution:** Download HIP from github and use hcc to build from source and then use the built HIP instead of /opt/rocm/hip.

2. **Issue:** For Carrizo - HCC RUNTIME ERROR: Failed to find compatible kernel

   **Solution:** Add the following to the cmake command when configuring: `-DCMAKE_CXX_FLAGS="-amdgpu-target=gfx801"

3. **Issue:** For MI25 (Vega10 Server) - HCC RUNTIME ERROR: Failed to find compatible kernel

   **Solution:** export HCC_AMDGPU_TARGET=gfx900
4. Issue: Could not find a package configuration file provided by “ROCM” with any of the following names:
   ROCMConfig.cmake |br|
   rocm-config.cmake
   
   **Solution:** Install ROCm cmake modules

5. Issue: Could not find a package configuration file provided by “ROCSPARSE” with any of the following names:
   ROCSPARSE.cmake |br|
   rocsparse-config.cmake
   
   **Solution:** Install rocSPARSE

6. Issue: Could not find a package configuration file provided by “ROCBLAS” with any of the following names:
   ROCBLAS.cmake |br|
   rocblas-config.cmake
   
   **Solution:** Install rocBLAS

### 2.9.16.11 Simple Test

You can test the installation by running a CG solver on a Laplace matrix. After compiling the library you can perform the CG solver test by executing

```bash
cd rocALUTION/build/release/examples
gzip -d gr_30_30.mtx.gz
./cg gr_30_30.mtx
```

For more information regarding rocALUTION library and corresponding API documentation, refer rocALUTION 2.9.16.12 API

### 2.9.16.12 API

This section provides details of the library API

#### 2.9.16.12.1 Host Utility Functions

**template<typename **DataType**>**

```cpp
void rocALUTION::**allocate_host**(int **size**, **DataType** **ptr**)  
Allocate buffer on the host.
```

allocate_host allocates a buffer on the host.

**Parameters**

- **[in]** **size**: number of elements the buffer need to be allocated for
- **[out]** **ptr**: pointer to the position in memory where the buffer should be allocated, it is expected that *ptr == NULL

**Template Parameters**

- **DataType**: can be char, int, unsigned int, float, double, std::complex<float> or std::complex<double>.

```cpp
void rocALUTION::**free_host**(**DataType** **ptr**)  
Free buffer on the host.
```

free_host deallocates a buffer on the host. *ptr will be set to NULL after successful deallocation.
Parameters

- [inout] `ptr`: pointer to the position in memory where the buffer should be deallocated, it is expected that `*ptr != NULL`

Template Parameters

- `DataType`: can be char, int, unsigned int, float, double, std::complex<float> or std::complex<double>.

template<typename `DataType`>
void rocalution::set_to_zero_host (int `size`, `DataType` *`ptr`)  
  Set a host buffer to zero.

  `set_to_zero_host` sets a host buffer to zero.

Parameters

- [in] `size`: number of elements
- [inout] `ptr`: pointer to the host buffer

Template Parameters

- `DataType`: can be char, int, unsigned int, float, double, std::complex<float> or std::complex<double>.

double rocalution::rocalution_time (void)  
  Return current time in microseconds.

2.9.16.12.2 Backend Manager

int rocalution::init_rocalution (int `rank` = -1, int `dev_per_node` = 1)  
  Initialize rocALUTION platform.

  `init_rocalution` defines a backend descriptor with information about the hardware and its specifications. All objects created after that contain a copy of this descriptor. If the specifications of the global descriptor are changed (e.g. set different number of threads) and new objects are created, only the new objects will use the new configurations.

  For control, the library provides the following functions

  - `set_device_rocalution()` is a unified function to select a specific device. If you have compiled the library with a backend and for this backend there are several available devices, you can use this function to select a particular one. This function has to be called before `init_rocalution()`.

  - `set_omp_threads_rocalution()` sets the number of OpenMP threads. This function has to be called after `init_rocalution()`.

Example

```c++
#include <rocalution.hpp>

using namespace rocalution;

int main(int argc, char* argv[])  
{  
   init_rocalution();
}
```
Parameters

- [in] rank: specifies MPI rank when multi-node environment
- [in] dev_per_node: number of accelerator devices per node, when in multi-GPU environment

```cpp
// ...
stop_rocalution();
return 0;
```

int rocalution::stop_rocalution (void)
Shutdown rocALUTION platform.

stop_rocalution shuts down the rocALUTION platform.

void rocalution::set_device_rocalution (int dev)
Set the accelerator device.

set_device_rocalution lets the user select the accelerator device that is supposed to be used for the computation.

Parameters

- [in] dev: accelerator device ID for computation

void rocalution::set_omp_threads_rocalution (int nthreads)
Set number of OpenMP threads.

The number of threads which rocALUTION will use can be set with set_omp_threads_rocalution or by the global OpenMP environment variable (for Unix-like OS this is OMP_NUM_THREADS). During the initialization phase, the library provides affinity thread-core mapping:

- If the number of cores (including SMT cores) is greater or equal than two times the number of threads, then all the threads can occupy every second core ID (e.g. 0, 2, 4, \ldots). This is to avoid having two threads working on the same physical core, when SMT is enabled.
- If the number of threads is less or equal to the number of cores (including SMT), and the previous clause is false, then the threads can occupy every core ID (e.g. 0, 1, 2, 3, \ldots).
- If non of the above criteria is matched, then the default thread-core mapping is used (typically set by the OS).

Note The thread-core mapping is available only for Unix-like OS.

Note The user can disable the thread affinity by calling set_omp_affinity_rocalution(), before initializing the library (i.e. before init_rocalution()).

Parameters

- [in] nthreads: number of OpenMP threads

void rocalution::set_omp_affinity_rocalution (bool affinity)
Enable/disable OpenMP host affinity.

set_omp_affinity_rocalution enables / disables OpenMP host affinity.

Parameters
• [in] affinity: boolean to turn on/off OpenMP host affinity

```cpp
void rocalution::set_omp_threshold_rocalution(int threshold)
```

Set OpenMP threshold size.

Whenever you want to work on a small problem, you might observe that the OpenMP host backend is (slightly) slower than using no OpenMP. This is mainly attributed to the small amount of work, which every thread should perform and the large overhead of forking/joining threads. This can be avoid by the OpenMP threshold size parameter in rocALUTION. The default threshold is set to 10000, which means that all matrices under (and equal) this size will use only one thread (disregarding the number of OpenMP threads set in the system). The threshold can be modified with `set_omp_threshold_rocalution`.

**Parameters**

- [in] threshold: OpenMP threshold size

```cpp
void rocalution::info_rocalution(void)
```

Print info about rocALUTION.

`info_rocalution` prints information about the rocALUTION platform

```cpp
void rocalution::info_rocalution(const struct Rocalution_Backend_Descriptor backend_descriptor)
```

Print info about specific rocALUTION backend descriptor.

`info_rocalution` prints information about the rocALUTION platform of the specific backend descriptor.

**Parameters**

- [in] backend_descriptor: rocALUTION backend descriptor

```cpp
void rocalution::disable_accelerator_rocalution(bool onoff = true)
```

Disable/Enable the accelerator.

If you want to disable the accelerator (without re-compiling the code), you need to call `disable_accelerator_rocalution` before `init_rocalution()`.

**Parameters**

- [in] onoff: boolean to turn on/off the accelerator

```cpp
void rocalution::_rocalution_sync(void)
```

Sync rocALUTION.

 `_rocalution_sync` blocks the host until all active asynchronous transfers are completed.

### 2.9.16.12.3 Base Rocalution

```cpp
template<typename ValueType>
class BaseRocalution : public rocalution::RocalutionObj
```

Base class for all operators and vectors.

**Template Parameters**

- `ValueType`: can be int, float, double, std::complex<float> and std::complex<double>

Subclassed by `rocalution::Operator< ValueType >, rocalution::Vector< ValueType >`
virtual void rocalution::BaseRocalution::MoveToAccelerator (void) = 0
Move the object to the accelerator backend.

virtual void rocalution::BaseRocalution::MoveToHost (void) = 0
Move the object to the host backend.

void rocalution::BaseRocalution::MoveToAcceleratorAsync (void)
Move the object to the accelerator backend with async move.

void rocalution::BaseRocalution::MoveToHostAsync (void)
Move the object to the host backend with async move.

void rocalution::BaseRocalution::Sync (void)
Sync (the async move)

void rocalution::BaseRocalution::CloneBackend (const BaseRocalution<ValueType> & src)
Clone the Backend descriptor from another object.

With CloneBackend, the backend can be cloned without copying any data. This is especially useful, if several objects should reside on the same backend, but keep their original data.

Example

LocalVector<ValueType> vec;
LocalMatrix<ValueType> mat;

// Allocate and initialize vec and mat
// ...

LocalVector<ValueType> tmp;
// By cloning backend, tmp and vec will have the same backend as mat
tmp.CloneBackend(mat);
vec.CloneBackend(mat);

// The following matrix vector multiplication will be performed on the backend
// selected in mat
mat.Apply(vec, &tmp);

Parameters
• [in] src: Object, where the backend should be cloned from.

virtual void rocalution::BaseRocalution::Info (void) const = 0
Print object information.

Info can print object information about any rocALUTION object. This information consists of object properties and backend data.

Example

mat.Info();
vec.Info();

virtual void rocalution::BaseRocalution::Clear (void) = 0
Clear (free all data) the object.
2.9.16.12.4 Operator

template<
  typename ValueType
>
class Operator : public rocalution::BaseRocalution<ValueType>
{

  // The Operator class defines the generic interface for applying an operator (e.g. matrix or stencil) from/to global and local vectors.

  // Template Parameters
  
  // • ValueType: - can be int, float, double, std::complex<float> and std::complex<double>

  // Subclassed by rocalution::GlobalMatrix<ValueType>, rocalution::LocalMatrix<ValueType>, rocalution::LocalStencil<ValueType>

  // virtual IndexType2 rocalution::Operator::GetM (void) const = 0
  // Return the number of rows in the matrix/stencil.

  // virtual IndexType2 rocalution::Operator::GetN (void) const = 0
  // Return the number of columns in the matrix/stencil.

  // virtual IndexType2 rocalution::Operator::GetNnz (void) const = 0
  // Return the number of non-zeros in the matrix/stencil.

  // int rocalution::Operator::GetLocalM (void) const
  // Return the number of rows in the local matrix/stencil.

  // int rocalution::Operator::GetLocalN (void) const
  // Return the number of columns in the local matrix/stencil.

  // int rocalution::Operator::GetLocalNnz (void) const
  // Return the number of non-zeros in the local matrix/stencil.

  // int rocalution::Operator::GetGhostM (void) const
  // Return the number of rows in the ghost matrix/stencil.

  // int rocalution::Operator::GetGhostN (void) const
  // Return the number of columns in the ghost matrix/stencil.

  // int rocalution::Operator::GetGhostNnz (void) const
  // Return the number of non-zeros in the ghost matrix/stencil.

  // void rocalution::Operator::Apply (const LocalVector<ValueType> &in, LocalVector<ValueType> *out) const
  // Apply the operator, out = Operator(in), where in and out are local vectors.

  // void rocalution::Operator::ApplyAdd (const LocalVector<ValueType> &in, ValueType scalar, LocalVector<ValueType> *out) const
  // Apply and add the operator, out += scalar * Operator(in), where in and out are local vectors.

  // void rocalution::Operator::Apply (const GlobalVector<ValueType> &in, GlobalVector<ValueType> *out) const
  // Apply the operator, out = Operator(in), where in and out are global vectors.

  // void rocalution::Operator::ApplyAdd (const GlobalVector<ValueType> &in, ValueType scalar, GlobalVector<ValueType> *out) const
  // Apply and add the operator, out += scalar * Operator(in), where in and out are global vectors.
2.9.16.12.5 Vector

template<typename ValueType>
class Vector : public rocalution::BaseRocalution<ValueType>
Vector class.

The Vector class defines the generic interface for local and global vectors.

Template Parameters

- ValueType: - can be int, float, double, std::complex<float> and std::complex<double>

Subclassed by rocalution::LocalVector<int>, rocalution::GlobalVector<ValueType>, rocalution::LocalVector<ValueType>

virtual IndexType2 rocalution::Vector::GetSize (void) const = 0
Return the size of the vector.

int rocalution::Vector::GetLocalSize (void) const
Return the size of the local vector.

int rocalution::Vector::GetGhostSize (void) const
Return the size of the ghost vector.

virtual bool rocalution::Vector::Check (void) const = 0
Perform a sanity check of the vector.
Checks, if the vector contains valid data, i.e. if the values are not infinity and not NaN (not a number).

Return Value

- true: if the vector is ok (empty vector is also ok).
- false: if there is something wrong with the values.

virtual void rocalution::Vector::Zeros (void) = 0
Set all values of the vector to 0.

virtual void rocalution::Vector::Ones (void) = 0
Set all values of the vector to 1.

virtual void rocalution::Vector::SetValues (ValueType val) = 0
Set all values of the vector to given argument.

virtual void rocalution::Vector::SetRandomUniform (unsigned long long seed, ValueType a = static_cast<ValueType>(-1), ValueType b = static_cast<ValueType>(1)) = 0
Fill the vector with random values from interval [a,b].

virtual void rocalution::Vector::SetRandomNormal (unsigned long long seed, ValueType mean = static_cast<ValueType>(0), ValueType var = static_cast<ValueType>(1)) = 0
Fill the vector with random values from normal distribution.

virtual void rocalution::Vector::ReadFileASCII (const std::string filename) = 0
Read vector from ASCII file.
Read a vector from ASCII file.

Example
LocalVector<ValueType> vec;
vec.ReadFileASCII("my_vector.dat");

Parameters
• [in] filename: name of the file containing the ASCII data.

virtual void rocalution::Vector::WriteFileASCII(const std::string filename) const = 0
Write vector to ASCII file.

Example
LocalVector<ValueType> vec;
// Allocate and fill vec
// ...
vec.WriteFileASCII("my_vector.dat");

Parameters
• [in] filename: name of the file to write the ASCII data to.

virtual void rocalution::Vector::ReadFileBinary(const std::string filename) = 0
Read vector from binary file.

Example
LocalVector<ValueType> vec;
vec.ReadFileBinary("my_vector.bin");

Parameters
• [in] filename: name of the file containing the data.

virtual void rocalution::Vector::WriteFileBinary(const std::string filename) const = 0
Write vector to binary file.

Write a vector to binary file.

The binary format contains a header, the rocALUTION version and the vector data as follows

// Header
out << "#rocALUTION binary vector file" << std::endl;

// rocALUTION version
out.write((char*)&version, sizeof(int));

// Vector data
out.write((char*)vec_val, size * sizeof(double));

Note Vector values array is always stored in double precision (e.g. double or std::complex<double>).

Example
LocalVector<ValueType> vec;
// Allocate and fill vec
// ...
vec.WriteFileBinary("my_vector.bin");

Parameters

- [in] filename: name of the file to write the data to.

```cpp
void rocalution::Vector::CopyFrom(const LocalVector<ValueType> &src)
    Copy vector from another vector.
```

CopyFrom copies values from another vector.

**Note** This function allows cross platform copying. One of the objects could be allocated on the accelerator backend.

**Example**

```cpp
LocalVector<ValueType> vec1, vec2;
// Allocate and initialize vec1 and vec2
// ...

// Move vec1 to accelerator
// vec1.MoveToAccelerator();

// Now, vec1 is on the accelerator (if available)
// and vec2 is on the host

// Copy vec1 to vec2 (or vice versa) will move data between host and
// accelerator backend
vec1.CopyFrom(vec2);
```

Parameters

- [in] src: `Vector`, where values should be copied from.

```cpp
void rocalution::Vector::CopyFrom(const GlobalVector<ValueType> &src)
    Copy vector from another vector.
```

CopyFrom copies values from another vector.

**Note** This function allows cross platform copying. One of the objects could be allocated on the accelerator backend.

**Example**

```cpp
LocalVector<ValueType> vec1, vec2;
// Allocate and initialize vec1 and vec2
// ...

// Move vec1 to accelerator
// vec1.MoveToAccelerator();

(continues on next page)```
// Now, vec1 is on the accelerator (if available)
// and vec2 is on the host

// Copy vec1 to vec2 (or vice versa) will move data between host and
// accelerator backend
vec1.CopyFrom(vec2);

Parameters

- [in] src: Vector, where values should be copied from.

void rocalution::Vector::CopyFromAsync(const LocalVector<ValueType> &src)
Async copy from another local vector.

void rocalution::Vector::CopyFromFloat(const LocalVector<float> &src)
Copy values from another local float vector.

void rocalution::Vector::CopyFromDouble(const LocalVector<double> &src)
Copy values from another local double vector.

void rocalution::Vector::CopyFrom(const LocalVector<ValueType> &src,
                               int src_offset,
                               int dst_offset,
                               int size)
Copy vector from another vector with offsets and size.

CopyFrom copies values with specific source and destination offsets and sizes from another vector.

Note This function allows cross platform copying. One of the objects could be allocated on the accelerator backend.

Parameters

- [in] src: Vector, where values should be copied from.
- [in] size: number of entries to be copied.

void rocalution::Vector::CloneFrom(const LocalVector<ValueType> &src)
Clone the vector.

CloneFrom clones the entire vector, with data and backend descriptor from another Vector.

Example

LocalVector<ValueType> vec;

// Allocate and initialize vec (host or accelerator)
// ...

LocalVector<ValueType> tmp;

// By cloning vec, tmp will have identical values and will be on the same
// backend as vec
tmp.CloneFrom(vec);

Parameters

- [in] src: Vector to clone from.
void rocalution::Vector::CloneFrom(const GlobalVector<ValueType> &src)
  Clone the vector.

CloneFrom clones the entire vector, with data and backend descriptor from another Vector.

Example

```cpp
LocalVector<ValueType> vec;
// Allocate and initialize vec (host or accelerator)
// ...
LocalVector<ValueType> tmp;
// By cloning vec, tmp will have identical values and will be on the same backend as vec
tmp.CloneFrom(vec);
```

Parameters

- [in] src: Vector to clone from.

void rocalution::Vector::AddScale(const LocalVector<ValueType> &x, ValueType alpha)
  Perform vector update of type this = this + alpha * x.

void rocalution::Vector::AddScale(const GlobalVector<ValueType> &x, ValueType alpha)
  Perform vector update of type this = this + alpha * x.

void rocalution::Vector::ScaleAdd(ValueType alpha, const LocalVector<ValueType> &x)
  Perform vector update of type this = alpha * this + x.

void rocalution::Vector::ScaleAdd(ValueType alpha, const GlobalVector<ValueType> &x)
  Perform vector update of type this = alpha * this + x.

void rocalution::Vector::ScaleAddScale(ValueType alpha, const LocalVector<ValueType> &x, ValueType beta)
  Perform vector update of type this = alpha * this + x * beta.

void rocalution::Vector::ScaleAddScale(ValueType alpha, const GlobalVector<ValueType> &x, ValueType beta)
  Perform vector update of type this = alpha * this + x * beta.

void rocalution::Vector::ScaleAddScale(ValueType alpha, const LocalVector<ValueType> &x, ValueType beta, int src_offset, int dst_offset, int size)
  Perform vector update of type this = alpha * this + x * beta with offsets.

void rocalution::Vector::ScaleAddScale(ValueType alpha, const GlobalVector<ValueType> &x, ValueType beta, int src_offset, int dst_offset, int size)
  Perform vector update of type this = alpha * this + x * beta with offsets.

void rocalution::Vector::ScaleAdd2 (ValueType alpha, const LocalVector<ValueType> &x, ValueType beta, const LocalVector<ValueType> &y, ValueType gamma)
  Perform vector update of type this = alpha * this + x * beta + y * gamma.

void rocalution::Vector::ScaleAdd2 (ValueType alpha, const GlobalVector<ValueType> &x, ValueType beta, const GlobalVector<ValueType> &y, ValueType gamma)
  Perform vector update of type this = alpha * this + x * beta + y * gamma.

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virtual void rocalution::Vector::Scale (ValueType alpha) = 0
Perform vector scaling this = alpha * this.

ValueType rocalution::Vector::Dot (const LocalVector<ValueType> &x) const
Compute dot (scalar) product, return this^T y.

ValueType rocalution::Vector::Dot (const GlobalVector<ValueType> &x) const
Compute dot (scalar) product, return this^T y.

ValueType rocalution::Vector::DotNonConj (const LocalVector<ValueType> &x) const
Compute non-conjugate dot (scalar) product, return this^T y.

ValueType rocalution::Vector::DotNonConj (const GlobalVector<ValueType> &x) const
Compute non-conjugate dot (scalar) product, return this^T y.

virtual ValueType rocalution::Vector::Norm (void) const = 0
Compute \( L_2 \) norm of the vector, return \( \sqrt{\text{this}^\text{T} \text{this}} \)

virtual ValueType rocalution::Vector::Reduce (void) const = 0
Reduce the vector.

virtual ValueType rocalution::Vector::Asum (void) const = 0
Compute the sum of absolute values of the vector, return \( \text{sum}(|\text{this}|) \)

void rocalution::Vector::PointWiseMult (const LocalVector<ValueType> &x)
Perform point-wise multiplication (element-wise) of this = this * x.

void rocalution::Vector::PointWiseMult (const GlobalVector<ValueType> &x)
Perform point-wise multiplication (element-wise) of this = this * x.

void rocalution::Vector::PointWiseMult (const LocalVector<ValueType> &x, const LocalVector<ValueType> &y)
Perform point-wise multiplication (element-wise) of this = x * y.

void rocalution::Vector::PointWiseMult (const GlobalVector<ValueType> &x, const GlobalVector<ValueType> &y)
Perform point-wise multiplication (element-wise) of this = x * y.

virtual void rocalution::Vector::Power (double power) = 0
Perform power operation to a vector.

2.9.16.12.6 Local Matrix

template<typename ValueType>
class LocalMatrix : public rocalution::Operator<ValueType>
LocalMatrix class.
A \textit{LocalMatrix} is called local, because it will always stay on a single system. The system can contain several CPUs via UMA or NUMA memory system or it can contain an accelerator.

Template Parameters
- \textit{ValueType}: - can be int, float, double, std::complex<float> and std::complex<double>

unsigned int rocalution::LocalMatrix::GetFormat (void) const
Return the matrix format id (see matrix_formats.hpp)
bool rocalution::LocalMatrix::Check (void) const
Perform a sanity check of the matrix.

Checks, if the matrix contains valid data, i.e. if the values are not infinity and not NaN (not a number) and if
the structure of the matrix is correct (e.g. indices cannot be negative, CSR and COO matrices have to be sorted,
etc.).

Return Value

- true: if the matrix is ok (empty matrix is also ok).
- false: if there is something wrong with the structure or values.

void rocalution::LocalMatrix::AllocateCSR (const std::string name, int nnz, int nrow, int ncol)
Allocate a local matrix with name and sizes.

The local matrix allocation functions require a name of the object (this is only for information purposes) and
corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending
on the matrix format, additional parameters are required.

Example

```cpp
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();
```

void rocalution::LocalMatrix::AllocateBCSR (void)
Allocate a local matrix with name and sizes.

The local matrix allocation functions require a name of the object (this is only for information purposes) and
corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending
on the matrix format, additional parameters are required.

Example

```cpp
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();
```

void rocalution::LocalMatrix::AllocateMCSR (const std::string name, int nnz, int nrow, int ncol)
Allocate a local matrix with name and sizes.

The local matrix allocation functions require a name of the object (this is only for information purposes) and
corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending
on the matrix format, additional parameters are required.

Example

```cpp
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();
```
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();

void rocalution::LocalMatrix::AllocateCOO(const std::string name, int nnz, int nrow, int ncol)
Allocate a local matrix with name and sizes.
The local matrix allocation functions require a name of the object (this is only for information purposes) and corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending on the matrix format, additional parameters are required.

Example

LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();

void rocalution::LocalMatrix::AllocateDIA(const std::string name, int nnz, int nrow, int ncol, int ndiag)
Allocate a local matrix with name and sizes.
The local matrix allocation functions require a name of the object (this is only for information purposes) and corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending on the matrix format, additional parameters are required.

Example

LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();

void rocalution::LocalMatrix::AllocateELL(const std::string name, int nnz, int nrow, int ncol, int max_row)
Allocate a local matrix with name and sizes.
The local matrix allocation functions require a name of the object (this is only for information purposes) and corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending on the matrix format, additional parameters are required.

Example
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();

void rocalution::LocalMatrix::AllocateHYB(const std::string name, int ell_nnz, int coo_nnz, int ell_max_row, int nrow, int ncol)
Allocate a local matrix with name and sizes.
The local matrix allocation functions require a name of the object (this is only for information purposes) and corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending on the matrix format, additional parameters are required.

Example
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();

void rocalution::LocalMatrix::AllocateDENSE (const std::string name, int nrow, int ncol)
Allocate a local matrix with name and sizes.
The local matrix allocation functions require a name of the object (this is only for information purposes) and corresponding number of non-zero elements, number of rows and number of columns. Furthermore, depending on the matrix format, additional parameters are required.

Example
LocalMatrix<ValueType> mat;
mat.AllocateCSR("my CSR matrix", 456, 100, 100);
mat.Clear();
mat.AllocateCOO("my COO matrix", 200, 100, 100);
mat.Clear();

void rocalution::LocalMatrix::SetDataPtrCOO(int **row, int **col, ValueType **val, std::string name, int nnz, int nrow, int ncol)
Initialize a LocalMatrix on the host with externally allocated data.
SetDataPtr functions have direct access to the raw data via pointers. Already allocated data can be set by passing their pointers.

Note Setting data pointers will leave the original pointers empty (set to NULL).

Example
// Allocate a CSR matrix
int* csr_row_ptr = new int[100 + 1];
int* csr_col_ind = new int[345];
ValueType* csr_val = new ValueType[345];

// Fill the CSR matrix
// ...

// rocALUTION local matrix object
LocalMatrix<ValueType> mat;

// Set the CSR matrix data, csr_row_ptr, csr_col and csr_val pointers become invalid
mat.SetDataPtrCSR(&csr_row_ptr, &csr_col, &csr_val, "my_matrix", 345, 100, 100);

void rocalution::LocalMatrix::SetDataPtrCSR(int **row_offset, int **col, ValueType **val,
       std::string name, int nnz, int nrow, int ncol)
Initialize a LocalMatrix on the host with externally allocated data.
SetDataPtr functions have direct access to the raw data via pointers. Already allocated data can be set by passing their pointers.

Note Setting data pointers will leave the original pointers empty (set to NULL).

Example

// Allocate a CSR matrix
int* csr_row_ptr = new int[100 + 1];
int* csr_col_ind = new int[345];
ValueType* csr_val = new ValueType[345];

// Fill the CSR matrix
// ...

// rocALUTION local matrix object
LocalMatrix<ValueType> mat;

// Set the CSR matrix data, csr_row_ptr, csr_col and csr_val pointers become invalid
mat.SetDataPtrCSR(&csr_row_ptr, &csr_col, &csr_val, "my_matrix", 345, 100, 100);

void rocalution::LocalMatrix::SetDataPtrMCSR(int **row_offset, int **col, ValueType **val,
       std::string name, int nnz, int nrow, int ncol)
Initialize a LocalMatrix on the host with externally allocated data.
SetDataPtr functions have direct access to the raw data via pointers. Already allocated data can be set by passing their pointers.

Note Setting data pointers will leave the original pointers empty (set to NULL).

Example

// Allocate a CSR matrix
int* csr_row_ptr = new int[100 + 1];
int* csr_col_ind = new int[345];

(continues on next page)
ValueType* csr_val = new ValueType[345];

// Fill the CSR matrix
// .../

// rocALUTION local matrix object
LocalMatrix<ValueType> mat;

// Set the CSR matrix data, csr_row_ptr, csr_col and csr_val pointers become invalid
mat.SetDataPtrCSR(&csr_row_ptr, &csr_col, &csr_val, "my_matrix", 345, 100, -100);

void rocalution::LocalMatrix::SetDataPtrELL(int** col, ValueType** val, std::string name, int nnz, int nrow, int ncol, int max_row)
Initialize a LocalMatrix on the host with externally allocated data.
SetDataPtr functions have direct access to the raw data via pointers. Already allocated data can be set by passing their pointers.

**Note** Setting data pointers will leave the original pointers empty (set to NULL).

**Example**

```cpp
// Allocate a CSR matrix
int* csr_row_ptr = new int[100 + 1];
int* csr_col_ind = new int[345];
ValueType* csr_val = new ValueType[345];

// Fill the CSR matrix
// ...

// rocALUTION local matrix object
LocalMatrix<ValueType> mat;

// Set the CSR matrix data, csr_row_ptr, csr_col and csr_val pointers become invalid
mat.SetDataPtrCSR(&csr_row_ptr, &csr_col, &csr_val, "my_matrix", 345, 100, -100);
```

void rocalution::LocalMatrix::SetDataPtrDIA(int** offset, ValueType** val, std::string name, int nnz, int nrow, int ncol, int num_diag)
Initialize a LocalMatrix on the host with externally allocated data.
SetDataPtr functions have direct access to the raw data via pointers. Already allocated data can be set by passing their pointers.

**Note** Setting data pointers will leave the original pointers empty (set to NULL).

**Example**

```cpp
// Allocate a CSR matrix
int* csr_row_ptr = new int[100 + 1];
int* csr_col_ind = new int[345];
ValueType* csr_val = new ValueType[345];
```
void rocalution::LocalMatrix::SetDataPtrDENSE (ValueType **val, std::string name, int nrow, int ncol)

Initialize a LocalMatrix on the host with externally allocated data.

SetDataPtr functions have direct access to the raw data via pointers. Already allocated data can be set by passing their pointers.

Note Setting data pointers will leave the original pointers empty (set to NULL).

Example

```cpp
// Allocate a CSR matrix
int* csr_row_ptr = new int[100 + 1];
int* csr_col_ind = new int[345];
ValueType* csr_val = new ValueType[345];

// Fill the CSR matrix
// ...

// rocALUTION local matrix object
LocalMatrix<ValueType> mat;

// Set the CSR matrix data, csr_row_ptr, csr_col and csr_val pointers become invalid
mat.SetDataPtrCSR(&csr_row_ptr, &csr_col, &csr_val, "my_matrix", 345, 100, 100);
```

void rocalution::LocalMatrix::LeaveDataPtrCOO (int **row, int **col, ValueType **val)

Leave a LocalMatrix to host pointers.

LeaveDataPtr functions have direct access to the raw data via pointers. A LocalMatrix object can leave its raw data to host pointers. This will leave the LocalMatrix empty.

Example

```cpp
// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...
int* csr_row_ptr = NULL;
```
void rocALUTION::LocalMatrix::LeaveDataPtrCSR(int **row_offset, int **col, ValueType **val)
Leave a LocalMatrix to host pointers. LeaveDataPtr functions have direct access to the raw data via pointers. A LocalMatrix object can leave its raw data to host pointers. This will leave the LocalMatrix empty.

Example

// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...

int* csr_row_ptr = NULL;
int* csr_col_ind = NULL;
ValueType* csr_val = NULL;

// Get (steal) the data from the matrix, this will leave the local matrix empty
mat.LeaveDataPtrCSR(&csr_row_ptr, &csr_col_ind, &csr_val);

void rocALUTION::LocalMatrix::LeaveDataPtrMCSR(int **row_offset, int **col, ValueType **val)
Leave a LocalMatrix to host pointers. LeaveDataPtr functions have direct access to the raw data via pointers. A LocalMatrix object can leave its raw data to host pointers. This will leave the LocalMatrix empty.

Example

// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...

int* csr_row_ptr = NULL;
int* csr_col_ind = NULL;
ValueType* csr_val = NULL;

// Get (steal) the data from the matrix, this will leave the local matrix empty
mat.LeaveDataPtrMCSR(&csr_row_ptr, &csr_col_ind, &csr_val);
void rocalution::LocalMatrix::LeaveDataPtrCSR(int **col, ValueType **val, int &max_row)
Leave a LocalMatrix to host pointers.

LeaveDataPtr functions have direct access to the raw data via pointers. A LocalMatrix object can leave its raw data to host pointers. This will leave the LocalMatrix empty.

Example

```cpp
// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...

int* csr_row_ptr = NULL;
int* csr_col_ind = NULL;
ValueType* csr_val = NULL;

// Get (steal) the data from the matrix, this will leave the local matrix empty
mat.LeaveDataPtrCSR(&csr_row_ptr, &csr_col_ind, &csr_val);
```

void rocalution::LocalMatrix::LeaveDataPtrELL(int **col, ValueType **val, int &max_row)
Leave a LocalMatrix to host pointers.

LeaveDataPtr functions have direct access to the raw data via pointers. A LocalMatrix object can leave its raw data to host pointers. This will leave the LocalMatrix empty.

Example

```cpp
// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...

int* csr_row_ptr = NULL;
int* csr_col_ind = NULL;
ValueType* csr_val = NULL;

// Get (steal) the data from the matrix, this will leave the local matrix empty
mat.LeaveDataPtrCSR(&csr_row_ptr, &csr_col_ind, &csr_val);
```

void rocalution::LocalMatrix::LeaveDataPtrDIA(int **offset, ValueType **val, int &num_diag)
Leave a LocalMatrix to host pointers.

LeaveDataPtr functions have direct access to the raw data via pointers. A LocalMatrix object can leave its raw data to host pointers. This will leave the LocalMatrix empty.

Example

```cpp
// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...

int* csr_row_ptr = NULL;
int* csr_col_ind = NULL;
ValueType* csr_val = NULL;

// Get (steal) the data from the matrix, this will leave the local matrix empty
mat.LeaveDataPtrCSR(&csr_row_ptr, &csr_col_ind, &csr_val);
```

void rocalution::LocalMatrix::LeaveDataPtrDENSE(ValueType **val)
Leave a LocalMatrix to host pointers.
LeaveDataPtr functions have direct access to the raw data via pointers. A `LocalMatrix` object can leave its raw data to host pointers. This will leave the `LocalMatrix` empty.

**Example**

```cpp
// rocALUTION CSR matrix object
LocalMatrix<ValueType> mat;

// Allocate the CSR matrix
mat.AllocateCSR("my_matrix", 345, 100, 100);

// Fill CSR matrix
// ...

int* csr_row_ptr = NULL;
int* csr_col_ind = NULL;
ValueType* csr_val = NULL;

// Get (steal) the data from the matrix, this will leave the local matrix object empty
mat.LeaveDataPtrCSR(&csr_row_ptr, &csr_col_ind, &csr_val);
```

- **Void Void rocalution::LocalMatrix::Zeros (void)**
  - Set all matrix values to zero.

- **Void Void rocalution::LocalMatrix::Scale (ValueType alpha)**
  - Scale all values in the matrix.

- **Void Void rocalution::LocalMatrix::ScaleDiagonal (ValueType alpha)**
  - Scale the diagonal entries of the matrix with alpha, all diagonal elements must exist.

- **Void Void rocalution::LocalMatrix::ScaleOffDiagonal (ValueType alpha)**
  - Scale the off-diagonal entries of the matrix with alpha, all diagonal elements must exist.

- **Void Void rocalution::LocalMatrix::AddScalar (ValueType alpha)**
  - Add a scalar to all matrix values.

- **Void Void rocalution::LocalMatrix::AddScalarDiagonal (ValueType alpha)**
  - Add alpha to the diagonal entries of the matrix, all diagonal elements must exist.

- **Void Void rocalution::LocalMatrix::AddScalarOffDiagonal (ValueType alpha)**
  - Add alpha to the off-diagonal entries of the matrix, all diagonal elements must exist.

- **Void Void rocalution::LocalMatrix::ExtractSubMatrix (int row_offset, int col_offset, int row_size, int col_size, LocalMatrix<ValueType>* mat) const**
  - Extract a sub-matrix with row/col_offset and row/col_size.

- **Void Void rocalution::LocalMatrix::ExtractSubMatrices (int row_num_blocks, int col_num_blocks, const int* row_offset, const int* col_offset, LocalMatrix<ValueType>* ***mat) const**
  - Extract array of non-overlapping sub-matrices (row/col_num_blocks define the blocks for rows/columns; row/col_offset have sizes col/row_num_blocks+1, where [i+1]-[i] defines the i-th size of the sub-matrix).

- **Void Void rocalution::LocalMatrix::ExtractDiagonal (LocalVector<ValueType>* vec_diag) const**
  - Extract the diagonal values of the matrix into a `LocalVector`. 

---

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void rocalution::LocalMatrix::ExtractInverseDiagonal (LocalVector< ValueType > * vec_inv_diag) const
Extract the inverse (reciprocal) diagonal values of the matrix into a LocalVector.

void rocalution::LocalMatrix::ExtractU (LocalMatrix< ValueType > * U, bool diag) const
Extract the upper triangular matrix.

void rocalution::LocalMatrix::ExtractL (LocalMatrix< ValueType > * L, bool diag) const
Extract the lower triangular matrix.

void rocalution::LocalMatrix::Permute (const LocalVector<int> & permutation)
Perform (forward) permutation of the matrix.

void rocalution::LocalMatrix::PermuteBackward (const LocalVector<int> & permutation)
Perform (backward) permutation of the matrix.

void rocalution::LocalMatrix::CMK (LocalVector<int> * permutation) const
Create permutation vector for CMK reordering of the matrix.
The Cuthill-McKee ordering minimize the bandwidth of a given sparse matrix.

Example

LocalVector<int> cmk;
mat.CMK(&cmk);
mat.Permute(cmk);

Parameters
• [out] permutation: permutation vector for CMK reordering

void rocalution::LocalMatrix::RCMK (LocalVector<int> * permutation) const
Create permutation vector for reverse CMK reordering of the matrix.
The Reverse Cuthill-McKee ordering minimize the bandwidth of a given sparse matrix.

Example

LocalVector<int> rcmk;
mat.RCMK(&rcmk);
mat.Permute(rcmk);

Parameters
• [out] permutation: permutation vector for reverse CMK reordering

void rocalution::LocalMatrix::ConnectivityOrder (LocalVector<int> * permutation) const
Create permutation vector for connectivity reordering of the matrix.
Connectivity ordering returns a permutation, that sorts the matrix by non-zero entries per row.

Example

LocalVector<int> conn;
mat.ConnectivityOrder(&conn);
mat.Permute(conn);

Parameters
• [out] permutation: permutation vector for connectivity reordering

```cpp
void rocalution::LocalMatrix::MultiColoring(int &num_colors, int **size_colors, LocalVector<int> *permutation) const
```

Perform multi-coloring decomposition of the matrix.

The Multi-Coloring algorithm builds a permutation (coloring of the matrix) in a way such that no two adjacent nodes in the sparse matrix have the same color.

**Example**

```cpp
LocalVector<int> mc;
int num_colors;
int* block_colors = NULL;
mat.MultiColoring(num_colors, &block_colors, &mc);
mat.Permute(mc);
```

**Parameters**

- [out] num_colors: number of colors
- [out] size_colors: pointer to array that holds the number of nodes for each color
- [out] permutation: permutation vector for multi-coloring reordering

```cpp
void rocalution::LocalMatrix::MaximalIndependentSet(int &size, LocalVector<int> *permutation) const
```

Perform maximal independent set decomposition of the matrix.

The Maximal Independent Set algorithm finds a set with maximal size, that contains elements that do not depend on other elements in this set.

**Example**

```cpp
LocalVector<int> mis;
int size;
mat.MaximalIndependentSet(size, &mis);
mat.Permute(mis);
```

**Parameters**

- [out] size: number of independent sets
- [out] permutation: permutation vector for maximal independent set reordering

```cpp
void rocalution::LocalMatrix::ZeroBlockPermutation(int &size, LocalVector<int> *permutation) const
```

Return a permutation for saddle-point problems (zero diagonal entries)

For Saddle-Point problems, (i.e. matrices with zero diagonal entries), the Zero Block Permutation maps all zero-diagonal elements to the last block of the matrix.

**Example**

```cpp
LocalVector<int> zbp;
int size;
```
Parameters

- [out] size:
- [out] permutation: permutation vector for zero block permutation

```cpp
mat.ZeroBlockPermutation(size, &zbp);
mat.Permute(zbp);
```

```cpp
Parameters

- [out] size:
- [out] permutation: permutation vector for zero block permutation

```cpp
void rocalution::LocalMatrix::ILUFactorize (void)
Perform LU factorization.

void rocalution::LocalMatrix::LUFactorize (void)
Perform LU factorization.

void rocalution::LocalMatrix::ILUTFactorize (double t, int maxrow)
Perform ILU(t,m) factorization based on threshold and maximum number of elements per row.

void rocalution::LocalMatrix::ILUpFactorize (int p, bool level = true)
Perform ILU(p) factorization based on power.

void rocalution::LocalMatrix::LUAnalyse (void)
Analyse the structure (level-scheduling)

void rocalution::LocalMatrix::LUAnalyseClear (void)
Delete the analysed data (see LUAnalyse)

void rocalution::LocalMatrix::LUSolve (const LocalVector<ValueType> &in, LocalVector<ValueType> *out) const
Solve LU out = in; if level-scheduling algorithm is provided then the graph traversing is performed in parallel.

void rocalution::LocalMatrix::ICFactorize (LocalVector<ValueType> *inv_diag)
Perform IC(0) factorization.

void rocalution::LocalMatrix::LLAnalyse (void)
Analyse the structure (level-scheduling)

void rocalution::LocalMatrix::LLAnalyseClear (void)
Delete the analysed data (see LLAnalyse)

void rocalution::LocalMatrix::LLSolve (const LocalVector<ValueType> &in, const LocalVector<ValueType> &inv_diag, LocalVector<ValueType> *out) const
Solve LL^T out = in; if level-scheduling algorithm is provided then the graph traversing is performed in parallel.

void rocalution::LocalMatrix::LAnalyse (bool diag_unit = false)
Analyze the structure (level-scheduling) L-part.

- diag_unit == true the diag is 1;
- diag_unit == false the diag is 0;

void rocalution::LocalMatrix::LAnalyseClear (void)
Delete the analysed data (see LAnalyse) L-part.
```
void rocalution::LocalMatrix::LSolve(const LocalVector<ValueType> &in, LocalVector<ValueType> *out) const

Solve L out = in; if level-scheduling algorithm is provided then the graph traversing is performed in parallel.

void rocalution::LocalMatrix::UAnalyse(bool diag_unit = false)

Analyse the structure (level-scheduling) U-part:

- diag_unit == true the diag is 1;
- diag_unit == false the diag is 0;

void rocalution::LocalMatrix::UAnalyseClear (void)

Delete the analysed data (see UAnalyse) U-part.

void rocalution::LocalMatrix::USolve(const LocalVector<ValueType> &in, LocalVector<ValueType> *out) const

Solve U out = in; if level-scheduling algorithm is provided then the graph traversing is performed in parallel.

void rocalution::LocalMatrix::Householder(int idx, ValueType &beta, LocalVector<ValueType> *vec) const

Compute Householder vector.

void rocalution::LocalMatrix::QRDecompose (void)

QR Decomposition.

void rocalution::LocalMatrix::QR Solve(const LocalVector<ValueType> &in, LocalVector<ValueType> *out) const

Solve QR out = in.

void rocalution::LocalMatrix::Invert (void)

Matrix inversion using QR decomposition.

void rocalution::LocalMatrix::ReadFileMTX(const std::string filename)

Read matrix from MTX (Matrix Market Format) file.

Read a matrix from Matrix Market Format file.

Example

```cpp
LocalMatrix<ValueType> mat;
mat.ReadFileMTX("my_matrix.mtx");
```

Parameters

- [in] filename: name of the file containing the MTX data.

void rocalution::LocalMatrix::WriteFileMTX(const std::string filename) const

Write matrix to MTX (Matrix Market Format) file.

Write a matrix to Matrix Market Format file.

Example

```cpp
LocalMatrix<ValueType> mat;
// Allocate and fill mat
// ... 
mat.WriteFileMTX("my_matrix.mtx");
```

Parameters
Read matrix from CSR (rocALUTION binary format) file.

Read a CSR matrix from binary file. For details on the format, see `WriteFileCSR()`.

**Example**

```cpp
LocalMatrix<ValueType> mat;
mat.ReadFileCSR("my_matrix.csr");
```

**Parameters**

- `[in]` `filename`: name of the file containing the data.

---

Write CSR matrix to binary file.

Write a CSR matrix to binary file.

The binary format contains a header, the rocALUTION version and the matrix data as follows

```cpp
// Header
out << "#rocALUTION binary csr file" << std::endl;

// rocALUTION version
out.write((char*)&version, sizeof(int));

// CSR matrix data
out.write((char*)&m, sizeof(int));
out.write((char*)&n, sizeof(int));
out.write((char*)&nnz, sizeof(int));
out.write((char*)csr_row_ptr, (m + 1) * sizeof(int));
out.write((char*)csr_col_ind, nnz * sizeof(int));
out.write((char*)csr_val, nnz * sizeof(double));
```

**Note**  
`Vector` values array is always stored in double precision (e.g. double or std::complex<double>).

**Example**

```cpp
LocalMatrix<ValueType> mat;

// Allocate and fill mat
// ...
mat.WriteFileCSR("my_matrix.csr");
```

**Parameters**

- `[in]` `filename`: name of the file to write the data to.

---

Copy matrix from another `LocalMatrix`.

CopyFrom copies values and structure from another local matrix. Source and destination matrix should be in the same format.
Note This function allows cross platform copying. One of the objects could be allocated on the accelerator backend.

Example

```cpp
LocalMatrix<ValueType> mat1, mat2;
// Allocate and initialize mat1 and mat2
// ...
// Move mat1 to accelerator
// mat1.MoveToAccelerator();
// Now, mat1 is on the accelerator (if available)
// and mat2 is on the host
// Copy mat1 to mat2 (or vice versa) will move data between host and accelerator backend
mat1.CopyFrom(mat2);
```

Parameters

- **[in]** `src`: Local matrix where values and structure should be copied from.

```cpp
class rocalution::LocalMatrix::CopyFromAsync (const LocalMatrix<ValueType> & src)
```

Async copy matrix (values and structure) from another `LocalMatrix`.

```cpp
class rocalution::LocalMatrix::CloneFrom (const LocalMatrix<ValueType> & src)
```

Clone the matrix.

`CloneFrom` clones the entire matrix, including values, structure and backend descriptor from another `LocalMatrix`.

Example

```cpp
LocalMatrix<ValueType> mat;
// Allocate and initialize mat (host or accelerator)
// ...
LocalMatrix<ValueType> tmp;
// By cloning mat, tmp will have identical values and structure and will be on
// the same backend as mat
tmp.CloneFrom(mat);
```

Parameters

- **[in]** `src`: `LocalMatrix` to clone from.

```cpp
class rocalution::LocalMatrix::UpdateValuesCSR (ValueType * val)
```

Update CSR matrix entries only, structure will remain the same.

```cpp
class rocalution::LocalMatrix::CopyFromCSR (const int * row_offsets, const int * col, const ValueType * val)
```

Copy (import) CSR matrix described in three arrays (offsets, columns, values). The object data has to be allocated (call AllocateCSR first)
void rocalution::LocalMatrix::CopyToCSR (int *row_offsets, int *col, ValueType *val) const
    Copy (export) CSR matrix described in three arrays (offsets, columns, values). The output arrays have to be allocated.

void rocalution::LocalMatrix::CopyFromCOO (const int *row, const int *col, const ValueType *val)
    Copy (import) COO matrix described in three arrays (rows, columns, values). The object data has to be allocated (call AllocateCOO first)

void rocalution::LocalMatrix::CopyToCOO (int *row, int *col, ValueType *val) const
    Copy (export) COO matrix described in three arrays (rows, columns, values). The output arrays have to be allocated.

void rocalution::LocalMatrix::CopyFromHostCSR (const int *row_offset, const int *col, const ValueType *val, const std::string name, int nnz, int nrow, int ncol)
    Allocates and copies (imports) a host CSR matrix.

If the CSR matrix data pointers are only accessible as constant, the user can create a LocalMatrix object and pass const CSR host pointers. The LocalMatrix will then be allocated and the data will be copied to the corresponding backend, where the original object was located at.

Parameters

- [in] val: CSR matrix values array.
- [in] name: Matrix object name.
- [in] nnz: Number of non-zero elements.
- [in] nrow: Number of rows.
- [in] ncol: Number of columns.

void rocalution::LocalMatrix::CreateFromMap (const LocalVector<int> &map, int n, int m)
    Create a restriction matrix operator based on an int vector map.

void rocalution::LocalMatrix::CreateFromMap (const LocalVector<int> &map, int n, int m, LocalMatrix<ValueType> *pro)
    Create a restriction and prolongation matrix operator based on an int vector map.

void rocalution::LocalMatrix::ConvertToCSR (void)
    Convert the matrix to CSR structure.

void rocalution::LocalMatrix::ConvertToMCSR (void)
    Convert the matrix to MCSR structure.

void rocalution::LocalMatrix::ConvertToBCSR (void)
    Convert the matrix to BCSR structure.

void rocalution::LocalMatrix::ConvertToCOO (void)
    Convert the matrix to COO structure.

void rocalution::LocalMatrix::ConvertToELL (void)
    Convert the matrix to ELL structure.

void rocalution::LocalMatrix::ConvertToDIA (void)
    Convert the matrix to DIA structure.
void rocalution::LocalMatrix::ConvertToHYB (void)
Convert the matrix to HYB structure.

void rocalution::LocalMatrix::ConvertToDENSE (void)
Convert the matrix to DENSE structure.

void rocalution::LocalMatrix::ConvertTo (unsigned int matrix_format)
Convert the matrix to specified matrix ID format.

void rocalution::LocalMatrix::SymbolicPower (int p)
Perform symbolic computation (structure only) of |this|^p.

void rocalution::LocalMatrix::MatrixAdd (const LocalMatrix<ValueType> &mat, ValueType alpha = static_cast<ValueType>(1), ValueType beta = static_cast<ValueType>(1), bool structure = false)
Perform matrix addition, this = alpha*this + beta*mat;.

- if structure==false the sparsity pattern of the matrix is not changed;
- if structure==true a new sparsity pattern is computed

void rocalution::LocalMatrix::MatrixMult (const LocalMatrix<ValueType> &A, const LocalMatrix<ValueType> &B)
Multiply two matrices, this = A * B.

void rocalution::LocalMatrix::DiagonalMatrixMult (const LocalVector<ValueType> &diag)
Multiply the matrix with diagonal matrix (stored in LocalVector), as DiagonalMatrixMultR().

void rocalution::LocalMatrix::DiagonalMatrixMultL (const LocalVector<ValueType> &diag)
Multiply the matrix with diagonal matrix (stored in LocalVector), this=diag*this.

void rocalution::LocalMatrix::DiagonalMatrixMultR (const LocalVector<ValueType> &diag)
Multiply the matrix with diagonal matrix (stored in LocalVector), this=this*diag.

void rocalution::LocalMatrix::Gershgorin (ValueType &lambda_min, ValueType &lambda_max)
Compute the spectrum approximation with Gershgorin circles theorem.

void rocalution::LocalMatrix::Compress (double drop_off)
Delete all entries in the matrix which abs(a_ij) <= drop_off; the diagonal elements are never deleted.

void rocalution::LocalMatrix::Transpose (void)
Transpose the matrix.

void rocalution::LocalMatrix::Sort (void)
Sort the matrix indices.
Sorts the matrix by indices.

- For CSR matrices, column values are sorted.
- For COO matrices, row indices are sorted.

void rocalution::LocalMatrix::Key (long int &row_key, long int &col_key, long int &val_key)
const
Compute a unique hash key for the matrix arrays.

Typically, it is hard to compare if two matrices have the same structure (and values). To do so, rocALUTION provides a keying function, that generates three keys, for the row index, column index and values array.

Parameters
• [out] row_key: row index array key
• [out] col_key: column index array key
• [out] val_key: values array key

```cpp
void rocalution::LocalMatrix::ReplaceColumnVector(int idx, const LocalVector<ValueType> &vec)
    Replace a column vector of a matrix.

void rocalution::LocalMatrix::ReplaceRowVector(int idx, const LocalVector<ValueType>& vec)
    Replace a row vector of a matrix.

void rocalution::LocalMatrix::ExtractColumnVector(int idx, LocalVector<ValueType> *vec) const
    Extract values from a column of a matrix to a vector.

void rocalution::LocalMatrix::ExtractRowVector(int idx, LocalVector<ValueType> *vec) const
    Extract values from a row of a matrix to a vector.

void rocalution::LocalMatrix::AMGConnect(ValueType eps, LocalVector<int> *connections) const
    Strong couplings for aggregation-based AMG.

void rocalution::LocalMatrix::AMGAggregate(const LocalVector<ValueType> &connections, LocalVector<int>* aggregates) const
    Plain aggregation - Modification of a greedy aggregation scheme from Vanek (1996)

void rocalution::LocalMatrix::AMGSmoothedAggregation(ValueType relax, const LocalVector<int> &aggregates, const LocalVector<int>& connections, LocalMatrix<ValueType>* prolong, LocalMatrix<ValueType>* restrict) const
    Interpolation scheme based on smoothed aggregation from Vanek (1996)

void rocalution::LocalMatrix::AMGAggregation(const LocalVector<int>& aggregates, LocalMatrix<ValueType>* prolong, LocalMatrix<ValueType>* restrict) const
    Aggregation-based interpolation scheme.

void rocalution::LocalMatrix::RugeStueben(ValueType eps, LocalMatrix<ValueType>* prolong, LocalMatrix<ValueType>* restrict) const
    Ruge Stueben coarsening.

void rocalution::LocalMatrix::FSAI(int power, const LocalMatrix<ValueType>* pattern)
    Factorized Sparse Approximate Inverse assembly for given system matrix power pattern or external sparsity pattern.

void rocalution::LocalMatrix::SPAI(void)
    SParse Approximate Inverse assembly for given system matrix pattern.

void rocalution::LocalMatrix::InitialPairwiseAggregation(ValueType beta, int &nc, LocalVector<int>* G, int &Gsize, int **rg, int &rgsize, int ordering) const
    Initial Pairwise Aggregation scheme.
```
void rocalution::LocalMatrix::InitialPairwiseAggregation(const LocalMatrix<ValueType> &mat, ValueType beta, int &nc, LocalVector<int> *G, int &Gsize, int **rG, int &rGsize, int ordering) const

Initial Pairwise Aggregation scheme for split matrices.

void rocalution::LocalMatrix::FurtherPairwiseAggregation(ValueType beta, int &nc, LocalVector<int> *G, int &Gsize, int **rG, int &rGsize, int ordering) const

Further Pairwise Aggregation scheme.

void rocalution::LocalMatrix::FurtherPairwiseAggregation(const LocalMatrix<ValueType> &mat, ValueType beta, int &nc, LocalVector<int> *G, int &Gsize, int **rG, int &rGsize, int ordering) const

Further Pairwise Aggregation scheme for split matrices.

void rocalution::LocalMatrix::CoarsenOperator(LocalMatrix<ValueType> *Ac, int nrow, int ncol, const LocalVector<int> &G, int Gsize, const int *rG, int rGsize) const

Build coarse operator for pairwise aggregation scheme.

2.9.16.12.7 Local Stencil

template<typename ValueType>
class LocalStencil : public rocalution::Operator<ValueType>

LocalStencil class.

A LocalStencil is called local, because it will always stay on a single system. The system can contain several CPUs via UMA or NUMA memory system or it can contain an accelerator.

Template Parameters

- ValueType: - can be int, float, double, std::complex<float> and std::complex<double>

rocalution::LocalStencil::LocalStencil(unsigned int type) Initialize a local stencil with a type.

int rocalution::LocalStencil::GetNDim(void) const Return the dimension of the stencil.

void rocalution::LocalStencil::SetGrid(int size) Set the stencil grid size.

2.9.16.12.8 Global Matrix

template<typename ValueType>
class GlobalMatrix : public rocalution::Operator<ValueType>

GlobalMatrix class.
A GlobalMatrix is called global, because it can stay on a single or on multiple nodes in a network. For this type of communication, MPI is used.

**Template Parameters**

- **ValueType**: can be int, float, double, std::complex<float> and std::complex<double>

```cpp
rocalution::GlobalMatrix::GlobalMatrix(const ParallelManager &pm)
```

Initialize a global matrix with a parallel manager.

```cpp
bool rocalution::GlobalMatrix::Check(void) const
```

Return true if the matrix is ok (empty matrix is also ok) and false if there is something wrong with the structure or some of values are NaN.

```cpp
void rocalution::GlobalMatrix::AllocateCSR(std::string name, int local_nnz, int ghost_nnz)
```

Allocate CSR Matrix.

```cpp
void rocalution::GlobalMatrix::AllocateCOO(std::string name, int local_nnz, int ghost_nnz)
```

Allocate COO Matrix.

```cpp
void rocalution::GlobalMatrix::SetParallelManager(const ParallelManager &pm)
```

Set the parallel manager of a global vector.

```cpp
void rocalution::GlobalMatrix::SetDataPtrCSR(int **local_row_offset, int **local_col, ValueType **local_val, int **ghost_row_offset, int **ghost_col, ValueType **ghost_val, std::string name, int local_nnz, int ghost_nnz)
```

Initialize a CSR matrix on the host with externally allocated data.

```cpp
void rocalution::GlobalMatrix::SetDataPtrCOO(int **local_row, int **local_col, ValueType **local_val, int **ghost_row, int **ghost_col, ValueType **ghost_val, std::string name, int local_nnz, int ghost_nnz)
```

Initialize a COO matrix on the host with externally allocated data.

```cpp
void rocalution::GlobalMatrix::SetLocalDataPtrCSR(int **row_offset, int **col, ValueType **val, std::string name, int nnz)
```

Initialize a CSR matrix on the host with externally allocated local data.

```cpp
void rocalution::GlobalMatrix::SetLocalDataPtrCOO(int **row, int **col, ValueType **val, std::string name, int nnz)
```

Initialize a COO matrix on the host with externally allocated local data.

```cpp
void rocalution::GlobalMatrix::SetGhostDataPtrCSR(int **row_offset, int **col, ValueType **val, std::string name, int nnz)
```

Initialize a CSR matrix on the host with externally allocated ghost data.

```cpp
void rocalution::GlobalMatrix::SetGhostDataPtrCOO(int **row, int **col, ValueType **val, std::string name, int nnz)
```

Initialize a COO matrix on the host with externally allocated ghost data.

```cpp
void rocalution::GlobalMatrix::LeaveDataPtrCSR(int **local_row_offset, int **local_col, ValueType **local_val, int **ghost_row_offset, int **ghost_col, ValueType **ghost_val)
```

Leave a CSR matrix to host pointers.

```cpp
void rocalution::GlobalMatrix::LeaveDataPtrCOO(int **local_row, int **local_col, ValueType **local_val, int **ghost_row, int **ghost_col, ValueType **ghost_val)
```

Leave a COO matrix to host pointers.
void rocalution::GlobalMatrix::LeaveLocalDataPtrCSR(int **row_offset, int **col, ValueType **val)

Leave a local CSR matrix to host pointers.

void rocalution::GlobalMatrix::LeaveLocalDataPtrCOO(int **row, int **col, ValueType **val)

Leave a local COO matrix to host pointers.

void rocalution::GlobalMatrix::LeaveGhostDataPtrCSR(int **row_offset, int **col, ValueType **val)

Leave a CSR ghost matrix to host pointers.

void rocalution::GlobalMatrix::LeaveGhostDataPtrCOO(int **row, int **col, ValueType **val)

Leave a COO ghost matrix to host pointers.

void rocalution::GlobalMatrix::CloneFrom(const GlobalMatrix<ValueType> &src)

Clone the entire matrix (values,structure+backend descr) from another GlobalMatrix.

void rocalution::GlobalMatrix::CopyFrom(const GlobalMatrix<ValueType> &src)

Copy matrix (values and structure) from another GlobalMatrix.

void rocalution::GlobalMatrix::ConvertToCSR(void)

Convert the matrix to CSR structure.

void rocalution::GlobalMatrix::ConvertToMCSR(void)

Convert the matrix to MCSR structure.

void rocalution::GlobalMatrix::ConvertToBCSR(void)

Convert the matrix to BCSR structure.

void rocalution::GlobalMatrix::ConvertToCOO(void)

Convert the matrix to COO structure.

void rocalution::GlobalMatrix::ConvertToELL(void)

Convert the matrix to ELL structure.

void rocalution::GlobalMatrix::ConvertToDIA(void)

Convert the matrix to DIA structure.

void rocalution::GlobalMatrix::ConvertToHYB(void)

Convert the matrix to HYB structure.

void rocalution::GlobalMatrix::ConvertToDENSE(void)

Convert the matrix to DENSE structure.

void rocalution::GlobalMatrix::ConvertTo(unsigned int matrix_format)

Convert the matrix to specified matrix ID format.

void rocalution::GlobalMatrix::ReadFileMTX(const std::string filename)

Read matrix from MTX (Matrix Market Format) file.

void rocalution::GlobalMatrix::WriteFileMTX(const std::string filename) const

Write matrix to MTX (Matrix Market Format) file.

void rocalution::GlobalMatrix::ReadFileCSR(const std::string filename)

Read matrix from CSR (ROCALUTION binary format) file.

void rocalution::GlobalMatrix::WriteFileCSR(const std::string filename) const

Write matrix to CSR (ROCALUTION binary format) file.

void rocalution::GlobalMatrix::Sort(void)

Sort the matrix indices.
void rocalution::GlobalMatrix::ExtractInverseDiagonal (GlobalVector<ValueType>* vec_inv_diag) const

Extract the inverse (reciprocal) diagonal values of the matrix into a GlobalVector.

void rocalution::GlobalMatrix::Scale (ValueType alpha)

Scale all the values in the matrix.

void rocalution::GlobalMatrix::InitialPairwiseAggregation (ValueType beta, int &nc, LocalVector<int>* G, int &Gsize, int **rG, int &rGsize, int ordering) const

Initial Pairwise Aggregation scheme.

void rocalution::GlobalMatrix::FurtherPairwiseAggregation (ValueType beta, int &nc, LocalVector<int>* G, int &Gsize, int **rG, int &rGsize, int ordering) const

Further Pairwise Aggregation scheme.

void rocalution::GlobalMatrix::CoarsenOperator (GlobalMatrix<ValueType>* Ac, ParallelManager* pm, int nrow, int ncol, const LocalVector<int>& G, int Gsize, const int*rG, int rGsize) const

Build coarse operator for pairwise aggregation scheme.

2.9.16.12.9 Local Vector

template<typename ValueType>
class LocalVector : public rocalution::Vector<ValueType>

LocalVector class.

A LocalVector is called local, because it will always stay on a single system. The system can contain several CPUs via UMA or NUMA memory system or it can contain an accelerator.

Template Parameters

- ValueType: - can be int, float, double, std::complex<float> and std::complex<double>

void rocalution::LocalVector::Allocate (std::string name, IndexType2 size)

Allocate a local vector with name and size.

The local vector allocation function requires a name of the object (this is only for information purposes) and corresponding size description for vector objects.

Example

```cpp
LocalVector<ValueType> vec;
vec.Allocate("my vector", 100);
vec.Clear();
```

Parameters

- [in] name: object name
- [in] size: number of elements in the vector
void rocalution::LocalVector::SetDataPtr (ValueType **ptr, std::string name, int size)
Initialize a LocalVector on the host with externally allocated data.

SetDataPtr has direct access to the raw data via pointers. Already allocated data can be set by passing the pointer.

**Note** Setting data pointer will leave the original pointer empty (set to NULL).

**Example**

```cpp
// Allocate vector
ValueType* ptr_vec = new ValueType[200];

// Fill vector
  // ...

// rocALUTION local vector object
LocalVector<ValueType> vec;

// Set the vector data, ptr_vec will become invalid
vec.SetDataPtr(ptr_vec, "my_vector", 200);
```

void rocalution::LocalVector::LeaveDataPtr (ValueType **ptr)
Leave a LocalVector to host pointers.

LeaveDataPtr has direct access to the raw data via pointers. A LocalVector object can leave its raw data to a host pointer. This will leave the LocalVector empty.

**Example**

```cpp
// rocALUTION local vector object
LocalVector<ValueType> vec;

// Allocate the vector
vec.Allocate("my_vector", 100);

// Fill vector
  // ...

ValueType* ptr_vec = NULL;

// Get (steal) the data from the vector, this will leave the local vector object empty
vec.LeaveDataPtr(&ptr_vec);
```

ValueType & rocalution::LocalVector::operator[] (int i)
Access operator (only for host data)

The elements in the vector can be accessed via [] operators, when the vector is allocated on the host.

**Return** value at index i

**Example**

```cpp
// rocALUTION local vector object
LocalVector<ValueType> vec;

// Allocate vector
```
vec.Allocate("my_vector", 100);
// Initialize vector with 1
vec.Ones();
// Set even elements to -1
for(int i = 0; i < vec.GetSize(); i += 2)
{
    vec[i] = -1;
}

Parameters

• [in] i: access data at index i

const ValueType &rocalution::LocalVector::operator[](int i) const

Access operator (only for host data)

The elements in the vector can be accessed via [] operators, when the vector is allocated on the host.

Return value at index i

Example

// rocALUTION local vector object
LocalVector<ValueType> vec;

// Allocate vector
vec.Allocate("my_vector", 100);

// Initialize vector with 1
vec.Ones();

// Set even elements to -1
for(int i = 0; i < vec.GetSize(); i += 2)
{
    vec[i] = -1;
}

Parameters

• [in] i: access data at index i

void rocalution::LocalVector::CopyFromPermute(const LocalVector<ValueType> &src, const LocalVector<int> &permutation)

Copy a vector under permutation (forward permutation)

void rocalution::LocalVector::CopyFromPermuteBackward(const LocalVector<ValueType> &src, const LocalVector<int> &permutation)

Copy a vector under permutation (backward permutation)

void rocalution::LocalVector::CopyFromData(const ValueType *data)

Copy (import) vector.

Copy (import) vector data that is described in one array (values). The object data has to be allocated with Allocate(), using the corresponding size of the data, first.
Parameters

- [in] data: data to be imported.

```cpp
void rocalution::LocalVector::CopyToData (ValueType *data) const
Copy (export) vector.
Copy (export) vector data that is described in one array (values). The output array has to be allocated, using the corresponding size of the data, first. Size can be obtained by GetSize().
```

Parameters

- [out] data: exported data.

```cpp
void rocalution::LocalVector::Permute (const LocalVector<int> &permutation)
Perform in-place permutation (forward) of the vector.
```

```cpp
void rocalution::LocalVector::PermuteBackward (const LocalVector<int> &permutation)
Perform in-place permutation (backward) of the vector.
```

```cpp
void rocalution::LocalVector::Restriction (const LocalVector<ValueType> &vec_fine, const LocalVector<int> &map)
Restriction operator based on restriction mapping vector.
```

```cpp
void rocalution::LocalVector::Prolongation (const LocalVector<ValueType> &vec_coarse, const LocalVector<int> &map)
Prolongation operator based on restriction mapping vector.
```

```cpp
void rocalution::LocalVector::SetIndexArray (int size, const int *index)
Set index array.
```

```cpp
void rocalution::LocalVector::GetIndexValues (ValueType *values) const
Get indexed values.
```

```cpp
void rocalution::LocalVector::SetIndexValues (const ValueType *values)
Set indexed values.
```

```cpp
void rocalution::LocalVector::GetContinuousValues (int start, int end, ValueType *values) const
Get continuous indexed values.
```

```cpp
void rocalution::LocalVector::SetContinuousValues (int start, int end, const ValueType *values)
Set continuous indexed values.
```

```cpp
void rocalution::LocalVector::ExtractCoarseMapping (int start, int end, const int *index, int nc, int *size, int *map) const
Extract coarse boundary mapping.
```

```cpp
void rocalution::LocalVector::ExtractCoarseBoundary (int start, int end, const int *index, int nc, int *size, int *boundary) const
Extract coarse boundary index.
```

2.9.16.12.10 Global Vector

template<typename ValueType>
class GlobalVector : public rocalution::Vector<ValueType>
GlobalVector class.
A *GlobalVector* is called global, because it can stay on a single or on multiple nodes in a network. For this type of communication, MPI is used.

**Template Parameters**

- `ValueType` - can be int, float, double, std::complex<float> and std::complex<double>

```cpp
template<typename ValueType>

rocalution::GlobalVector::GlobalVector(const ParallelManager &pm)

  Initialize a global vector with a parallel manager.

void rocalution::GlobalVector::Allocate(std::string name, IndexType2 size)

  Allocate a global vector with name and size.

void rocalution::GlobalVector::SetParallelManager(const ParallelManager &pm)

  Set the parallel manager of a global vector.

ValueType &rocalution::GlobalVector::operator[](int i)

  Access operator (only for host data)

const ValueType &rocalution::GlobalVector::operator[](int i) const

  Access operator (only for host data)

void rocalution::GlobalVector::SetDataPtr(ValueType **ptr, std::string name, IndexType2 size)

  Initialize the local part of a global vector with externally allocated data.

void rocalution::GlobalVector::LeaveDataPtr(ValueType **ptr)

  Get a pointer to the data from the local part of a global vector and free the global vector object.

void rocalution::GlobalVector::Restriction(const GlobalVector<ValueType> &vec_fine, const LocalVector<int> &map)

  Restriction operator based on restriction mapping vector.

void rocalution::GlobalVector::Prolongation(const GlobalVector<ValueType> &vec_coarse, const LocalVector<int> &map)

  Prolongation operator based on restriction mapping vector.
```

### 2.9.16.12.11 Parallel Manager

**class ParallelManager : public rocalution::RocalutionObj**

Parallel Manager class.

The parallel manager class handles the communication and the mapping of the global operators. Each global operator and vector need to be initialized with a valid parallel manager in order to perform any operation. For many distributed simulations, the underlying operator is already distributed. This information need to be passed to the parallel manager.

```cpp
void rocalution::ParallelManager::SetMPICommunicator(const void *comm)

  Set the MPI communicator.

void rocalution::ParallelManager::Clear(void)

  Clear all allocated resources.

IndexType2 rocalution::ParallelManager::GetGlobalSize(void) const

  Return the global size.

int rocalution::ParallelManager::GetLocalSize(void) const

  Return the local size.
```
int rocalution::ParallelManager::GetNumReceivers (void) const
    Return the number of receivers.

int rocalution::ParallelManager::GetNumSenders (void) const
    Return the number of senders.

int rocalution::ParallelManager::GetNumProcs (void) const
    Return the number of involved processes.

void rocalution::ParallelManager::SetGlobalSize (IndexType2 size)
    Initialize the global size.

void rocalution::ParallelManager::SetLocalSize (int size)
    Initialize the local size.

void rocalution::ParallelManager::SetBoundaryIndex (int size, const int *index)
    Set all boundary indices of this rank's process.

void rocalution::ParallelManager::SetReceivers (int nrecv, const int *recvs, const int *recv_offset)
    Number of processes, the current process is receiving data from, array of the processes, the current process is receiving data from and offsets, where the boundary for process 'receiver' starts.

void rocalution::ParallelManager::SetSenders (int nsend, const int *sends, const int *send_offset)
    Number of processes, the current process is sending data to, array of the processes, the current process is sending data to and offsets where the ghost part for process 'sender' starts.

void rocalution::ParallelManager::LocalToGlobal (int proc, int local, int &global)
    Mapping local to global.

void rocalution::ParallelManager::GlobalToLocal (int global, int &proc, int &local)
    Mapping global to local.

bool rocalution::ParallelManager::Status (void) const
    Check sanity status of parallel manager.

void rocalution::ParallelManager::ReadFileASCII (const std::string filename)
    Read file that contains all relevant parallel manager data.

void rocalution::ParallelManager::WriteFileASCII (const std::string filename) const
    Write file that contains all relevant parallel manager data.

2.9.16.12.12 Solvers

template<class OperatorType, class VectorType, typename ValueType>
    class Solver : public rocalution::RocalutionObj
        Base class for all solvers and preconditioners.
        Most of the solvers can be performed on linear operators LocalMatrix, LocalStencil and GlobalMatrix - i.e. the solvers can be performed locally (on a shared memory system) or in a distributed manner (on a cluster) via MPI. The only exception is the AMG (Algebraic Multigrid) solver which has two versions (one for LocalMatrix and one for GlobalMatrix class). The only pure local solvers (which do not support global/MPI operations) are the mixed-precision defect-correction solver and all direct solvers.
        All solvers need three template parameters - Operators, Vectors and Scalar type.
        The Solver class is purely virtual and provides an interface for
        • SetOperator() to set the operator $A$, i.e. the user can pass the matrix here.
• **Build()** to build the solver (including preconditioners, sub-solvers, etc.). The user need to specify the operator first before calling **Build()**.

• **Solve()** to solve the system $Ax = b$. The user need to pass a right-hand-side $b$ and a vector $x$, where the solution will be obtained.

• **Print()** to show solver information.

• **ReBuildNumeric()** to only re-build the solver numerically (if possible).

• **MoveToHost()** and **MoveToAccelerator()** to offload the solver (including preconditioners and sub-solvers) to the host/accelerator.

**Template Parameters**

- **OperatorType**: can be `LocalMatrix`, `GlobalMatrix` or `LocalStencil`
- **VectorType**: can be `LocalVector` or `GlobalVector`
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

Subclassed by `rocalution::DirectLinearSolver< OperatorType, VectorType, ValueType >`, `rocalution::IterativeLinearSolver< OperatorType, VectorType, ValueType >`, `rocalution::Preconditioner< OperatorType, VectorType, ValueType >`

```cpp
void rocalution::Solver::SetOperator(const OperatorType &op)
    Set the Operator of the solver.

void rocalution::Solver::ResetOperator(const OperatorType &op)
    Reset the operator; see **ReBuildNumeric()**
```

```cpp
virtual void rocalution::Solver::Print (void) const = 0
    Print information about the solver.
```

```cpp
virtual void rocalution::Solver::Solve (const VectorType &rhs, VectorType *x) = 0
    Solve Operator $x = rhs$.
```

```cpp
void rocalution::Solver::SolveZeroSol (const VectorType &rhs, VectorType *x)
    Solve Operator $x = rhs$, setting initial $x = 0$.
```

```cpp
void rocalution::Solver::Clear (void)
    Clear (free all local data) the solver.
```

```cpp
void rocalution::Solver::Build (void)
    Build the solver (data allocation, structure and numerical computation)
```

```cpp
void rocalution::Solver::BuildMoveToAcceleratorAsync (void)
    Build the solver and move it to the accelerator asynchronously.
```

```cpp
void rocalution::Solver::Sync (void)
    Synchronize the solver.
```

```cpp
void rocalution::Solver::ReBuildNumeric (void)
    Rebuild the solver only with numerical computation (no allocation or data structure computation)
```

```cpp
void rocalution::Solver::MoveToHost (void)
    Move all data (i.e. move the solver) to the host.
```

```cpp
void rocalution::Solver::MoveToAccelerator (void)
    Move all data (i.e. move the solver) to the accelerator.
```

```cpp
void rocalution::Solver::Verbose (int verb = 1)
    Provide verbose output of the solver.
```
• verb = 0 -> no output
• verb = 1 -> print info about the solver (start, end);
• verb = 2 -> print (iter, residual) via iteration control;

```
template<class OperatorType, class VectorType, typename ValueType>
class IterativeLinearSolver : public roculation::Solver<OperatorType, VectorType, ValueType>
```

Base class for all linear iterative solvers.

The iterative solvers are controlled by an iteration control object, which monitors the convergence properties of
the solver, i.e. maximum number of iteration, relative tolerance, absolute tolerance and divergence tolerance.
The iteration control can also record the residual history and store it in an ASCII file.

• Init(), InitMinIter(), InitMaxIter() and InitTol() initialize the solver and set the stopping criteria.
• RecordResidualHistory() and RecordHistory() start the recording of the residual and write it into a file.
• Verbose() sets the level of verbose output of the solver (0 - no output, 2 - detailed output, including residual
  and iteration information).
• SetPreconditioner() sets the preconditioning.

All iterative solvers are controlled based on

• Absolute stopping criteria, when \( \| r_k \|_{L_p} \leq \epsilon_{abs} \)
• Relative stopping criteria, when \( \| r_k \|_{L_p} / \| r_1 \|_{L_p} \leq \epsilon_{rel} \)
• Divergence stopping criteria, when \( \| r_k \|_{L_p} / \| r_1 \|_{L_p} \geq \epsilon_{div} \)
• Maximum number of iteration \( N \), when \( k = N \)

where \( k \) is the current iteration, \( r_k \) the residual for the current iteration \( k \) (i.e. \( r_k = b - Ax_k \)) and \( r_1 \) the starting
residual (i.e. \( r_1 = b - Ax_{init} \)). In addition, the minimum number of iterations \( M \) can be specified. In this case,
the solver will not stop to iterate, before \( k \geq M \).

The \( L_p \) norm is used for the computation, where \( p \) could be 1, 2 and \( \infty \). The norm computation can be set
with SetResidualNorm() with 1 for \( L_1 \), 2 for \( L_2 \) and 3 for \( L_\infty \). For the computation with \( L_\infty \), the index of
the maximum value can be obtained with GetAmaxResidualIndex(). If this function is called and \( L_\infty \) was not
selected, this function will return -1.

The reached criteria can be obtained with GetSolverStatus(), returning

• 0, if no criteria has been reached yet
• 1, if absolute tolerance has been reached
• 2, if relative tolerance has been reached
• 3, if divergence tolerance has been reached
• 4, if maximum number of iteration has been reached

Template Parameters

• OperatorType: - can be LocalMatrix, GlobalMatrix or LocalStencil
• VectorType: - can be LocalVector or GlobalVector
• ValueType: - can be float, double, std::complex<float> or std::complex<double>

Subclassed by roculation::BaseMultiGrid< OperatorType, VectorType, ValueType >, roculation::BiCGStab< OperatorType, VectorType, ValueType >, roculation::BiCGStabl< OperatorType, VectorType, ValueType >
void rocalution::IterativeLinearSolver::Init (double abs_tol, double rel_tol, double div_tol, int max_iter)
Initialize the solver with absolute/relative/divergence tolerance and maximum number of iterations.

void rocalution::IterativeLinearSolver::Init (double abs_tol, double rel_tol, double div_tol, int min_iter, int max_iter)
Initialize the solver with absolute/relative/divergence tolerance and minimum/maximum number of iterations.

void rocalution::IterativeLinearSolver::InitMinIter (int min_iter)
Set the minimum number of iterations.

void rocalution::IterativeLinearSolver::InitMaxIter (int max_iter)
Set the maximum number of iterations.

void rocalution::IterativeLinearSolver::InitTol (double abs, double rel, double div)
Set the absolute/relative/divergence tolerance.

void rocalution::IterativeLinearSolver::SetResidualNorm (int resnorm)
Set the residual norm to $L_1$, $L_2$ or $L_\infty$ norm.

- resnorm = 1 -> $L_1$ norm
- resnorm = 2 -> $L_2$ norm
- resnorm = 3 -> $L_\infty$ norm

void rocalution::IterativeLinearSolver::RecordResidualHistory (void)
Record the residual history.

void rocalution::IterativeLinearSolver::RecordHistory (const std::string filename)
Write the history to file.

void rocalution::IterativeLinearSolver::Verbose (int verb = 1)
Set the solver verbosity output.

void rocalution::IterativeLinearSolver::Solve (const VectorType &rhs, VectorType *x)
Solve $Operator \cdot x = rhs$.

void rocalution::IterativeLinearSolver::SetPreconditioner (Solver<OperatorType, VectorType, ValueType> &precond)
Set a preconditioner of the linear solver.

int rocalution::IterativeLinearSolver::GetIterationCount (void)
Return the iteration count.

double rocalution::IterativeLinearSolver::GetCurrentResidual (void)
Return the current residual.

int rocalution::IterativeLinearSolver::GetSolverStatus (void)
Return the current status.

int rocalution::IterativeLinearSolver::GetAmaxResidualIndex (void)
Return absolute maximum index of residual vector when using $L_\infty$ norm.
template<class OperatorType, class VectorType, typename ValueType>
class FixedPoint : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Fixed-Point Iteration Scheme.

The Fixed-Point iteration scheme is based on additive splitting of the matrix $A = M + N$. The scheme reads

$$x_{k+1} = M^{-1}(b - Nx_k).$$

It can also be reformulated as a weighted defect correction scheme

$$x_{k+1} = x_k - \omega M^{-1}(Ax_k - b).$$

The inversion of $M$ can be performed by preconditioners (*Jacobi*, *Gauss-Seidel*, *ILU*, etc.) or by any type of solvers.

**Template Parameters**

- **OperatorType**: - can be *LocalMatrix*, *GlobalMatrix* or *LocalStencil*
- **VectorType**: - can be *LocalVector* or *GlobalVector*
- **ValueType**: - can be *float*, *double*, *std::complex<float>* or *std::complex<double>*

```cpp
void rocalution::FixedPoint::SetRelaxation(ValueType omega)
Set relaxation parameter $\omega$.
```

template<class OperatorTypeH, class VectorTypeH, typename ValueTypeH, class OperatorTypeL, class VectorTypeL, typename ValueTypeL>
class MixedPrecisionDC : public rocalution::IterativeLinearSolver<OperatorTypeH, VectorTypeH, ValueTypeH>
Mixed-Precision Defect Correction Scheme.

The Mixed-Precision solver is based on a defect-correction scheme. The current implementation of the library is using host based correction in double precision and accelerator computation in single precision. The solver is implementing the scheme

$$x_{k+1} = x_k + A^{-1}r_k,$$

where the computation of the residual $r_k = b - Ax_k$ and the update $x_{k+1} = x_k + d_k$ are performed on the host in double precision. The computation of the residual system $Ad_k = r_k$ is performed on the accelerator in single precision. In addition to the setup functions of the iterative solver, the user need to specify the inner ($Ad_k = r_k$) solver.

**Template Parameters**

- **OperatorTypeH**: - can be *LocalMatrix*
- **VectorTypeH**: - can be *LocalVector*
- **ValueTypeH**: - can be *double*
- **OperatorTypeL**: - can be *LocalMatrix*
- **VectorTypeL**: - can be *LocalVector*
- **ValueTypeL**: - can be *float*

```cpp
void rocalution::MixedPrecisionDC::Set(Solver<OperatorTypeL, VectorTypeL, ValueTypeL> &Solver_L)
Set the inner solver for $Ad_k = r_k$.
```

2.9. ROCm Libraries
class Chebyshev : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>

Chebyshev Iteration Scheme.

The Chebyshev Iteration scheme (also known as acceleration scheme) is similar to the CG method but requires minimum and maximum eigenvalues of the operator.

Template Parameters

- **OperatorType**: can be *LocalMatrix*, *GlobalMatrix* or *LocalStencil*
- **VectorType**: can be *LocalVector* or *GlobalVector*
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

```cpp
void rocalution::Chebyshev::Set(ValueType lambda_min, ValueType lambda_max)
```

Set the minimum and maximum eigenvalues of the operator.

template<class OperatorType, class VectorType, typename ValueType>
class BiCGStab : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>

Bi-Conjugate Gradient Stabilized Method.

The Bi-Conjugate Gradient Stabilized method is a variation of CGS and solves sparse (non) symmetric linear systems $Ax = b$. SAAD

Template Parameters

- **OperatorType**: can be *LocalMatrix*, *GlobalMatrix* or *LocalStencil*
- **VectorType**: can be *LocalVector* or *GlobalVector*
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class BiCGStabl : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
```

Bi-Conjugate Gradient Stabilized (l) Method.

The Bi-Conjugate Gradient Stabilized (l) method is a generalization of BiCGStab for solving sparse (non) symmetric linear systems $Ax = b$. It minimizes residuals over $l$-dimensional Krylov subspaces. The degree $l$ can be set with `SetOrder(l)`. bicgstabl

Template Parameters

- **OperatorType**: can be *LocalMatrix* or *GlobalMatrix*
- **VectorType**: can be *LocalVector* or *GlobalVector*
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

```cpp
void rocalution::BiCGStabl::SetOrder(int l)
```

Set the order.

template<class OperatorType, class VectorType, typename ValueType>
class CG : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>

Conjugate Gradient Method.

The Conjugate Gradient method is the best known iterative method for solving sparse symmetric positive definite (SPD) linear systems $Ax = b$. It is based on orthogonal projection onto the Krylov subspace $K_m(r_0, A)$, where $r_0$ is the initial residual. The method can be preconditioned, where the approximation should also be SPD.

SAAD

Template Parameters
• OperatorType: can be LocalMatrix, GlobalMatrix or LocalStencil
• VectorType: can be LocalVector or GlobalVector
• ValueType: can be float, double, std::complex<float> or std::complex<double>

```
template<class OperatorType, class VectorType, typename ValueType>
class CR : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Conjugate Residual Method.

The Conjugate Residual method is an iterative method for solving sparse symmetric semi-positive definite linear systems $Ax = b$. It is a Krylov subspace method and differs from the much more popular Conjugate Gradient method that the system matrix is not required to be positive definite. The method can be preconditioned where the approximation should also be SPD or semi-positive definite. SAAD

**Template Parameters**

• OperatorType: can be LocalMatrix, GlobalMatrix or LocalStencil
• VectorType: can be LocalVector or GlobalVector
• ValueType: can be float, double, std::complex<float> or std::complex<double>
```

```
template<class OperatorType, class VectorType, typename ValueType>
class FCG : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Flexible Conjugate Gradient Method.

The Flexible Conjugate Gradient method is an iterative method for solving sparse symmetric positive definite linear systems $Ax = b$. It is similar to the Conjugate Gradient method with the only difference, that it allows the preconditioner $M^{-1}$ to be not a constant operator. This can be especially helpful if the operation $M^{-1}x$ is the result of another iterative process and not a constant operator. fcg

**Template Parameters**

• OperatorType: can be LocalMatrix or GlobalMatrix
• VectorType: can be LocalVector or GlobalVector
• ValueType: can be float, double, std::complex<float> or std::complex<double>
```

```
template<class OperatorType, class VectorType, typename ValueType>
class GMRES : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Generalized Minimum Residual Method.

The Generalized Minimum Residual method (GMRES) is a projection method for solving sparse (non) symmetric linear systems $Ax = b$, based on restarting technique. The solution is approximated in a Krylov subspace $K = K_m$ and $L = AK_m$ with minimal residual, where $K_m$ is the $m$-th Krylov subspace with $v_1 = r_0/||r_0||_2$. SAAD

The Krylov subspace basis size can be set using `SetBasisSize()`. The default size is 30.

**Template Parameters**

• OperatorType: can be LocalMatrix, GlobalMatrix or LocalStencil
• VectorType: can be LocalVector or GlobalVector
• ValueType: can be float, double, std::complex<float> or std::complex<double>
```

```
void rocalution::GMRES::SetBasisSize (int size_basis)
Set the size of the Krylov subspace basis.
```
Flexible Generalized Minimum Residual Method. The Flexible Generalized Minimum Residual method (FGMRES) is a projection method for solving sparse (non) symmetric linear systems $Ax = b$. It is similar to the GMRES method with the only difference, the FGMRES is based on a window shifting of the Krylov subspace and thus allows the preconditioner $M^{-1}$ to be not a constant operator. This can be especially helpful if the operation $M^{-1}x$ is the result of another iterative process and not a constant operator. SAAD

The Krylov subspace basis size can be set using `SetBasisSize()`. The default size is 30.

Template Parameters

- `OperatorType`: can be `LocalMatrix`, `GlobalMatrix` or `LocalStencil`
- `VectorType`: can be `LocalVector` or `GlobalVector`
- `ValueType`: can be float, double, std::complex<float> or std::complex<double>

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class FGMRES : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Flexible Generalized Minimum Residual Method.
```

Induced Dimension Reduction Method.

The Induced Dimension Reduction method is a Krylov subspace method for solving sparse (non) symmetric linear systems $Ax = b$. IDR(s) generates residuals in a sequence of nested subspaces. IDR 1 IDR 2

The dimension of the shadow space can be set by `SetShadowSpace()`. The default size of the shadow space is 4.

Template Parameters

- `OperatorType`: can be `LocalMatrix`, `GlobalMatrix` or `LocalStencil`
- `VectorType`: can be `LocalVector` or `GlobalVector`
- `ValueType`: can be float, double, std::complex<float> or std::complex<double>

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class IDR : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Induced Dimension Reduction Method.
```

Quasi-Minimal Residual Conjugate Gradient Stabilized Method.

The Quasi-Minimal Residual Conjugate Gradient Stabilized method is a variant of the Krylov subspace Bicgstab method for solving sparse (non) symmetric linear systems $Ax = b$. qmrcgstab

Template Parameters

- `OperatorType`: can be `LocalMatrix` or `GlobalMatrix`
- `VectorType`: can be `LocalVector` or `GlobalVector`
- `ValueType`: can be float, double, std::complex<float> or std::complex<double>

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class QMRCGStab : public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Quasi-Minimal Residual Conjugate Gradient Stabilized Method.
```
class BaseMultiGrid: public rocalution::IterativeLinearSolver<OperatorType, VectorType, ValueType>
Base class for all multigrid solvers Trottenberg2003.

Template Parameters

• OperatorType: - can be LocalMatrix or GlobalMatrix
• VectorType: - can be LocalVector or GlobalVector
• ValueType: - can be float, double, std::complex<float> or std::complex<double>

Subclassed by rocalution::BaseAMG< OperatorType, VectorType, ValueType >, rocalution::MultiGrid< OperatorType, VectorType, ValueType >

void rocalution::BaseMultiGrid::SetSolver(Solver<OperatorType, VectorType, ValueType>& solver)
Set the coarse grid solver.

void rocalution::BaseMultiGrid::SetSmooother(IterativeLinearSolver<OperatorType, VectorType, ValueType> **smoother)
Set the smoother for each level.

void rocalution::BaseMultiGrid::SetSmoootherPreIter(int iter)
Set the number of pre-smoothing steps.

void rocalution::BaseMultiGrid::SetSmoootherPostIter(int iter)
Set the number of post-smoothing steps.

virtual void rocalution::BaseMultiGrid::SetRestrictOperator(OperatorType **op) = 0
Set the restriction operator for each level.

virtual void rocalution::BaseMultiGrid::SetProlongOperator(OperatorType **op) = 0
Set the prolongation operator for each level.

virtual void rocalution::BaseMultiGrid::SetOperatorHierarchy(OperatorType **op) = 0
Set the operator for each level.

void rocalution::BaseMultiGrid::SetScaling(bool scaling)
Enable/disable scaling of intergrid transfers.

void rocalution::BaseMultiGrid::SetHostLevels(int levels)
Force computation of coarser levels on the host backend.

void rocalution::BaseMultiGrid::SetCycle(unsigned int cycle)
Set the MultiGrid Cycle (default: Vcycle)

void rocalution::BaseMultiGrid::SetKcycleFull(bool kcycle_full)
Set the MultiGrid Kcycle on all levels or only on finest level.

void rocalution::BaseMultiGrid::InitLevels(int levels)
Set the depth of the multigrid solver.

template<class OperatorType, class VectorType, typename ValueType>
class MultiGrid: public rocalution::BaseMultiGrid<OperatorType, VectorType, ValueType>

MultiGrid Method.

The MultiGrid method can be used with external data, such as externally computed restriction, prolongation and operator hierarchy. The user need to pass all this information for each level and for its construction. This includes smoothing step, prolongation/restriction, grid traversing and coarse grid solver. This data need to be passed to the solver. Trottenberg2003

• Restriction and prolongation operations can be performed in two ways, based on Restriction() and Prolongation() of the LocalVector class, or by matrix-vector multiplication. This is configured by a set function.
• Smoothers can be of any iterative linear solver. Valid options are *Jacobi*, Gauss-Seidel, *ILU*, etc. using a *FixedPoint* iteration scheme with pre-defined number of iterations. The smoothers could also be a solver such as *CG*, *BiCGStab*, etc.

• Coarse grid solver could be of any iterative linear solver type. The class also provides mechanisms to specify, where the coarse grid solver has to be performed, on the host or on the accelerator. The coarse grid solver can be preconditioned.

• Grid scaling based on a $L_2$ norm ratio.

• *Operator* matrices need to be passed on each grid level.

**Template Parameters**

- **OperatorType**: can be *LocalMatrix* or *GlobalMatrix*
- **VectorType**: can be *LocalVector* or *GlobalVector*
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class BaseAMG : public rocalution::BaseMultiGrid<OperatorType, VectorType, ValueType>
```

Base class for all algebraic multigrid solvers.

The Algebraic *MultiGrid* solver is based on the *BaseMultiGrid* class. The coarsening is obtained by different aggregation techniques. The smoothers can be constructed inside or outside of the class.

All parameters in the Algebraic *MultiGrid* class can be set externally, including smoothers and coarse grid solver.

**Template Parameters**

- **OperatorType**: can be *LocalMatrix* or *GlobalMatrix*
- **VectorType**: can be *LocalVector* or *GlobalVector*
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

Subclassed by *rocalution::GlobalPairwiseAMG<OperatorType, VectorType, ValueType>*,
*rocalution::PairwiseAMG<OperatorType, VectorType, ValueType>*,
*rocalution::RugeStuebenAMG<OperatorType, VectorType, ValueType>*,
*rocalution::SAAMG<OperatorType, VectorType, ValueType>*,
*rocalution::UAAMG<OperatorType, VectorType, ValueType>*

```cpp
void rocalution::BaseAMG::ClearLocal (void)
Clear all local data.

void rocalution::BaseAMG::BuildHierarchy (void)
Create AMG hierarchy.

void rocalution::BaseAMG::BuildSmoothers (void)
Create AMG smoothers.

void rocalution::BaseAMG::SetCoarsestLevel (int coarse_size)
Set coarsest level for hierarchy creation.

void rocalution::BaseAMG::SetManualSmoothers (bool sm_manual)
Set flag to pass smoothers manually for each level.

void rocalution::BaseAMG::SetManualSolver (bool s_manual)
Set flag to pass coarse grid solver manually.

void rocalution::BaseAMG::SetDefaultSmootherFormat (unsigned int op_format)
Set the smoother operator format.
```
void rocalution::BaseAMG::SetOperatorFormat (unsigned int op_format)
Set the operator format.

int rocalution::BaseAMG::GetNumLevels (void)
Returns the number of levels in hierarchy.

template-class OperatorType, class VectorType, typename ValueType>
class UAAMG: public rocalution::BaseAMG<OperatorType, VectorType, ValueType>
Unsmoothed Aggregation Algebraic MultiGrid Method.

The Unsmoothed Aggregation Algebraic MultiGrid method is based on unsmoothed aggregation based interpolation scheme.

Template Parameters
  • OperatorType: - can be LocalMatrix
  • VectorType: - can be LocalVector
  • ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::UAAMG::SetCouplingStrength (ValueType eps)
Set coupling strength.

void rocalution::UAAMG::SetOverInterp (ValueType overInterp)
Set over-interpolation parameter for aggregation.

template-class OperatorType, class VectorType, typename ValueType>
class SAAMG: public rocalution::BaseAMG<OperatorType, VectorType, ValueType>
Smoothed Aggregation Algebraic MultiGrid Method.

The Smoothed Aggregation Algebraic MultiGrid method is based on smoothed aggregation based interpolation scheme.

Template Parameters
  • OperatorType: - can be LocalMatrix
  • VectorType: - can be LocalVector
  • ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::SAAMG::SetCouplingStrength (ValueType eps)
Set coupling strength.

void rocalution::SAAMG::SetInterpRelax (ValueType relax)
Set the relaxation parameter.

template-class OperatorType, class VectorType, typename ValueType>
class RugeStuebenAMG: public rocalution::BaseAMG<OperatorType, VectorType, ValueType>
Ruge-Stueben Algebraic MultiGrid Method.

The Ruge-Stueben Algebraic MultiGrid method is based on the classic Ruge-Stueben coarsening with direct interpolation. The solver provides high-efficiency in terms of complexity of the solver (i.e. number of iterations). However, most of the time it has a higher building step and requires higher memory usage.

Template Parameters
  • OperatorType: - can be LocalMatrix
  • VectorType: - can be LocalVector
  • ValueType: - can be float, double, std::complex<float> or std::complex<double>
void rocalution::RugeStuebenAMG::SetCouplingStrength (ValueType eps)
   Set coupling strength.

template<class OperatorType, class VectorType, typename ValueType>
class PairwiseAMG : public rocalution::BaseAMG<OperatorType, VectorType, ValueType>
Pairwise Aggregation Algebraic MultiGrid Method.

The Pairwise Aggregation Algebraic MultiGrid method is based on a pairwise aggregation matching scheme. It delivers very efficient building phase which is suitable for Poisson-like equation. Most of the time it requires K-cycle for the solving phase to provide low number of iterations. pairwiseamg

**Template Parameters**

- OperatorType: - can be LocalMatrix
- VectorType: - can be LocalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::PairwiseAMG::SetBeta (ValueType beta)
   Set beta for pairwise aggregation.

void rocalution::PairwiseAMG::SetOrdering (unsigned int ordering)
   Set re-ordering for aggregation.

void rocalution::PairwiseAMG::SetCoarseningFactor (double factor)
   Set target coarsening factor.

template<class OperatorType, class VectorType, typename ValueType>
class GlobalPairwiseAMG : public rocalution::BaseAMG<OperatorType, VectorType, ValueType>
Pairwise Aggregation Algebraic MultiGrid Method (multi-node)

The Pairwise Aggregation Algebraic MultiGrid method is based on a pairwise aggregation matching scheme. It delivers very efficient building phase which is suitable for Poisson-like equation. Most of the time it requires K-cycle for the solving phase to provide low number of iterations. This version has multi-node support. pairwiseamg

**Template Parameters**

- OperatorType: - can be GlobalMatrix
- VectorType: - can be GlobalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::GlobalPairwiseAMG::SetBeta (ValueType beta)
   Set beta for pairwise aggregation.

void rocalution::GlobalPairwiseAMG::SetOrdering (const _aggregation_ordering ordering)
   Set re-ordering for aggregation.

void rocalution::GlobalPairwiseAMG::SetCoarseningFactor (double factor)
   Set target coarsening factor.

template<class OperatorType, class VectorType, typename ValueType>
class DirectLinearSolver : public rocalution::Solver<OperatorType, VectorType, ValueType>
Base class for all direct linear solvers.

The library provides three direct methods - LU, QR and Inversion (based on QR decomposition). The user can pass a sparse matrix, internally it will be converted to dense and then the selected method will be applied. These methods are not very optimal and due to the fact that the matrix is converted to a dense format, these methods should be used only for very small matrices.
Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

Subclassed by `roculation::Inversion< OperatorType, VectorType, ValueType >, roculation::LU< OperatorType, VectorType, ValueType >, roculation::QR< OperatorType, VectorType, ValueType >`

template<class OperatorType, class VectorType, typename ValueType>
class Inversion : public roculation::DirectLinearSolver<OperatorType, VectorType, ValueType>
Matrix Inversion.

Full matrix inversion based on **QR** decomposition.

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

template<class OperatorType, class VectorType, typename ValueType>
class LU : public roculation::DirectLinearSolver<OperatorType, VectorType, ValueType>
LU Decomposition.

Lower-Upper Decomposition factors a given square matrix into lower and upper triangular matrix, such that $A = LU$.

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

template<class OperatorType, class VectorType, typename ValueType>
class QR : public roculation::DirectLinearSolver<OperatorType, VectorType, ValueType>
QR Decomposition.

The **QR** Decomposition decomposes a given matrix into $A = QR$, such that $Q$ is an orthogonal matrix and $R$ an upper triangular matrix.

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

### 2.9.16.12.13 Preconditioners

template<class OperatorType, class VectorType, typename ValueType>
class Preconditioner : public roculation::Solver<OperatorType, VectorType, ValueType>
Base class for all preconditioners.
Template Parameters

- OperatorType: can be LocalMatrix or GlobalMatrix
- VectorType: can be LocalVector or GlobalVector
- ValueType: can be float, double, std::complex<float> or std::complex<double>

Subclassed by:
- rocalution::AIChebyshev< OperatorType, VectorType, ValueType >
- rocalution::AS< OperatorType, VectorType, ValueType >
- rocalution::BlockJacobi< OperatorType, VectorType, ValueType >
- rocalution::BlockPreconditioner< OperatorType, VectorType, ValueType >
- rocalution::DiagJacobiSaddlePointPrecond< OperatorType, VectorType, ValueType >
- rocalution::FSAI< OperatorType, VectorType, ValueType >
- rocalution::GSS< OperatorType, VectorType, ValueType >
- rocalution::IC< OperatorType, VectorType, ValueType >
- rocalution::ILUC< OperatorType, VectorType, ValueType >
- rocalution::ILUT< OperatorType, VectorType, ValueType >
- rocalution::Jacobi< OperatorType, VectorType, ValueType >
- rocalution::MultiColored< OperatorType, VectorType, ValueType >
- rocalution::MultiElimination< OperatorType, VectorType, ValueType >
- rocalution::SPLAI< OperatorType, VectorType, ValueType >
- rocalution::TNS< OperatorType, VectorType, ValueType >
- rocalution::VariablePreconditioner< OperatorType, VectorType, ValueType >

template<class OperatorType, class VectorType, typename ValueType>
class AIChebyshev : public rocalution::Preconditioner<OperatorType, VectorType, ValueType> Approximate Inverse - Chebyshev Preconditioner.

The Approximate Inverse - Chebyshev Preconditioner is an inverse matrix preconditioner with values from a linear combination of matrix-valued Chebyshev polynomials. chebpoly

Template Parameters

- OperatorType: can be LocalMatrix
- VectorType: can be LocalVector
- ValueType: can be float, double, std::complex<float> or std::complex<double>

void rocalution::AIChebyshev::Set (int p, ValueType lambda_min, ValueType lambda_max)
Set order, min and max eigenvalues.

template<class OperatorType, class VectorType, typename ValueType>
class FSAI : public rocalution::Preconditioner<OperatorType, VectorType, ValueType> Factorized Approximate Inverse Preconditioner.

The Factorized Sparse Approximate Inverse preconditioner computes a direct approximation of $M^{-1}$ by minimizing the Frobenius norm $\|IGL||_F$, where $L$ denotes the exact lower triangular part of $A$ and $G := M^{-1}$. The FSAI preconditioner is initialized by $q$, based on the sparsity pattern of $|A^q|$. However, it is also possible to supply external sparsity patterns in form of the LocalMatrix class. kolotilina

Note The FSAI preconditioner is only suited for symmetric positive definite matrices.

Template Parameters

- OperatorType: can be LocalMatrix
- VectorType: can be LocalVector
- ValueType: can be float, double, std::complex<float> or std::complex<double>

void rocalution::FSAI::Set (int power)
Set the power of the system matrix sparsity pattern.
void rocalution::FSAI::Set(const OperatorType &pattern)
Set an external sparsity pattern.

void rocalution::FSAI::SetPrecondMatrixFormat (unsigned int mat_format)
Set the matrix format of the preconditioner.

template<class OperatorType, class VectorType, typename ValueType>
class SPAI : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
SParse Approximate Inverse Preconditioner.

The SParse Approximate Inverse algorithm is an explicitly computed preconditioner for general sparse linear systems. In its current implementation, only the sparsity pattern of the system matrix is supported. The SPAI computation is based on the minimization of the Frobenius norm $||AMI||_F$.

Template Parameters

- OperatorType: - can be LocalMatrix
- VectorType: - can be LocalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::SPAI::SetPrecondMatrixFormat (unsigned int mat_format)
Set the matrix format of the preconditioner.

template<class OperatorType, class VectorType, typename ValueType>
class TNS : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Truncated Neumann Series Preconditioner.

The Truncated Neumann Series (TNS) preconditioner is based on $M^{-1} = K^T D^{-1} K$, where $K = (I - LD^{-1} + (LD^{-1})^2)$, with the diagonal $D$ of $A$ and the strictly lower triangular part $L$ of $A$. The preconditioner can be computed in two forms - explicitly and implicitly. In the implicit form, the full construction of $M$ is performed via matrix-matrix operations, whereas in the explicit form, the application of the preconditioner is based on matrix-vector operations only. The matrix format for the stored matrices can be specified.

Template Parameters

- OperatorType: - can be LocalMatrix
- VectorType: - can be LocalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::TNS::Set (bool imp)
Set implicit (true) or explicit (false) computation.

void rocalution::TNS::SetPrecondMatrixFormat (unsigned int mat_format)
Set the matrix format of the preconditioner.

template<class OperatorType, class VectorType, typename ValueType>
class AS : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Additive Schwarz Preconditioner.

The Additive Schwarz preconditioner relies on a preconditioning technique, where the linear system $Ax = b$ can be decomposed into small sub-problems based on $A_i = R_i^T AR_i$, where $R_i$ are restriction operators. Those restriction operators produce sub-matrices which overlap. This leads to contributions from two preconditioners on the overlapped area which are scaled by $1/2$. RAS

Template Parameters

- OperatorType: - can be LocalMatrix
• **VectorType**: can be `LocalVector`
• **ValueType**: can be float, double, std::complex<float> or std::complex<double>

Subclassed by `rocalution::RAS< OperatorType, VectorType, ValueType >`

```cpp
void rocalution::RAS::Set(int nb, int overlap, Solver<OperatorType, VectorType, ValueType> **preconds)
```
Set number of blocks, overlap and array of preconditioners.

template<class OperatorType, class VectorType, typename ValueType>
class RAS : public rocalution::AS<OperatorType, VectorType, ValueType>

Restricted Additive Schwarz Preconditioner.

The Restricted Additive Schwarz preconditioner relies on a preconditioning technique, where the linear system $A x = b$ can be decomposed into small sub-problems based on $A_i = R_i^T A R_i$, where $R_i$ are restriction operators. The RAS method is a mixture of block Jacobi and the AS scheme. In this case, the sub-matrices contain overlapped areas from other blocks, too. RAS

**Template Parameters**
• **OperatorType**: can be `LocalMatrix`
• **VectorType**: can be `LocalVector`
• **ValueType**: can be float, double, std::complex<float> or std::complex<double>
The solution of $P$ can be performed in two ways. It can be solved by block-lower-triangular sweeps with inversion of the blocks $A_d \ldots Z_d$ and with a multiplication of the corresponding blocks. This is set by `SetLSolver()` (which is the default solution scheme). Alternatively, it can be used only with an inverse of the diagonal $A_d \ldots Z_d$ (Block-Jacobi type) by using `SetDiagonalSolver()`.

**Template Parameters**

- `OperatorType`: can be `LocalMatrix`
- `VectorType`: can be `LocalVector`
- `ValueType`: can be `float`, `double`, `std::complex<float>` or `std::complex<double>`

```
void rocALUTION::BlockPreconditioner::Set(int n, const int *size, Solver<OperatorType, VectorType, ValueType> **D_solver)
```
Set number, size and diagonal solver.

```
void rocALUTION::BlockPreconditioner::SetDiagonalSolver(void)
```
Set diagonal solver mode.

```
void rocALUTION::BlockPreconditioner::SetLSolver(void)
```
Set lower triangular sweep mode.

```
void rocALUTION::BlockPreconditioner::SetExternalLastMatrix(const OperatorType &mat)
```
Set external last block matrix.

```
void rocALUTION::BlockPreconditioner::SetPermutation(const LocalVector<int> &perm)
```
Set permutation vector.

```template<class OperatorType, class VectorType, typename ValueType>
<OperatorType, VectorType, ValueTypeBALL
```

**class Jacobi : public rocALUTION::Preconditioner<OperatorType, VectorType, ValueType>**
Jacobi Method.

The Jacobi method is for solving a diagonally dominant system of linear equations $Ax = b$. It solves for each diagonal element iteratively until convergence, such that

$$x_i^{(k+1)} = (1 - \omega)x_i^{(k)} + \frac{\omega}{a_{ii}} \left( b_i - \sum_{j=1}^{i-1} a_{ij}x_j^{(k)} - \sum_{j=i}^{n} a_{ij}x_j^{(k)} \right)$$

**Template Parameters**

- `OperatorType`: can be `LocalMatrix` or `GlobalMatrix`
- `VectorType`: can be `LocalVector` or `GlobalVector`
- `ValueType`: can be `float`, `double`, `std::complex<float>` or `std::complex<double>`

```template<class OperatorType, class VectorType, typename ValueType>
<OperatorType, VectorType, ValueTypeBALL
```

**class GS : public rocALUTION::Preconditioner<OperatorType, VectorType, ValueType>**
Gauss-Seidel / Successive Over-Relaxation Method.

The Gauss-Seidel / SOR method is for solving system of linear equations $Ax = b$. It approximates the solution iteratively with

$$x_i^{(k+1)} = (1 - \omega)x_i^{(k)} + \frac{\omega}{a_{ii}} \left( b_i - \sum_{j=1}^{i-1} a_{ij}x_j^{(k+1)} - \sum_{j=i}^{n} a_{ij}x_j^{(k)} \right),$$

with $\omega \in (0, 2)$. 2.9. ROCm Libraries
Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be `float`, `double`, `std::complex<float>` or `std::complex<double>`

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class SGS : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>

The Symmetric Gauss-Seidel / SSOR method is for solving system of linear equations \( A x = b \). It approximates the solution iteratively.
```

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be `float`, `double`, `std::complex<float>` or `std::complex<double>`

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class ILU : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Incomplete LU Factorization based on levels.

The Incomplete LU Factorization based on levels computes a sparse lower and sparse upper triangular matrix such that \( A = LU - R \).
```

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be `float`, `double`, `std::complex<float>` or `std::complex<double>`

```cpp
void rocalution::ILU::Set(int p, bool level = true)
Initialize ILU(p) factorization.

Initialize ILU(p) factorization based on power. SAAD
- level = true build the structure based on levels
- level = false build the structure only based on the power(p+1)
```

```cpp
template<class OperatorType, class VectorType, typename ValueType>
class ILUT : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Incomplete LU Factorization based on threshold.

The Incomplete LU Factorization based on threshold computes a sparse lower and sparse upper triangular matrix such that \( A = LU - R \). Fill-in values are dropped depending on a threshold and number of maximal fill-ins per row. SAAD
```

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be `float`, `double`, `std::complex<float>` or `std::complex<double>`
void rocalution::ILUT::Set (double t)
Set drop-off threshold.

void rocalution::ILUT::Set (double t, int maxrow)
Set drop-off threshold and maximum fill-ins per row.

template<class OperatorType, class VectorType, typename ValueType>
class IC: public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Incomplete Cholesky Factorization without fill-ins.

The Incomplete Cholesky Factorization computes a sparse lower triangular matrix such that \( A = LL^T - R \). Additional fill-ins are dropped and the sparsity pattern of the original matrix is preserved.

Template Parameters

- OperatorType: - can be LocalMatrix
- VectorType: - can be LocalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

template<class OperatorType, class VectorType, typename ValueType>
class VariablePreconditioner : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Variable Preconditioner.

The Variable Preconditioner can hold a selection of preconditioners. Thus, any type of preconditioners can be combined. As example, the variable preconditioner can combine Jacobi, GS and ILU - then, the first iteration of the iterative solver will apply Jacobi, the second iteration will apply GS and the third iteration will apply ILU. After that, the solver will start again with Jacobi, GS, ILU.

Template Parameters

- OperatorType: - can be LocalMatrix
- VectorType: - can be LocalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::VariablePreconditioner::SetPreconditioner (int n, Solver< OperatorType, VectorType, ValueType> **precond)
Set the preconditioner sequence.

template<class OperatorType, class VectorType, typename ValueType>
class MultiColored : public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
Base class for all multi-colored preconditioners.

Template Parameters

- OperatorType: - can be LocalMatrix
- VectorType: - can be LocalVector
- ValueType: - can be float, double, std::complex<float> or std::complex<double>

Subclassed by rocalution::MultiColoredILU< OperatorType, VectorType, ValueType >, rocalution::MultiColoredSGS< OperatorType, VectorType, ValueType >

void rocalution::MultiColored::SetPrecondMatrixFormat (unsigned int mat_format)
Set a specific matrix type of the decomposed block matrices.
void rocalution::MultiColored::SetDecomposition (bool decomp)

Set if the preconditioner should be decomposed or not.

template<class OperatorType, class VectorType, typename ValueType>

class MultiColoredSGS : public rocalution::MultiColored<OperatorType, VectorType, ValueType>

Multi-Colored Symmetric Gauss-Seidel / SSOR Preconditioner.

The Multi-Colored Symmetric Gauss-Seidel / SSOR preconditioner is based on the splitting of the original matrix. Higher parallelism in solving the forward and backward substitution is obtained by performing a multi-colored decomposition. Details on the Symmetric Gauss-Seidel / SSOR algorithm can be found in the SGS preconditioner.

Template Parameters

• OperatorType: - can be LocalMatrix
• VectorType: - can be LocalVector
• ValueType: - can be float, double, std::complex<float> or std::complex<double>

Subclassed by rocalution::MultiColoredGS< OperatorType, VectorType, ValueType >

void rocalution::MultiColoredSGS::SetRelaxation (ValueType omega)

Set the relaxation parameter for the SOR/SSOR scheme.

template<class OperatorType, class VectorType, typename ValueType>

class MultiColoredGS : public rocalution::MultiColoredSGS<OperatorType, VectorType, ValueType>

Multi-Colored Gauss-Seidel / SOR Preconditioner.

The Multi-Colored Symmetric Gauss-Seidel / SOR preconditioner is based on the splitting of the original matrix. Higher parallelism in solving the forward substitution is obtained by performing a multi-colored decomposition. Details on the Gauss-Seidel / SOR algorithm can be found in the GS preconditioner.

Template Parameters

• OperatorType: - can be LocalMatrix
• VectorType: - can be LocalVector
• ValueType: - can be float, double, std::complex<float> or std::complex<double>

template<class OperatorType, class VectorType, typename ValueType>

class MultiColoredILU : public rocalution::MultiColoredSGS<OperatorType, VectorType, ValueType>

Multi-Colored Incomplete LU Factorization Preconditioner.

Multi-Colored Incomplete LU Factorization based on the ILU(p) factorization with a power(q)-pattern method. This method provides a higher degree of parallelism of forward and backward substitution compared to the standard ILU(p) preconditioner. Lukarski2012

Template Parameters

• OperatorType: - can be LocalMatrix
• VectorType: - can be LocalVector
• ValueType: - can be float, double, std::complex<float> or std::complex<double>

void rocalution::MultiColoredILU::Set (int p)

Initialize a multi-colored ILU(p, p+1) preconditioner.
void rocalution::MultiColoredILU::Set (int p, int q, bool level = true)
    Initialize a multi-colored ILU(p, q) preconditioner.

    level = true will perform the factorization with levels level = false will perform the factorization only on the power(q)-pattern

template<class OperatorType, class VectorType, typename ValueType>
class MultiElimination public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
    Multi-Elimination Incomplete LU Factorization Preconditioner.

    The Multi-Elimination Incomplete LU preconditioner is based on the following decomposition

    $$A = \begin{pmatrix} D & F \\ E & C \end{pmatrix} = \begin{pmatrix} I & 0 \\ E D^{-1} & I \end{pmatrix} \times \begin{pmatrix} D & F \\ 0 & \hat{A} \end{pmatrix},$$

    where $$\hat{A} = C - ED^{-1}F$$. To make the inversion of D easier, we permute the preconditioning before the factorization with a permutation $$P$$ to obtain only diagonal elements in D. The permutation here is based on a maximal independent set. This procedure can be applied to the block matrix $$\hat{A}$$, in this way we can perform the factorization recursively. In the last level of the recursion, we need to provide a solution procedure. By the design of the library, this can be any kind of solver. SAAD

Template Parameters

- **OperatorType**: can be `LocalMatrix`
- **VectorType**: can be `LocalVector`
- **ValueType**: can be float, double, std::complex<float> or std::complex<double>

int rocalution::MultiElimination::GetSizeDiagBlock (void) const
    Returns the size of the first (diagonal) block of the preconditioner.

int rocalution::MultiElimination::GetLevel (void) const
    Return the depth of the current level.

void rocalution::MultiElimination::Set (Solver<OperatorType, VectorType, ValueType>
    &AA_Solver, int level, double drop_off = 0.0)
    Initialize (recursively) ME-ILU with level (depth of recursion)

    AA_Solvers - defines the last-block solver drop_off - defines drop-off tolerance

void rocalution::MultiElimination::SetPrecondMatrixFormat (unsigned int mat_format)
    Set a specific matrix type of the decomposed block matrices.

template<class OperatorType, class VectorType, typename ValueType>
class DiagJacobiSaddlePointPrecond public rocalution::Preconditioner<OperatorType, VectorType, ValueType>
    Diagonal Preconditioner for Saddle-Point Problems.

    Consider the following saddle-point problem

    $$A = \begin{pmatrix} K & F \\ E & 0 \end{pmatrix}.$$ 

    For such problems we can construct a diagonal Jacobi-type preconditioner of type

    $$P = \begin{pmatrix} K & 0 \\ 0 & S \end{pmatrix},$$

    with $$S = ED^{-1}F$$, where D are the diagonal elements of K. The matrix S is fully constructed (via sparse matrix-matrix multiplication). The preconditioner needs to be initialized with two external solvers/preconditioners - one for the matrix K and one for the matrix S.
Template Parameters

- **OperatorType:** can be `LocalMatrix`
- **VectorType:** can be `LocalVector`
- **ValueType:** can be float, double, std::complex<float> or std::complex<double>

```cpp
void rocalution::DiagJacobiSaddlePointPrecond::Set (Solver<OperatorType, VectorType, ValueType> &K_Solver, Solver<OperatorType, VectorType, ValueType> &S_Solver)
```

Initialize solver for $K$ and $S$.

## 2.9.17 rocSPARSE

### 2.9.17.1 Introduction

rocSPARSE is a library that contains basic linear algebra subroutines for sparse matrices and vectors written in HiP for GPU devices. It is designed to be used from C and C++ code.

The functionality of rocSPARSE is organized in the following categories:

- **Sparse Auxiliary Functions** describe available helper functions that are required for subsequent library calls.
- **Sparse Level 1 Functions** describe operations between a vector in sparse format and a vector in dense format.
- **Sparse Level 2 Functions** describe operations between a matrix in sparse format and a vector in dense format.
- **Sparse Level 3 Functions** describe operations between a matrix in sparse format and multiple vectors in dense format.
- **Preconditioner Functions** describe manipulations on a matrix in sparse format to obtain a preconditioner.
- **Sparse Conversion Functions** describe operations on a matrix in sparse format to obtain a different matrix format.

The code is open and hosted here: [https://github.com/ROCmSoftwarePlatform/rocSPARSE](https://github.com/ROCmSoftwarePlatform/rocSPARSE)

### 2.9.17.2 Device and Stream Management

`hipSetDevice()` and `hipGetDevice()` are HIP device management APIs. They are NOT part of the rocSPARSE API.

#### 2.9.17.2.1 Asynchronous Execution

All rocSPARSE library functions, unless otherwise stated, are non blocking and executed asynchronously with respect to the host. They may return before the actual computation has finished. To force synchronization, `hipDeviceSynchronize()` or `hipStreamSynchronize()` can be used. This will ensure that all previously executed rocSPARSE functions on the device / this particular stream have completed.

#### 2.9.17.2.2 HIP Device Management

Before a HIP kernel invocation, users need to call `hipSetDevice()` to set a device, e.g. device 1. If users do not explicitly call it, the system by default sets it as device 0. Unless users explicitly call `hipSetDevice()` to set to another device, their HIP kernels are always launched on device 0.
The above is a HIP (and CUDA) device management approach and has nothing to do with rocSPARSE. rocSPARSE honors the approach above and assumes users have already set the device before a rocSPARSE routine call.

Once users set the device, they create a handle with `rocsparse_create_handle()`. Subsequent rocSPARSE routines take this handle as an input parameter. rocSPARSE ONLY queries (by `hipGetDevice()`) the user’s device; rocSPARSE does NOT set the device for users. If rocSPARSE does not see a valid device, it returns an error message. It is the users’ responsibility to provide a valid device to rocSPARSE and ensure the device safety.

Users CANNOT switch devices between `rocsparse_create_handle()` and `rocsparse_destroy_handle()`. If users want to change device, they must destroy the current handle and create another rocSPARSE handle.

### 2.9.17.2.3 HIP Stream Management

HIP kernels are always launched in a queue (also known as stream).

If users do not explicitly specify a stream, the system provides a default stream, maintained by the system. Users cannot create or destroy the default stream. However, users can freely create new streams (with `hipStreamCreate()`) and bind it to the rocSPARSE handle. HIP kernels are invoked in rocSPARSE routines. The rocSPARSE handle is always associated with a stream, and rocSPARSE passes its stream to the kernels inside the routine. One rocSPARSE routine only takes one stream in a single invocation. If users create a stream, they are responsible for destroying it.

### 2.9.17.2.4 Multiple Streams and Multiple Devices

If the system under test has multiple HIP devices, users can run multiple rocSPARSE handles concurrently, but can NOT run a single rocSPARSE handle on different discrete devices. Each handle is associated with a particular singular device, and a new handle should be created for each additional device.

### 2.9.17.3 Building and Installing

#### 2.9.17.3.1 Installing from AMD ROCm repositories

rocSPARSE can be installed from AMD ROCm repositories by

```
sudo apt install rocsparse
```

#### 2.9.17.3.2 Building rocSPARSE from Open-Source repository

**Download rocSPARSE**

The rocSPARSE source code is available at the rocSPARSE github page. Download the master branch using:

```
git clone -b master https://github.com/ROCmSoftwarePlatform/rocSPARSE.git cd rocSPARSE
```

Note that if you want to contribute to rocSPARSE, you will need to checkout the develop branch instead of the master branch.

Below are steps to build different packages of the library, including dependencies and clients. It is recommended to install rocSPARSE using the `install.sh` script.
2.9.17.3.3 Using *install.sh* to build dependencies + library

The following table lists common uses of *install.sh* to build dependencies + library.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>./install.sh -h</code></td>
<td>Print help information.</td>
</tr>
<tr>
<td><code>./install.sh -d</code></td>
<td>Build dependencies and library in your local directory. The <code>-d</code> flag only needs to be used once. For subsequent invocations of <em>install.sh</em> it is not necessary to rebuild the dependencies.</td>
</tr>
<tr>
<td><code>./install.sh</code></td>
<td>Build library in your local directory. It is assumed dependencies are available.</td>
</tr>
<tr>
<td><code>./install.sh -i</code></td>
<td>Build library, then build and install rocSPARSE package in /opt/rocm/rocsparse. You will be prompted for sudo access. This will install for all users.</td>
</tr>
</tbody>
</table>

2.9.17.3.4 Using *install.sh* to build dependencies + library + client

The client contains example code, unit tests and benchmarks. Common uses of *install.sh* to build them are listed in the table below.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>./install.sh -h</code></td>
<td>Print help information.</td>
</tr>
<tr>
<td><code>./install.sh -dc</code></td>
<td>Build dependencies, library and client in your local directory. The <code>-d</code> flag only needs to be used once. For subsequent invocations of <em>install.sh</em> it is not necessary to rebuild the dependencies.</td>
</tr>
<tr>
<td><code>./install.sh -c</code></td>
<td>Build library and client in your local directory. It is assumed dependencies are available.</td>
</tr>
<tr>
<td><code>./install.sh -idc</code></td>
<td>Build library, dependencies and client, then build and install rocSPARSE package in /opt/rocm/rocsparse. You will be prompted for sudo access. This will install for all users.</td>
</tr>
<tr>
<td><code>./install.sh -ic</code></td>
<td>Build library and client, then build and install rocSPARSE package in opt/rocm/rocsparse. You will be prompted for sudo access. This will install for all users.</td>
</tr>
</tbody>
</table>

2.9.17.3.5 Using individual commands to build rocSPARSE

CMake 3.5 or later is required in order to build rocSPARSE. The rocSPARSE library contains both, host and device code, therefore the HCC compiler must be specified during cmake configuration process.

rocSPARSE can be built using the following commands:

```
# Create and change to build directory
mkdir -p build/release ; cd build/release
```

(continues on next page)
Boost and GoogleTest is required in order to build rocSPARSE client.

rocSPARSE with dependencies and client can be built using the following commands:

```
# Default install path is /opt/rocm, use -DCMAKE_INSTALL_PREFIX=<path> to adjust it
# Compile rocSPARSE library
make -j$(nproc)
# Install rocSPARSE to /opt/rocm
sudo make install
```

### 2.9.17.3.6 Common build problems

1. **Issue:** HIP (/opt/rocm/hip) was built using hcc 1.0.xxx-xxx-xxx-xxx, but you are using /opt/rocm/bin/hcc with version 1.0.yyy-yyy-yyy-yyy from hipcc (version mismatch). Please rebuild HIP including cmake or update HCC_HOME variable.

   **Solution:** Download HIP from github and use hcc to build from source and then use the built HIP instead of /opt/rocm/hip.

2. **Issue:** For Carrizo - HCC RUNTIME ERROR: Failed to find compatible kernel

   **Solution:** Add the following to the cmake command when configuring: `-DCMAKE_CXX_FLAGS=’-amdgpu-target=gfx801’`

3. **Issue:** For MI25 (Vega10 Server) - HCC RUNTIME ERROR: Failed to find compatible kernel

   **Solution:** `export HCC_AMDGPU_TARGET=gfx900`

4. **Issue:** Could not find a package configuration file provided by “ROCM” with any of the following names:
   ROCMConfig.cmake | br| rocm-config.cmake

2.9. ROCm Libraries
Solution: Install ROCm cmake modules

2.9.17.4 Storage Formats

2.9.17.4.1 COO storage format

The Coordinate (COO) storage format represents a $m \times n$ matrix by

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>number of rows (integer).</td>
</tr>
<tr>
<td>$n$</td>
<td>number of columns (integer).</td>
</tr>
<tr>
<td>$nnz$</td>
<td>number of non-zero elements (integer).</td>
</tr>
<tr>
<td>coo_val</td>
<td>array of $nnz$ elements containing the data (floating point).</td>
</tr>
<tr>
<td>coo_row_ind</td>
<td>array of $nnz$ elements containing the row indices (integer).</td>
</tr>
<tr>
<td>coo_col_ind</td>
<td>array of $nnz$ elements containing the column indices (integer).</td>
</tr>
</tbody>
</table>

The COO matrix is expected to be sorted by row indices and column indices per row. Furthermore, each pair of indices should appear only once. Consider the following $3 \times 5$ matrix and the corresponding COO structures, with $m = 3, n = 5$ and $nnz = 8$ using zero based indexing:

$$A = \begin{pmatrix} 1.0 & 2.0 & 0.0 & 3.0 & 0.0 \\ 0.0 & 4.0 & 5.0 & 0.0 & 0.0 \\ 6.0 & 0.0 & 0.0 & 7.0 & 8.0 \end{pmatrix}$$

where

- $\text{coo\_val}[8] = \{1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0\}$
- $\text{coo\_row\_ind}[8] = \{0, 0, 0, 1, 1, 2, 2\}$
- $\text{coo\_col\_ind}[8] = \{0, 1, 3, 1, 2, 0, 3, 4\}$

2.9.17.4.2 CSR storage format

The Compressed Sparse Row (CSR) storage format represents a $m \times n$ matrix by

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>number of rows (integer).</td>
</tr>
<tr>
<td>$n$</td>
<td>number of columns (integer).</td>
</tr>
<tr>
<td>$nnz$</td>
<td>number of non-zero elements (integer).</td>
</tr>
<tr>
<td>csr_val</td>
<td>array of $nnz$ elements containing the data</td>
</tr>
<tr>
<td>csr_row_ptr</td>
<td>array of $m+1$ elements that point to the start</td>
</tr>
<tr>
<td>csr_col_ind</td>
<td>array of $nnz$ elements containing the column</td>
</tr>
</tbody>
</table>

The CSR matrix is expected to be sorted by column indices within each row. Furthermore, each pair of indices should appear only once. Consider the following $3 \times 5$ matrix and the corresponding CSR structures, with $m = 3, n = 5$ and $nnz = 8$ using one based indexing:

$$A = \begin{pmatrix} 1.0 & 2.0 & 0.0 & 3.0 & 0.0 \\ 0.0 & 4.0 & 5.0 & 0.0 & 0.0 \\ 6.0 & 0.0 & 0.0 & 7.0 & 8.0 \end{pmatrix}$$

where

- $\text{csr\_val}[8] = \{1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0\}$
- $\text{csr\_row\_ptr}[4] = \{1, 4, 6, 9\}$
- $\text{csr\_col\_ind}[8] = \{1, 2, 4, 2, 3, 1, 4, 5\}$
### 2.9.17.4.3 ELL storage format

The Ellpack-Itpack (ELL) storage format represents a $m \times n$ matrix by

- $m$ number of rows (integer).
- $n$ number of columns (integer).
- $\text{ell\_width}$ maximum number of non-zero elements per row (integer).
- $\text{ell\_val}$ array of $m$ times $\text{ell\_width}$ elements containing the data (floating point).
- $\text{ell\_col\_ind}$ array of $m$ times $\text{ell\_width}$ elements containing the column indices (integer).

The ELL matrix is assumed to be stored in column-major format. Rows with less than $\text{ell\_width}$ non-zero elements are padded with zeros ($\text{ell\_val}$) and $-1$ ($\text{ell\_col\_ind}$). Consider the following $3 \times 5$ matrix and the corresponding ELL structures, with $m = 3$, $n = 5$ and $\text{nnz}$ number of non-zero elements of the COO part (integer) $\text{ell\_width}$ maximum number of non-zero elements per row of the ELL part (integer) $\text{ell\_val}$ array of $m$ times $\text{ell\_width}$ elements containing the ELL part data (floating point) $\text{ell\_col\_ind}$ array of $m$ times $\text{ell\_width}$ elements containing the ELL part column indices (integer) $\text{coo\_val}$ array of $\text{nnz}$ elements containing the COO part data (floating point) $\text{coo\_row\_ind}$ array of $\text{nnz}$ elements containing the COO part row indices (integer) $\text{coo\_col\_ind}$ array of $\text{nnz}$ elements containing the COO part column indices (integer).

The HYB format is a combination of the ELL and COO sparse matrix formats. Typically, the regular part of the matrix is stored in ELL storage format, and the irregular part of the matrix is stored in COO storage format. Three different partitioning schemes can be applied when converting a CSR matrix to a matrix in HYB storage format. For further details on the partitioning schemes, see rocsparse_hyb_partition_.

### 2.9.17.5 Types

#### 2.9.17.5.1 rocsparse_handle

**typedef struct _rocsparse_handle **rocsparse_handle**

Handle to the rocSPARSE library context queue.

The rocSPARSE handle is a structure holding the rocSPARSE library context. It must be initialized using `rocsparse_create_handle()` and the returned handle must be passed to all subsequent library function calls. It should be destroyed at the end using `rocsparse_destroy_handle()`.

#### 2.9.17.5.2 rocsparse_mat_descr

**typedef struct _rocsparse_mat_descr **rocsparse_mat_descr**

Descriptor of the matrix.

The rocSPARSE matrix descriptor is a structure holding all properties of a matrix. It must be initialized using `rocsparse_create_mat_descr()` and the returned descriptor must be passed to all subsequent library calls that involve the matrix. It should be destroyed at the end using `rocsparse_destroy_mat_descr()`.
2.9.17.5.3 rocsparse_mat_info

typedef struct _rocsparse_mat_info *rocsparse_mat_info
    Info structure to hold all matrix meta data.

    The rocSPARSE matrix info is a structure holding all matrix information that is gathered during analysis routines. It must be initialized using rocsparse_create_mat_info() and the returned info structure must be passed to all subsequent library calls that require additional matrix information. It should be destroyed at the end using rocsparse_destroy_mat_info().

2.9.17.5.4 rocsparse_hyb_mat

typedef struct _rocsparse_hyb_mat *rocsparse_hyb_mat
    HYB matrix storage format.

    The rocSPARSE HYB matrix structure holds the HYB matrix. It must be initialized using rocsparse_create_hyb_mat() and the returned HYB matrix must be passed to all subsequent library calls that involve the matrix. It should be destroyed at the end using rocsparse_destroy_hyb_mat().

2.9.17.5.5 rocsparse_action

enum rocsparse_action
    Specify where the operation is performed on.

    The rocsparse_action indicates whether the operation is performed on the full matrix, or only on the sparsity pattern of the matrix.

    Values:

        rocsparse_action_symbolic = 0
            Operate only on indices.

        rocsparse_action_numeric = 1
            Operate on data and indices.

2.9.17.5.6 rocsparse_hyb_partition

enum rocsparse_hyb_partition
    HYB matrix partitioning type.

    The rocsparse_hyb_partition type indicates how the hybrid format partitioning between COO and ELL storage formats is performed.

    Values:

        rocsparse_hyb_partition_auto = 0
            automatically decide on ELL nnz per row.

        rocsparse_hyb_partition_user = 1
            user given ELL nnz per row.

        rocsparse_hyb_partition_max = 2
            max ELL nnz per row, no COO part.
2.9.17.5.7 rocsparse_index_base

enum rocsparse_index_base

Specify the matrix index base.

The `rocsparse_index_base` indicates the index base of the indices. For a given `rocsparse_mat_descr`, the `rocsparse_index_base` can be set using `rocsparse_set_mat_index_base()`. The current `rocsparse_index_base` of a matrix can be obtained by `rocsparse_get_mat_index_base()`.

Values:

- `rocsparse_index_base_zero` = 0
  - zero based indexing.

- `rocsparse_index_base_one` = 1
  - one based indexing.

2.9.17.5.8 rocsparse_matrix_type

enum rocsparse_matrix_type

Specify the matrix type.

The `rocsparse_matrix_type` indices the type of a matrix. For a given `rocsparse_mat_descr`, the `rocsparse_matrix_type` can be set using `rocsparse_set_mat_type()`. The current `rocsparse_matrix_type` of a matrix can be obtained by `rocsparse_get_mat_type()`.

Values:

- `rocsparse_matrix_type_general` = 0
  - general matrix type.

- `rocsparse_matrix_type_symmetric` = 1
  - symmetric matrix type.

- `rocsparse_matrix_type_hermitian` = 2
  - hermitian matrix type.

- `rocsparse_matrix_type_triangular` = 3
  - triangular matrix type.

2.9.17.5.9 rocsparse_fill_mode

enum rocsparse_fill_mode

Specify the matrix fill mode.

The `rocsparse_fill_mode` indicates whether the lower or the upper part is stored in a sparse triangular matrix. For a given `rocsparse_mat_descr`, the `rocsparse_fill_mode` can be set using `rocsparse_set_mat_fill_mode()`. The current `rocsparse_fill_mode` of a matrix can be obtained by `rocsparse_get_mat_fill_mode()`.

Values:

- `rocsparse_fill_mode_lower` = 0
  - lower triangular part is stored.

- `rocsparse_fill_mode_upper` = 1
  - upper triangular part is stored.
2.9.17.5.10 rocsparse_diag_type

enum rocsparse_diag_type

Indicates if the diagonal entries are unity.

The rocsparse_diag_type indicates whether the diagonal entries of a matrix are unity or not. If rocsparse_diag_type_non_unit is specified, all present diagonal values will be ignored. For a given rocsparse_mat_descr, the rocsparse_diag_type can be set using rocsparse_set_mat_diag_type(). The current rocsparse_diag_type of a matrix can be obtained by rocsparse_get_mat_diag_type().

Values:

rocsparse_diag_type_non_unit = 0
  diagonal entries are non-unity.

rocsparse_diag_type_unit = 1
  diagonal entries are unity

2.9.17.5.11 rocsparse_operation

enum rocsparse_operation

Specify whether the matrix is to be transposed or not.

The rocsparse_operation indicates the operation performed with the given matrix.

Values:

rocsparse_operation_none = 111
  Operate with matrix.

rocsparse_operation_transpose = 112
  Operate with transpose.

rocsparse_operation_conjugate_transpose = 113
  Operate with conj. transpose.

2.9.17.5.12 rocsparse_pointer_mode

enum rocsparse_pointer_mode

Indicates if the pointer is device pointer or host pointer.

The rocsparse_pointer_mode indicates whether scalar values are passed by reference on the host or device. The rocsparse_pointer_mode can be changed by rocsparse_set_pointer_mode(). The currently used pointer mode can be obtained by rocsparse_get_pointer_mode().

Values:

rocsparse_pointer_mode_host = 0
  scalar pointers are in host memory.

rocsparse_pointer_mode_device = 1
  scalar pointers are in device memory.

2.9.17.5.13 rocsparse_analysis_policy

enum rocsparse_analysis_policy

Specify policy in analysis functions.
The `rocsparse_analysis_policy` specifies whether gathered analysis data should be re-used or not. If meta data from a previous e.g. `rocsparse_csrilu0_analysis()` call is available, it can be re-used for subsequent calls to e.g. `rocsparse_csrsv_analysis()` and greatly improve performance of the analysis function.

Values:

- `rocsparse_analysis_policy_reuse = 0`  
  try to re-use meta data.
- `rocsparse_analysis_policy_force = 1`  
  force to re-build meta data.

### 2.9.17.5.14 rocsparse_solve_policy

**enum rocsparse_solve_policy**  
Specify policy in triangular solvers and factorizations.  
This is a placeholder.

Values:

- `rocsparse_solve_policy_auto = 0`  
  automatically decide on level information.

### 2.9.17.5.15 rocsparse_layer_mode

**enum rocsparse_layer_mode**  
Indicates if layer is active with bitmask.

The `rocsparse_layer_mode` bit mask indicates the logging characteristics.

Values:

- `rocsparse_layer_mode_none = 0x0`  
  layer is not active.
- `rocsparse_layer_mode_log_trace = 0x1`  
  layer is in logging mode.
- `rocsparse_layer_mode_log_bench = 0x2`  
  layer is in benchmarking mode.

### 2.9.17.5.16 rocsparse_status

**enum rocsparse_status**  
List of rocsparse status codes definition.

This is a list of the `rocsparse_status` types that are used by the rocSPARSE library.

Values:

- `rocsparse_status_success = 0`  
  success.
- `rocsparse_status_invalid_handle = 1`  
  handle not initialized, invalid or null.
- `rocsparse_status_not_implemented = 2`  
  function is not implemented.
rocsparse_status_invalid_pointer = 3
invalid pointer parameter.

rocsparse_status_invalid_size = 4
invalid size parameter.

rocsparse_status_memory_error = 5
failed memory allocation, copy, dealloc.

rocsparse_status_internal_error = 6
other internal library failure.

rocsparse_status_invalid_value = 7
invalid value parameter.

rocsparse_status_arch_mismatch = 8
device arch is not supported.

rocsparse_status_zero_pivot = 9
encountered zero pivot.

2.9.17.6 Logging

Three different environment variables can be set to enable logging in rocSPARSE: ROCSPARSE_LAYER,
ROCSPARSE_LOG_TRACE_PATH and ROCSPARSE_LOG_BENCH_PATH.

ROCSPARSE_LAYER is a bit mask, where several logging modes can be combined as follows:

<table>
<thead>
<tr>
<th>ROCSPARSE_LAYER</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>unset</td>
<td>logging is disabled.</td>
</tr>
<tr>
<td>set to 1</td>
<td>trace logging is enabled.</td>
</tr>
<tr>
<td>set to 2</td>
<td>bench logging is enabled.</td>
</tr>
<tr>
<td>set to 3</td>
<td>trace logging and bench logging is enabled.</td>
</tr>
</tbody>
</table>

When logging is enabled, each rocSPARSE function call will write the function name as well as function arguments

to the logging stream. The default logging stream is stderr.

If the user sets the environment variable ROCSPARSE_LOG_TRACE_PATH to the full path name for a file, the file is
opened and trace logging is streamed to that file. If the user sets the environment variable

ROCSPARSE_LOG_BENCH_PATH to the full path name for a file, the file is opened and bench logging is streamed
to that file. If the file cannot be opened, logging output is stream to stderr.

Note that performance will degrade when logging is enabled. By default, the environment variable

ROCSPARSE_LAYER is unset and logging is disabled.

2.9.17.7 Sparse Auxiliary Functions

This module holds all sparse auxiliary functions.

The functions that are contained in the auxiliary module describe all available helper functions that are required for

subsequent library calls.

2.9.17.7.1 rocsparse_create_handle()
rocsparse_create_handle creates the rocSPARSE library context. It must be initialized before any other rocSPARSE API function is invoked and must be passed to all subsequent library function calls. The handle should be destroyed at the end using rocsparse_destroy_handle().

Parameters

- [out] handle: the pointer to the handle to the rocSPARSE library context.

Return Value

- rocsparse_status_success: the initialization succeeded.
- rocsparse_status_invalid_handle: handle pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.

2.9.17.7.2 rocsparse_destroy_handle()

rocsparse_status rocsparse_destroy_handle (rocsparse_handle handle)

Destroy a rocsparse handle.

rocsparse_destroy_handle destroys the rocSPARSE library context and releases all resources used by the rocSPARSE library.

Parameters

- [in] handle: the handle to the rocSPARSE library context.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: handle is invalid.
- rocsparse_status_internal_error: an internal error occurred.

2.9.17.7.3 rocsparse_set_stream()

rocsparse_status rocsparse_set_stream (rocsparse_handle handle, hipStream_t stream)

Specify user defined HIP stream.

rocsparse_set_stream specifies the stream to be used by the rocSPARSE library context and all subsequent function calls.

Example  This example illustrates, how a user defined stream can be used in rocSPARSE.

```c
// Create rocSPARSE handle
rocsparse_handle handle;
rocsparse_create_handle(&handle);

// Create stream
hipStream_t stream;
hipStreamCreate(&stream);

// Set stream to rocSPARSE handle
rocsparse_set_stream(handle, stream);

// Do some work
```

(continues on next page)
// ...  
// Clean up  
rocspars_destroy_handle(handle);  
hipStreamDestroy(stream);  

Parameters  
• [inout] handle: the handle to the rocSPARSE library context.  
• [in] stream: the stream to be used by the rocSPARSE library context.  

Return Value  
• rocspars_status_success: the operation completed successfully.  
• rocspars_status_invalid_handle: handle is invalid.  

2.9.17.7.4 rocspars_get_stream()  

rocspars_status rocspars_get_stream(rocspars_handle handle, hipStream_t *stream)  
Get current stream from library context.  
rocspars_get_stream gets the rocSPARSE library context stream which is currently used for all subsequent function calls.  

Parameters  
• [in] handle: the handle to the rocSPARSE library context.  
• [out] stream: the stream currently used by the rocSPARSE library context.  

Return Value  
• rocspars_status_success: the operation completed successfully.  
• rocspars_status_invalid_handle: handle is invalid.  

2.9.17.7.5 rocspars_set_pointer_mode()  

rocspars_status rocspars_set_pointer_mode(rocspars_handle handle, rocspars_pointer_mode pointer_mode)  
Specify pointer mode.  
rocspars_set_pointer_mode specifies the pointer mode to be used by the rocSPARSE library context and all subsequent function calls. By default, all values are passed by reference on the host. Valid pointer modes are rocspars_pointer_mode_host or rocspars_pointer_mode_device.  

Parameters  
• [in] handle: the handle to the rocSPARSE library context.  
• [in] pointer_mode: the pointer mode to be used by the rocSPARSE library context.  

Return Value  
• rocspars_status_success: the operation completed successfully.  
• rocspars_status_invalid_handle: handle is invalid.
2.9.17.7.6 rocsparse_get_pointer_mode()

rocsparse_status rocsparse_get_pointer_mode(rocsparse_handle handle, rocsparse_pointer_mode *pointer_mode)

Get current pointer mode from library context.

rocsparse_get_pointer_mode gets the rocSPARSE library context pointer mode which is currently used for all subsequent function calls.

Parameters

• [in] handle: the handle to the rocSPARSE library context.
• [out] pointer_mode: the pointer mode that is currently used by the rocSPARSE library context.

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: handle is invalid.

2.9.17.7.7 rocsparse_get_version()

rocsparse_status rocsparse_get_version(rocsparse_handle handle, int *version)

Get rocSPARSE version.

rocsparse_get_version gets the rocSPARSE library version number.

• patch = version % 100
• minor = version / 100 % 1000
• major = version / 10000

Parameters

• [in] handle: the handle to the rocSPARSE library context.
• [out] version: the version number of the rocSPARSE library.

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: handle is invalid.

2.9.17.7.8 rocsparse_get_git_rev()

rocsparse_status rocsparse_get_git_rev(rocsparse_handle handle, char *rev)

Get rocSPARSE git revision.

rocsparse_get_git_rev gets the rocSPARSE library git commit revision (SHA-1).

Parameters

• [in] handle: the handle to the rocSPARSE library context.
• [out] rev: the git commit revision (SHA-1).

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: handle is invalid.

2.9.17.7.9 rocsparse_create_mat_descr()

rocsparse_status rocsparse_create_mat_descr (rocsparse_mat_descr *descr)

Create a matrix descriptor.

rocsparse_create_mat_descr creates a matrix descriptor. It initializes rocsparse_matrix_type to rocsparse_matrix_type_general and rocsparse_index_base to rocsparse_index_base_zero. It should be destroyed at the end using rocsparse_destroy_mat_descr().

Parameters
• [out] descr: the pointer to the matrix descriptor.

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: descr pointer is invalid.

2.9.17.7.10 rocsparse_destroy_mat_descr()

rocsparse_status rocsparse_destroy_mat_descr (rocsparse_mat_descr descr)

Destroy a matrix descriptor.

rocsparse_destroy_mat_descr destroys a matrix descriptor and releases all resources used by the descriptor.

Parameters
• [in] descr: the matrix descriptor.

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: descr is invalid.

2.9.17.7.11 rocsparse_copy_mat_descr()

rocsparse_status rocsparse_copy_mat_descr (rocsparse_mat_descr dest, const rocsparse_mat_descr src)

Copy a matrix descriptor.

rocsparse_copy_mat_descr copies a matrix descriptor. Both, source and destination matrix descriptors must be initialized prior to calling rocsparse_copy_mat_descr.

Parameters
• [out] dest: the pointer to the destination matrix descriptor.
• [in] src: the pointer to the source matrix descriptor.

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: src or dest pointer is invalid.
2.9.17.12 rocsparse_set_mat_index_base()

\[
\text{rocsparse_status rocsparse_set_mat_index_base(rocsparse_mat_descr descr, rocsparse_index_base base)}
\]

Specify the index base of a matrix descriptor.
rocsparse_set_mat_index_base sets the index base of a matrix descriptor. Valid options are \text{rocsparse_index_base_zero} or \text{rocsparse_index_base_one}.

Parameters

\begin{itemize}
\item \text{[inout]} descr: the matrix descriptor.
\item \text{[in]} base: \text{rocsparse_index_base_zero} or \text{rocsparse_index_base_one}.
\end{itemize}

Return Value

\begin{itemize}
\item \text{rocsparse_status_success}: the operation completed successfully.
\item \text{rocsparse_status_invalid_pointer}: descr pointer is invalid.
\item \text{rocsparse_status_invalid_value}: base is invalid.
\end{itemize}

2.9.17.13 rocsparse_get_mat_index_base()

\[
\text{rocsparse_index_base rocsparse_get_mat_index_base(const rocsparse_mat_descr descr)}
\]

Get the index base of a matrix descriptor.
rocsparse_get_mat_index_base returns the index base of a matrix descriptor.

Parameters

\begin{itemize}
\item \text{[in]} descr: the matrix descriptor.
\end{itemize}

2.9.17.14 rocsparse_set_mat_type()

\[
\text{rocsparse_status rocsparse_set_mat_type(rocsparse_mat_descr descr, rocsparse_matrix_type type)}
\]

Specify the matrix type of a matrix descriptor.
rocsparse_set_mat_type sets the matrix type of a matrix descriptor. Valid matrix types are \text{rocsparse_matrix_type_general}, \text{rocsparse_matrix_type_symmetric}, \text{rocsparse_matrix_type_hermitian} or \text{rocsparse_matrix_type_triangular}.

Parameters

\begin{itemize}
\item \text{[inout]} descr: the matrix descriptor.
\item \text{[in]} type: \text{rocsparse_matrix_type_general}, \text{rocsparse_matrix_type_symmetric}, \text{rocsparse_matrix_type_hermitian} or \text{rocsparse_matrix_type_triangular}.
\end{itemize}

Return Value

\begin{itemize}
\item \text{rocsparse_status_success}: the operation completed successfully.
\item \text{rocsparse_status_invalid_pointer}: descr pointer is invalid.
\item \text{rocsparse_status_invalid_value}: type is invalid.
\end{itemize}
2.9.17.15 rocsparse_get_mat_type()

rocsparse_matrix_type rocsparse_get_mat_type(const rocsparse_mat_descr descr)
Get the matrix type of a matrix descriptor.
rocsparse_get_mat_type returns the matrix type of a matrix descriptor.

Return rocsparse_matrix_type_general, rocsparse_matrix_type_symmetric, rocsparse_matrix_type_hermitian
or rocsparse_matrix_type_triangular.

Parameters
• [in] descr: the matrix descriptor.

2.9.17.16 rocsparse_set_mat_fill_mode()

rocsparse_status rocsparse_set_mat_fill_mode(rocsparse_mat_descr descr, rocsparse_fill_mode fill_mode)
Specify the matrix fill mode of a matrix descriptor.
rocsparse_set_mat_fill_mode sets the matrix fill mode of a matrix descriptor. Valid fill modes are
rocsparse_fill_mode_lower or rocsparse_fill_mode_upper.

Parameters
• [inout] descr: the matrix descriptor.
• [in] fill_mode: rocsparse_fill_mode_lower or rocsparse_fill_mode_upper.

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: descr pointer is invalid.
• rocsparse_status_invalid_value: fill_mode is invalid.

2.9.17.17 rocsparse_get_mat_fill_mode()

rocsparse_fill_mode rocsparse_get_mat_fill_mode(const rocsparse_mat_descr descr)
Get the matrix fill mode of a matrix descriptor.
rocsparse_get_mat_fill_mode returns the matrix fill mode of a matrix descriptor.

Return rocsparse_fill_mode_lower or rocsparse_fill_mode_upper.

Parameters
• [in] descr: the matrix descriptor.

2.9.17.18 rocsparse_set_mat_diag_type()

rocsparse_status rocsparse_set_mat_diag_type(rocsparse_mat_descr descr, rocsparse_diag_type diag_type)
Specify the matrix diagonal type of a matrix descriptor.
rocsparse_set_mat_diag_type sets the matrix diagonal type of a matrix descriptor. Valid diagonal
types are rocsparse_diag_type_unit or rocsparse_diag_type_non_unit.
Parameters

- [inout] descr: the matrix descriptor.
- [in] diag_type: rocsparse_diag_type_unit or rocsparse_diag_type_non_unit.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_pointer: descr pointer is invalid.
- rocsparse_status_invalid_value: diag_type is invalid.

2.9.17.7.19 rocsparse_get_mat_diag_type()

rocsparse_diag_type rocsparse_get_mat_diag_type(const rocsparse_mat_descr descr)

Get the matrix diagonal type of a matrix descriptor.

rocsparse_get_mat_diag_type returns the matrix diagonal type of a matrix descriptor.

Return rocsparse_diag_type_unit or rocsparse_diag_type_non_unit.

Parameters


2.9.17.7.20 rocsparse_create_hyb_mat()

rocsparse_status rocsparse_create_hyb_mat (rocsparse_hyb_mat *hyb)

Create a HYB matrix structure.

rocsparse_create_hyb_mat creates a structure that holds the matrix in HYB storage format. It should be destroyed at the end using rocsparse_destroy_hyb_mat().

Parameters

- [inout] hyb: the pointer to the hybrid matrix.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_pointer: hyb pointer is invalid.

2.9.17.7.21 rocsparse_destroy_hyb_mat()

rocsparse_status rocsparse_destroy_hyb_mat (rocsparse_hyb_mat hyb)

Destroy a HYB matrix structure.

rocsparse_destroy_hyb_mat destroys a HYB structure.

Parameters


Return Value

- rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: hyb pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.

2.9.17.7.22 rocsparse_create_mat_info()

rocsparse_status rocsparse_create_mat_info (rocsparse_mat_info *info)

Create a matrix info structure.

rocsparse_create_mat_info creates a structure that holds the matrix info data that is gathered during the analysis routines available. It should be destroyed at the end using rocsparse_destroy_mat_info().

Parameters
• [inout] info: the pointer to the info structure.

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: info pointer is invalid.

2.9.17.7.23 rocsparse_destroy_mat_info()

rocsparse_status rocsparse_destroy_mat_info (rocsparse_mat_info info)

Destroy a matrix info structure.

rocsparse_destroy_mat_info destroys a matrix info structure.

Parameters
• [in] info: the info structure.

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_pointer: info pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.

2.9.17.8 Sparse Level 1 Functions

The sparse level 1 routines describe operations between a vector in sparse format and a vector in dense format. This section describes all rocSPARSE level 1 sparse linear algebra functions.

2.9.17.8.1 rocsparse_axpyi()

rocsparse_status rocsparse_saxpyi (rocsparse_handle handle, rocsparse_int nnz, const float *alpha, const float *x_val, const rocsparse_int *x_ind, float *y, rocsparse_index_base idx_base)

rocsparse_status rocsparse_daxpyi (rocsparse_handle handle, rocsparse_int nnz, const double *alpha, const double *x_val, const rocsparse_int *x_ind, double *y, rocsparse_index_base idx_base)

Scale a sparse vector and add it to a dense vector.
rocsparse_axpyi multiplies the sparse vector $x$ with scalar $\alpha$ and adds the result to the dense vector $y$, such that

$$y := y + \alpha \cdot x$$

```c
for(i = 0; i < nnz; ++i)
{
    y[x_ind[i]] = y[x_ind[i]] + alpha * x_val[i];
}
```

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Parameters**

- `[in]` handle: handle to the rocsparse library context queue.
- `[in]` nnz: number of non-zero entries of vector $x$.
- `[in]` alpha: scalar $\alpha$.
- `[in]` x_val: array of nnz elements containing the values of $x$.
- `[in]` x_ind: array of nnz elements containing the indices of the non-zero values of $x$.
- `[inout]` y: array of values in dense format.
- `[in]` idx_base: `rocsparse_index_base_zero` or `rocsparse_index_base_one`.

**Return Value**

- `rocsparse_status_success`: the operation completed successfully.
- `rocsparse_status_invalid_handle`: the library context was not initialized.
- `rocsparse_status_invalid_value`: idx_base is invalid.
- `rocsparse_status_invalid_size`: nnz is invalid.
- `rocsparse_status_invalid_pointer`: alpha, x_val, x_ind or y pointer is invalid.

### 2.9.17.8.2 rocsparse_doti()

```c
rocsparse_status rocsparse_sdoti (rocsparse_handle handle, rocsparse_int nnz, const float *x_val, const rocsparse_int *x_ind, const float *y, float *result, rocsparse_index_base idx_base)
```

```c
rocsparse_status rocsparse_ddoti (rocsparse_handle handle, rocsparse_int nnz, const double *x_val, const rocsparse_int *x_ind, const double *y, double *result, rocsparse_index_base idx_base)
```

Compute the dot product of a sparse vector with a dense vector.

`rocsparse_doti` computes the dot product of the sparse vector $x$ with the dense vector $y$, such that

$$\text{result} := y^T x$$
for(i = 0; i < nnz; ++i)
{
    result += x_val[i] * y[x_ind[i]];
}

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] nnz: number of non-zero entries of vector x.
- [in] x_val: array of nnz values.
- [in] x_ind: array of nnz elements containing the indices of the non-zero values of x.
- [in] y: array of values in dense format.
- [out] result: pointer to the result, can be host or device memory
- [in] idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_value: idx_base is invalid.
- rocsparse_status_invalid_size: nnz is invalid.
- rocsparse_status_invalid_pointer: x_val, x_ind, y or result pointer is invalid.
- rocsparse_status_memory_error: the buffer for the dot product reduction could not be allocated.
- rocsparse_status_internal_error: an internal error occurred.

2.9.17.8.3 rocsparse_gthr()

rocsparse_status rocsparse_sgthr(rocsparse_handle handle, rocsparse_int nnz, const float *y, float *x_val, const rocsparse_int *x_ind, rocsparse_index_base idx_base)

rocsparse_status rocsparse_dgthr(rocsparse_handle handle, rocsparse_int nnz, const double *y, double *x_val, const rocsparse_int *x_ind, rocsparse_index_base idx_base)

Gather elements from a dense vector and store them into a sparse vector.

rocsparse_gthr gathers the elements that are listed in x_ind from the dense vector y and stores them in the sparse vector x.

for(i = 0; i < nnz; ++i)
{
    x_val[i] = y[x_ind[i]];
}

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.
Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] nnz: number of non-zero entries of \( x \).
- [in] y: array of values in dense format.
- [out] x_val: array of \( \text{nnz} \) elements containing the values of \( x \).
- [in] x_ind: array of \( \text{nnz} \) elements containing the indices of the non-zero values of \( x \).
- [in] idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_value: idx_base is invalid.
- rocsparse_status_invalid_size: nnz is invalid.
- rocsparse_status_invalid_pointer: y, x_val or x_ind pointer is invalid.

2.9.17.8.4 rocsparse_gthrz()

```c
rocsparse_status rocsparse_sgthrz (rocsparse_handle handle, rocsparse_int nnz, float *y, float *x_val,
                                 const rocsparse_int *x_ind, rocsparse_index_base idx_base)
```

Gather and zero out elements from a dense vector and store them into a sparse vector.

rocsparse_gthrz gathers the elements that are listed in \( x\_\text{ind} \) from the dense vector \( y \) and stores them in the sparse vector \( x \). The gathered elements in \( y \) are replaced by zero.

```c
for(i = 0; i < nnz; ++i)
{
    x_val[i] = y[x_ind[i]];
    y[x_ind[i]] = 0;
}
```

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] nnz: number of non-zero entries of \( x \).
- [inout] y: array of values in dense format.
- [out] x_val: array of \( \text{nnz} \) elements containing the non-zero values of \( x \).
- [in] x_ind: array of \( \text{nnz} \) elements containing the indices of the non-zero values of \( x \).
- [in] idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

Return Value

- rocsparse_status_success: the operation completed successfully.
• `rocsparse_status_invalid_handle` : the library context was not initialized.
• `rocsparse_status_invalid_value`  : `idx_base` is invalid.
• `rocsparse_status_invalid_size` : `nnz` is invalid.
• `rocsparse_status_invalid_pointer` : `y`, `x_val` or `x_ind` pointer is invalid.

### 2.9.17.8.5 `rocsparse_roti()`

```c
rocsparse_status rocsparse_sroti (rocsparse_handle handle, rocsparse_int nnz, float *x_val, const rocsparse_int *x_ind, float *y, const float *c, const float *s, rocsparse_index_base idx_base)
```  
```c
rocsparse_status rocsparse_droti (rocsparse_handle handle, rocsparse_int nnz, double *x_val, const rocsparse_int *x_ind, double *y, const double *c, const double *s, rocsparse_index_base idx_base)
```  
Apply Givens rotation to a dense and a sparse vector.

`rocsparse_roti` applies the Givens rotation matrix $G$ to the sparse vector $x$ and the dense vector $y$, where

$$
G = \begin{pmatrix}
c & s \\
-s & c
\end{pmatrix}
$$

```c
for(i = 0; i < nnz; ++i)
{
    x_tmp = x_val[i];
    y_tmp = y[x_ind[i]];
    x_val[i] = c * x_tmp + s * y_tmp;
    y[x_ind[i]] = c * y_tmp - s * x_tmp;
}
```

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Parameters**

- **[in]** `handle` : handle to the rocsparse library context queue.
- **[in]** `nnz` : number of non-zero entries of $x$.
- **[inout]** `x_val` : array of `nnz` elements containing the non-zero values of $x$.
- **[in]** `x_ind` : array of `nnz` elements containing the indices of the non-zero values of $x$.
- **[inout]** `y` : array of values in dense format.
- **[in]** `c` : pointer to the cosine element of $G$, can be on host or device.
- **[in]** `s` : pointer to the sine element of $G$, can be on host or device.
- **[in]** `idx_base` : `rocsparse_index_base_zero` or `rocsparse_index_base_one`.

**Return Value**

- `rocsparse_status_success` : the operation completed successfully.
- `rocsparse_status_invalid_handle` : the library context was not initialized.
- `rocsparse_status_invalid_value` : `idx_base` is invalid.
- `rocsparse_status_invalid_size` : `nnz` is invalid.
2.9.17.8.6  rocsparse_sctr()

rocsparse_status rocsparse_sctr (rocsparse_handle handle, rocsparse_int nnz, const float *x_val, const rocsparse_int *x_ind, float *y, rocsparse_index_base idx_base)

rocsparse_status rocsparse_dctr (rocsparse_handle handle, rocsparse_int nnz, const double *x_val, const rocsparse_int *x_ind, double *y, rocsparse_index_base idx_base)

Scatter elements from a dense vector across a sparse vector.

rocsparse_sctr scatters the elements that are listed in x_ind from the sparse vector x into the dense vector y. Indices of y that are not listed in x_ind remain unchanged.

for(i = 0; i < nnz; ++i)
{
    y[x_ind[i]] = x_val[i];
}

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] nnz: number of non-zero entries of x.
- [in] x_val: array of nnz elements containing the non-zero values of x.
- [in] x_ind: array of nnz elements containing the indices of the non-zero values of x.
- [inout] y: array of values in dense format.
- [in] idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_value: idx_base is invalid.
- rocsparse_status_invalid_size: nnz is invalid.
- rocsparse_status_invalid_pointer: x_val, x_ind or y pointer is invalid.
2.9.17.9.1 rocsparse_coomv()

rocsparse_status rocsparse_coomv(rocsparse_handle handle, rocsparse_operation trans, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, const float *alpha, const rocsparse_mat_descr descr, const float *coo_val, const rocsparse_int *coo_row_ind, const rocsparse_int *coo_col_ind, const float *x, const float *beta, float *y)

Sparse matrix vector multiplication using COO storage format.

rocsparse_coomv multiplies the scalar \(\alpha\) with a sparse \(m \times n\) matrix, defined in COO storage format, and the dense vector \(x\) and adds the result to the dense vector \(y\) that is multiplied by the scalar \(\beta\), such that

\[ y := \alpha \cdot \text{op}(A) \cdot x + \beta \cdot y, \]

with

\[
\text{op}(A) = \begin{cases} 
A, & \text{if } \text{trans} == \text{rocsparse_operation_none} \\
A^T, & \text{if } \text{trans} == \text{rocsparse_operation_transpose} \\
A^H, & \text{if } \text{trans} == \text{rocsparse_operation_conjugate_transpose}
\end{cases}
\]

The COO matrix has to be sorted by row indices. This can be achieved by using rocsparse_coosort_by_row().

```
for(i = 0; i < m; ++i)
{
    y[i] = beta * y[i];
}
for(i = 0; i < nnz; ++i)
{
    y[coo_row_ind[i]] += alpha * coo_val[i] * x[coo_col_ind[i]];}
```

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Note** Currently, only \text{trans} == \text{rocsparse_operation_none} is supported.

**Parameters**

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse COO matrix.
- [in] n: number of columns of the sparse COO matrix.
- [in] nnz: number of non-zero entries of the sparse COO matrix.
- [in] alpha: scalar \(\alpha\).
- [in] descr: descriptor of the sparse COO matrix. Currently, only \text{rocsparse_matrix_type_general} is supported.
• [in] `coo_row_ind`: array of `nnz` elements containing the row indices of the sparse COO matrix.
• [in] `coo_col_ind`: array of `nnz` elements containing the column indices of the sparse COO matrix.
• [in] `x`: array of `n` elements (\( op(A) = A \)) or `m` elements (\( op(A) = A^T \) or \( op(A) = A^H \)).
• [in] `beta`: scalar \( \beta \).
• [inout] `y`: array of `m` elements (\( op(A) = A \)) or `n` elements (\( op(A) = A^T \) or \( op(A) = A^H \)).

Return Value

• `rocsparse_status_success`: the operation completed successfully.
• `rocsparse_status_invalid_handle`: the library context was not initialized.
• `rocsparse_status_invalid_size`: `m`, `n` or `nnz` is invalid.
• `rocsparse_status_invalid_pointer`: `descr`, `alpha`, `coo_val`, `coo_row_ind`, `coo_col_ind`, `x`, `beta` or `y` pointer is invalid.
• `rocsparse_status_arch_mismatch`: the device is not supported.
• `rocsparse_status_not_implemented`: `trans` \( \neq \) `rocsparse_operation_none` or `rocsparse_matrix_type_general`.

2.9.17.9.2 rocsparse_csrmv_analysis()

```c
rocsparse_status rocsparse_scscrmv_analysis(rocsparse_handle handle, rocsparse_operation trans,
                                          rocsparse_int m, rocsparse_int n, rocsparse_int nnz,
                                          const rocsparse_matdescr descr, const float *
csr_val, const rocsparse_int *csr_row_ptr, const
rocsparse_int *csr_col_ind, rocsparse_matinfo info)
```

```c
rocsparse_status rocsparse_dcsrmv_analysis(rocsparse_handle handle, rocsparse_operation trans,
                                          rocsparse_int m, rocsparse_int n, rocsparse_int nnz,
                                          const rocsparse_matdescr descr, const double *
csr_val, const rocsparse_int *csr_row_ptr, const
rocsparse_int *csr_col_ind, rocsparse_matinfo info)
```

Sparse matrix vector multiplication using CSR storage format.

`rocsparse_csrmv_analysis` performs the analysis step for `rocsparse_scscrmv()` and `rocsparse_dcsrmv()`. It is expected that this function will be executed only once for a given matrix and particular operation type. The gathered analysis meta data can be cleared by `rocsparse_csrmv_clear()`.

**Note** If the matrix sparsity pattern changes, the gathered information will become invalid.

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

• [in] `handle`: handle to the rocsparse library context queue.
• [in] `trans`: matrix operation type.
• [in] `m`: number of rows of the sparse CSR matrix.
• [in] `n`: number of columns of the sparse CSR matrix.
• [in] `nnz`: number of non-zero entries of the sparse CSR matrix.
• [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
• [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
• [out] info: structure that holds the information collected during the analysis step.

Return Value

• rocspare_status_success: the operation completed successfully.
• rocspare_status_invalid_handle: the library context was not initialized.
• rocspare_status_invalid_size: m, n or nnz is invalid.
• rocspare_status_invalid_pointer: descr, csr_val, csr_row_ptr, csr_col_ind or info pointer is invalid.
• rocspare_status_memory_error: the buffer for the gathered information could not be allocated.
• rocspare_status_internal_error: an internal error occurred.
• rocspare_status_not_implemented: trans != rocspare_operation_none or rocspare_matrix_type != rocspare_matrix_type_general.

2.9.17.9.3 rocspare_csrmv()}

rocspare_status rocspare_csrmv (rocspare_handle handle, rocspare_operation trans, rocspare_int m, rocspare_int n, rocspare_int nnz, const float *alpha, const rocspare_mat_desc descr, const float *csr_val, const rocspare_int *csr_row_ptr, const rocspare_int *csr_col_ind, rocspare_mat_info info, const float *x, const float *beta, float *y)

rocspare_status rocspare_dcsrmv (rocspare_handle handle, rocspare_operation trans, rocspare_int m, rocspare_int n, rocspare_int nnz, const double *alpha, const rocspare_mat_desc descr, const double *csr_val, const rocspare_int *csr_row_ptr, const rocspare_int *csr_col_ind, rocspare_mat_info info, const double *x, const double *beta, double *y)

Sparse matrix vector multiplication using CSR storage format.

rocspare_csrmv multiplies the scalar $\alpha$ with a sparse $m \times n$ matrix, defined in CSR storage format, and the dense vector $x$ and adds the result to the dense vector $y$ that is multiplied by the scalar $\beta$, such that

\[ y := \alpha \cdot \text{op}(A) \cdot x + \beta \cdot y, \]

with

\[ \text{op}(A) = \begin{cases} 
A, & \text{if } \text{trans} == \text{rocspare_operation_none} \\
A^T, & \text{if } \text{trans} == \text{rocspare_operation_transpose} \\
A^H, & \text{if } \text{trans} == \text{rocspare_operation_conjugate_transpose}
\end{cases} \]

The info parameter is optional and contains information collected by rocspare_scsrmv_analysis() or rocspare_dcsrmv_analysis(). If present, the information will be used to speed up the csrmv computation. If info == NULL, general csrmv routine will be used instead.
for(i = 0; i < m; ++i)
{
    y[i] = beta * y[i];
    for(j = csr_row_ptr[i]; j < csr_row_ptr[i + 1]; ++j)
    {
        y[i] = y[i] + alpha * csr_val[j] * x[csr_col_ind[j]];
    }
}

Note  This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Note  Currently, only trans == rocsparse_operation_none is supported.

Example  This example performs a sparse matrix vector multiplication in CSR format using additional meta data to improve performance.

// Create matrix info structure
rocsparse_mat_info info;
rocsparse_create_mat_info(&info);

// Perform analysis step to obtain meta data
rocsparse_scsrmv_analysis(handle,
rocsparse_operation_none,
m,
n,
.nnz,
descr,
csr_val,
csr_row_ptr,
csr_col_ind,
info);

// Compute y = Ax
rocsparse_scsrmv(handle,
rocsparse_operation_none,
m,
n,
nnz,
alpha,
descr,
csr_val,
csr_row_ptr,
csr_col_ind,
info,
x,
beta,
y);

// Do more work
// ...

// Clean up
rocsparse_destroy_mat_info(info);

Parameters
• **[in]** `handle`: handle to the rocsparse library context queue.
• **[in]** `trans`: matrix operation type.
• **[in]** `m`: number of rows of the sparse CSR matrix.
• **[in]** `n`: number of columns of the sparse CSR matrix.
• **[in]** `nnz`: number of non-zero entries of the sparse CSR matrix.
• **[in]** `alpha`: scalar $\alpha$.
• **[in]** `descr`: descriptor of the sparse CSR matrix. Currently, only `rocsparse_matrix_type_general` is supported.
• **[in]** `csr_val`: array of `nnz` elements of the sparse CSR matrix.
• **[in]** `csr_row_ptr`: array of `m+1` elements that point to the start of every row of the sparse CSR matrix.
• **[in]** `csr_col_ind`: array of `nnz` elements containing the column indices of the sparse CSR matrix.
• **[in]** `info`: information collected by `rocsparse_scsrmv_analysis()` or `rocsparse_dcsrmv_analysis()`, can be NULL if no information is available.
• **[in]** `x`: array of $n$ elements ($\text{op}(A) == A$) or $m$ elements ($\text{op}(A) == A^T$ or $\text{op}(A) == A^H$).
• **[in]** `beta`: scalar $\beta$.
• **[inout]** `y`: array of $m$ elements ($\text{op}(A) == A$) or $n$ elements ($\text{op}(A) == A^T$ or $\text{op}(A) == A^H$).

**Return Value**

• `rocsparse_status_success`: the operation completed successfully.
• `rocsparse_status_invalid_handle`: the library context was not initialized.
• `rocsparse_status_invalid_size`: `m`, `n` or `nnz` is invalid.
• `rocsparse_status_invalid_pointer`: `descr`, `alpha`, `csr_val`, `csr_row_ptr`, `csr_col_ind`, `x`, `beta` or `y` pointer is invalid.
• `rocsparse_status_arch_mismatch`: the device is not supported.
• `rocsparse_status_not_implemented`: `trans` $\neq$ `rocsparse_operation_none` or `rocsparse_matrix_type` $\neq$ `rocsparse_matrix_type_general`.

### 2.9.17.9.4 `rocsparse_csrmm_analysis_clear()`

**rocsparse_status** `rocsparse_csrmm_clear`(`rocsparse_handle handle`, `rocsparse_mat_info info`)  
Sparse matrix vector multiplication using CSR storage format.

`rocsparse_csrmm_clear` deallocates all memory that was allocated by `rocsparse_scsrmv_analysis()` or `rocsparse_dcsrmv_analysis()`. This is especially useful, if memory is an issue and the analysis data is not required anymore for further computation, e.g. when switching to another sparse matrix format.

**Note** Calling `rocsparse_csrmm_clear` is optional. All allocated resources will be cleared, when the opaque `rocsparse_mat_info` struct is destroyed using `rocsparse_destroy_mat_info()`.

**Parameters**

• **[in]** `handle`: handle to the rocsparse library context queue.
• **[inout]** `info`: structure that holds the information collected during analysis step.
Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_pointer: info pointer is invalid.
- rocsparse_status_memory_error: the buffer for the gathered information could not be deallocated.
- rocsparse_status_internal_error: an internal error occurred.

2.9.17.9.5 rocsparse_ellmv()

rocsparse_status rocsparse_ellmv(rocsparse_handle handle, rocsparse_operation trans, rocsparse_int m, rocsparse_int n, const float *alpha, const rocsparse_mat_descr descr, const float *ell_val, const rocsparse_int *ell_col_ind, rocsparse_int ell_width, const float *x, const float *beta, float *y)

Sparse matrix vector multiplication using ELL storage format.

rocsparse_ellmv multiplies the scalar $\alpha$ with a sparse $m \times n$ matrix, defined in ELL storage format, and the dense vector $x$ and adds the result to the dense vector $y$ that is multiplied by the scalar $\beta$, such that

$$
y := \alpha \cdot op(A) \cdot x + \beta \cdot y,$$

with

$$
op(A) = \begin{cases} 
A, & \text{if } \text{trans} == \text{rocsparse_operation_none} \\
A^T, & \text{if } \text{trans} == \text{rocsparse_operation_transpose} \\
A^H, & \text{if } \text{trans} == \text{rocsparse_operation_conjugate_transpose}
\end{cases}
$$

```c
for (i = 0; i < m; ++i)
{
    y[i] = beta * y[i];

    for (p = 0; p < ell_width; ++p)
    {
        idx = p * m + i;

        if ((ell_col_ind[idx] >= 0) && (ell_col_ind[idx] < n))
        {
            y[i] = y[i] + alpha * ell_val[idx] * x[ell_col_ind[idx]];}
    }
}
```

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Note Currently, only $\text{trans} == \text{rocsparse_operation_none}$ is supported.
Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse ELL matrix.
- [in] n: number of columns of the sparse ELL matrix.
- [in] alpha: scalar $\alpha$.
- [in] descr: descriptor of the sparse ELL matrix. Currently, only `rocsparse_matrix_type_general` is supported.
- [in] ell_val: array that contains the elements of the sparse ELL matrix. Padded elements should be zero.
- [in] ell_col_ind: array that contains the column indices of the sparse ELL matrix. Padded column indices should be -1.
- [in] ell_width: number of non-zero elements per row of the sparse ELL matrix.
- [in] x: array of $n$ elements ($op(A) == A$) or $m$ elements ($op(A) == A^T$ or $op(A) == A^H$).
- [in] beta: scalar $\beta$.
- [inout] y: array of $m$ elements ($op(A) == A$) or $n$ elements ($op(A) == A^T$ or $op(A) == A^H$).

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: $m$, $n$, or `ell_width` is invalid.
- rocsparse_status_invalid_pointer: descr, alpha, `ell_val`, `ell_col_ind`, x, beta or y pointer is invalid.
- rocsparse_status_not_implemented: `trans` != `rocsparse_operation_none` or `rocsparse_matrix_type` != `rocsparse_matrix_type_general`.

2.9.17.9.6 rocsparse_hybmv()

rocsparse_status rocsparse_hybmv (rocsparse_handle handle, rocsparse_operation trans, const float *alpha, const rocsparse_mat_descr descr, const rocsparse_hyb_mat hyb, const float *x, const float *beta, float *y)

Sparse matrix vector multiplication using HYB storage format.

rocsparse_hybmv multiplies the scalar $\alpha$ with a sparse $m \times n$ matrix, defined in HYB storage format, and the dense vector $x$ and adds the result to the dense vector $y$ that is multiplied by the scalar $\beta$, such that

$$y := \alpha \cdot op(A) \cdot x + \beta \cdot y,$$

with

$$op(A) = \begin{cases} A, & \text{if } trans == \text{rocsparse_operation_none} \\ A^T, & \text{if } trans == \text{rocsparse_operation_transpose} \\ A^H, & \text{if } trans == \text{rocsparse_operation_conjugate_transpose} \end{cases}$$
Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Note Currently, only \texttt{trans == rocsparse_operation\_none} is supported.

Parameters

- [in] \texttt{handle}: handle to the rocsparse library context queue.
- [in] \texttt{trans}: matrix operation type.
- [in] \texttt{alpha}: scalar \(\alpha\).
- [in] \texttt{descr}: descriptor of the sparse HYB matrix. Currently, only \texttt{rocsparse\_matrix\_type\_general} is supported.
- [in] \texttt{hyb}: matrix in HYB storage format.
- [in] \texttt{x}: array of \(n\) elements (\(op(A) == A\)) or \(m\) elements (\(op(A) == A^T\) or \(op(A) == A^H\)).
- [in] \texttt{beta}: scalar \(\beta\).
- [inout] \texttt{y}: array of \(m\) elements (\(op(A) == A\)) or \(n\) elements (\(op(A) == A^T\) or \(op(A) == A^H\)).

Return Value

- \texttt{rocsparse\_status\_success}: the operation completed successfully.
- \texttt{rocsparse\_status\_invalid\_handle}: the library context was not initialized.
- \texttt{rocsparse\_status\_invalid\_size}: hyb structure was not initialized with valid matrix sizes.
- \texttt{rocsparse\_status\_invalid\_pointer}: descr, alpha, hyb, x, beta or y pointer is invalid.
- \texttt{rocsparse\_status\_invalid\_value}: hyb structure was not initialized with a valid partitioning type.
- \texttt{rocsparse\_status\_arch\_mismatch}: the device is not supported.
- \texttt{rocsparse\_status\_memory\_error}: the buffer could not be allocated.
- \texttt{rocsparse\_status\_internal\_error}: an internal error occurred.
- \texttt{rocsparse\_status\_not\_implemented}: \texttt{trans != rocsparse\_operation\_none} or \texttt{rocsparse\_matrix\_type !== rocsparse\_matrix\_type\_general}.

2.9.17.9.7 \texttt{rocsparse\_csrsv\_zero\_pivot()} \texttt{rocsparse\_status rocsparse\_csrsv\_zero\_pivot(rocsparse\_handle handle, const rocsparse\_mat\_descr descr, rocsparse\_mat\_info info, rocsparse\_int *position)}

Sparse triangular solve using CSR storage format.

\texttt{rocsparse\_csrsv\_zero\_pivot} returns \texttt{rocsparse\_status\_zero\_pivot}, if either a structural or numerical zero has been found during \texttt{rocsparse\_scsrsv\_solve()} or \texttt{rocsparse\_dcsrsv\_solve()} computation. The first zero pivot \(j\) at \(A_{j,j}\) is stored in \texttt{position}, using same index base as the CSR matrix.

\texttt{position} can be in host or device memory. If no zero pivot has been found, \texttt{position} is set to -1 and \texttt{rocsparse\_status\_success} is returned instead.

Note \texttt{rocsparse\_csrsv\_zero\_pivot} is a blocking function. It might influence performance negatively.

Parameters
• [in] handle: handle to the rocsparse library context queue.
• [in] info: structure that holds the information collected during the analysis step.
• [inout] position: pointer to zero pivot $j$, can be in host or device memory.

**Return Value**

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_pointer: info or position pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.
- rocsparse_status_zero_pivot: zero pivot has been found.

### 2.9.17.9.8 rocsparse_csrsv_buffer_size()

```c
rocsparse_status rocsparse_csrsv_buffer_size(rocsparse_handle handle, rocsparse_operation trans, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, size_t *buffer_size)
```

Sparse triangular solve using CSR storage format.

`rocsparse_csrsv_buffer_size` returns the size of the temporary storage buffer that is required by `rocsparse_scsrsv_analysis()`, `rocsparse_dcsrsv_analysis()`, `rocsparse_scsrsv_solve()` and `rocsparse_dcsrsv_solve()`. The temporary storage buffer must be allocated by the user. The size of the temporary storage buffer is identical to the size returned by `rocsparse_scsrilu0_buffer_size()` and `rocsparse_dcsrilu0_buffer_size()` if the matrix sparsity pattern is identical. The user allocated buffer can thus be shared between subsequent calls to those functions.

**Parameters**

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
• [out] info: structure that holds the information collected during the analysis step.
• [in] buffer_size: number of bytes of the temporary storage buffer required by rocsparse_scsrsv_analysis(), rocsparse_dcsrsv_analysis(), rocsparse_scsrsv_solve() and rocsparse_dcsrsv_solve().

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m or nnz is invalid.
• rocsparse_status_invalid_pointer: descr, csr_val, csr_row_ptr, csr_col_ind, info or buffer_size pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.
• rocsparse_status_not_implemented: trans != rocsparse_operation_none or rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.9.9 rocsparse_csrsv_analysis()

rocsparse_status rocsparse_scsrsv_analysis(rocsparse_handle handle, rocsparse_operation trans, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, rocsparse_analysis_policy analysis, rocsparse_solve_policy solve, void *temp_buffer)

rocsparse_status rocsparse_dcsrsv_analysis(rocsparse_handle handle, rocsparse_operation trans, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const double *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, rocsparse_analysis_policy analysis, rocsparse_solve_policy solve, void *temp_buffer)

Sparse triangular solve using CSR storage format.

rocsparse_csrsv_analysis performs the analysis step for rocsparse_scsrsv_solve() and rocsparse_dcsrsv_solve(). It is expected that this function will be executed only once for a given matrix and particular operation type. The analysis meta data can be cleared by rocsparse_csrsv_clear().

rocsparse_csrsv_analysis can share its meta data with rocsparse_scsrilu0_analysis() and rocsparse_dcsrilu0_analysis(). Selecting rocsparse_analysis_policyReuse policy can greatly improve computation performance of meta data. However, the user need to make sure that the sparsity pattern remains unchanged. If this cannot be assured, rocsparse_analysis_policy_force has to be used.

Note If the matrix sparsity pattern changes, the gathered information will become invalid.

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters
• [in] handle: handle to the rocsparse library context queue.
• [in] trans: matrix operation type.
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- [in] m: number of rows of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
- [out] info: structure that holds the information collected during the analysis step.
- [in] analysis: rocsparse_analysis_policy_reuse or rocsparse_analysis_policy_force.
- [in] temp_buffer: temporary storage buffer allocated by the user.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m or nnz is invalid.
- rocsparse_status_invalid_pointer: descr, csr_row_ptr, csr_col_ind, info or temp_buffer pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.
- rocsparse_status_not_implemented: trans != rocsparse_operation_none or rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.9.10 rocsparse_csrsv_solve()

rocsparse_status rocsparse_csrsv_solve (rocsparse_handle handle, rocsparse_operation trans, rocsparse_int m, rocsparse_int nnz, const float *alpha, const rocsparse_matdescr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_matinfo info, const float *x, float *y, rocsparse_solve_policy policy, void *temp_buffer)

Sparse triangular solve using CSR storage format.

rocsparse_csrsv_solve solves a sparse triangular linear system of a sparse m × m matrix, defined in CSR storage format, a dense solution vector y and the right-hand side x that is multiplied by α, such that

\[ op(A) \cdot y = \alpha \cdot x, \]
with

\[
op(A) = \begin{cases} 
A, & \text{if } \text{trans} == \text{rocsparse_operation_none} \\
A^T, & \text{if } \text{trans} == \text{rocsparse_operationTranspose} \\
A^H, & \text{if } \text{trans} == \text{rocsparse_operationConjugateTranspose}
\end{cases}
\]

\text{rocsparse_csrsv_solve} requires a user allocated temporary buffer. Its size is returned by \text{rocsparse_dcsrsv_buffer_size()} or \text{rocsparse_dcsrsv_buffer_size()}. Furthermore, analysis meta data is required. It can be obtained by \text{rocsparse_scsrsv_analysis()} or \text{rocsparse_dcsrsv_analysis()}. \text{rocsparse_csrsv_solve} reports the first zero pivot (either numerical or structural zero). The zero pivot status can be checked calling \text{rocsparse_csrsv_zero_pivot()}. If \text{rocsparse_diag_type} == \text{rocsparse_diag_type_unit}, no zero pivot will be reported, even if \(A_{j,j} = 0\) for some \(j\).

\textbf{Note} The sparse CSR matrix has to be sorted. This can be achieved by calling \text{rocsparse_csrsv_sort()}.  

\textbf{Note} This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

\textbf{Note} Currently, only \text{trans} == \text{rocsparse_operation_none} is supported.

\textbf{Example} Consider the lower triangular \(m \times m\) matrix \(L\), stored in CSR storage format with unit diagonal. The following example solves \(L \cdot y = x\).

```c
// Create rocSPARSE handle  
rocsparse_handle handle;  
rocsparse_create_handle(&handle);

// Create matrix descriptor  
rocsparse_mat_descr descr;  
rocsparse_create_mat_descr(&descr);  
rocsparse_set_mat_fill_mode(descr, rocsparse_fill_mode_lower);  
rocsparse_set_mat_diag_type(descr, rocsparse_diag_type_unit);

// Create matrix info structure  
rocsparse_mat_info info;  
rocsparse_create_mat_info(&info);

// Obtain required buffer size  
size_t buffer_size;  
rocsparse_dcsrsv_buffer_size(handle,  
    rocsparse_operation_none,  
    m,  
    nnz,  
    descr,  
    csr_val,  
    csr_row_ptr,  
    csr_col_ind,  
    info,  
    &buffer_size);

// Allocate temporary buffer  
void* temp_buffer;  
hipMalloc(&temp_buffer, buffer_size);

// Perform analysis step  
rocsparse_dcsrsv_analysis(handle,  
    rocsparse_operation_none,  
    m,
(continues on next page)
nnz,
descr,
csr_val,
csr_row_ptr,
csr_col_ind,
info,
rocsparse_analysis_policy_reuse,
rocsparse_solve_policy_auto,
temp_buffer);

// Solve Ly = x
rocsparse_dcsrsv_solve(handle,
rocsparse_operation_none,

// No zero pivot should be found, with L having unit diagonal

// Clean up
hipFree(temp_buffer);
rocsparse_destroy_mat_info(info);
rocsparse_destroy_mat_descr(descr);
rocsparse_destroy_handle(handle);

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
- [in] info: structure that holds the information collected during the analysis step.
- [in] x: array of m elements, holding the right-hand side.
- [out] y: array of m elements, holding the solution.
• [in] policy: \texttt{rocsparse\_solve\_policy\_auto}.
• [in] temp_buffer: temporary storage buffer allocated by the user.

Return Value
• rocsparse\_status\_success: the operation completed successfully.
• rocsparse\_status\_invalid\_handle: the library context was not initialized.
• rocsparse\_status\_invalid\_size: m or nnz is invalid.
• rocsparse\_status\_invalid\_pointer: descr, alpha, csr\_val, csr\_row\_ptr, csr\_col\_ind, x or y pointer is invalid.
• rocsparse\_status\_arch\_mismatch: the device is not supported.
• rocsparse\_status\_internal\_error: an internal error occurred.
• rocsparse\_status\_not\_implemented: trans \(!=\) rocsparse\_operation\_none or rocsparse\_matrix\_type

2.9.17.9.11 rocsparse\_csrsv\_clear()

\texttt{rocsparse\_csrsv\_clear(handle, descr, info)}

Sparse triangular solve using CSR storage format.
rocsparse\_csrsv\_clear deallocates all memory that was allocated by rocsparse\_scsrsv\_analysis() or rocsparse\_dcsrsv\_analysis(). This is especially useful, if memory is an issue and the analysis data is not required for further computation, e.g. when switching to another sparse matrix format. Calling rocsparse\_csrsv\_clear is optional. All allocated resources will be cleared, when the opaque rocsparse\_mat\_info struct is destroyed using rocsparse\_destroy\_mat\_info().

Parameters
• [in] handle: handle to the rocsparse library context queue.
• [inout] info: structure that holds the information collected during the analysis step.

Return Value
• rocsparse\_status\_success: the operation completed successfully.
• rocsparse\_status\_invalid\_handle: the library context was not initialized.
• rocsparse\_status\_invalid\_pointer: info pointer is invalid.
• rocsparse\_status\_memory\_error: the buffer holding the meta data could not be deallocated.
• rocsparse\_status\_internal\_error: an internal error occurred.

2.9.17.10 Sparse Level 3 Functions

This module holds all sparse level 3 routines.
The sparse level 3 routines describe operations between a matrix in sparse format and multiple vectors in dense format that can also be seen as a dense matrix.
2.9.17.10.1 rocsparse_csrmm()

rocsparse_status rocsparse_csrmm(rocsparse_handle handle, rocsparse_operation trans_A, rocsparse_operation trans_B, rocsparse_int m, rocsparse_int n, rocsparse_int k, rocsparse_int nnz, const float *alpha, const rocsparse_mat_descr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, const float *B, rocsparse_int ldb, const float *beta, float *C, rocsparse_int ldc)

rocsparse_status rocsparse_dcsrmm(rocsparse_handle handle, rocsparse_operation trans_A, rocsparse_operation trans_B, rocsparse_int m, rocsparse_int n, rocsparse_int k, rocsparse_int nnz, const double *alpha, const rocsparse_mat_descr descr, const double *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, const double *B, rocsparse_int ldb, const double *beta, double *C, rocsparse_int ldc)

Sparse matrix dense matrix multiplication using CSR storage format.

rocsparse_csrmm multiplies the scalar $\alpha$ with a sparse $m \times k$ matrix $A$, defined in CSR storage format, and the dense $k \times n$ matrix $B$ and adds the result to the dense $m \times n$ matrix $C$ that is multiplied by the scalar $\beta$, such that

$$C := \alpha \cdot \text{op}(A) \cdot \text{op}(B) + \beta \cdot C,$$

with

$$\text{op}(A) = \begin{cases} A, & \text{if } \text{trans}_A = \text{rocsparse_operation_none} \\ A^T, & \text{if } \text{trans}_A = \text{rocsparse_operation_transpose} \\ A^H, & \text{if } \text{trans}_A = \text{rocsparse_operation_conjugate_transpose} \end{cases}$$

and

$$\text{op}(B) = \begin{cases} B, & \text{if } \text{trans}_B = \text{rocsparse_operation_none} \\ B^T, & \text{if } \text{trans}_B = \text{rocsparse_operation_transpose} \\ B^H, & \text{if } \text{trans}_B = \text{rocsparse_operation_conjugate_transpose} \end{cases}$$

```c
for(i = 0; i < ldc; ++i) {
    for(j = 0; j < n; ++j) {
        C[i][j] = beta * C[i][j];
        for(k = csr_row_ptr[i]; k < csr_row_ptr[i + 1]; ++k) {
            C[i][j] += alpha * csr_val[k] * B[csr_col_ind[k]][j];
        }
    }
}
```

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Note Currently, only $\text{trans}_A = \text{rocsparse_operation_none}$ is supported.

Example This example multiplies a CSR matrix with a dense matrix.
```c
// 1 2 0 3 0
// A = 0 4 5 0 0
// 6 0 0 7 8

rocspaire_int m = 3;
rocspaire_int k = 5;
rocspaire_int nnz = 8;
csr_row_ptr[m+1] = {0, 3, 5, 8};  // device memory
csr_col_ind[nnz] = {0, 1, 3, 1, 2, 0, 3, 4};  // device memory
csr_val[nnz] = {1, 2, 3, 4, 5, 6, 7, 8};  // device memory

// Set dimension n of B
rocspaire_int n = 64;

// Allocate and generate dense matrix B
std::vector<float> hB(k * n);
for(rocspaire_int i = 0; i < k * n; ++i)
{
    hB[i] = static_cast<float>(rand()) / RAND_MAX;
}

// Copy B to the device
float* B;
hipMalloc((void**)&B, sizeof(float) * k * n);
hipMemcpy(B, hB.data(), sizeof(float) * k * n, hipMemcpyHostToDevice);

// alpha and beta
float alpha = 1.0f;
float beta = 0.0f;

// Allocate memory for the resulting matrix C
float* C;
hipMalloc((void**)&C, sizeof(float) * m * n);

// Perform the matrix multiplication
rocspaire_scsrmm(handle,
    rocspaire_operation_none,
    rocspaire_operation_none,
    m,
    n,
    k,
    nnz,
    &alpha,
    descr,
    csr_val,
    csr_row_ptr,
    csr_col_ind,
    B,
    k,
    &beta,
    C,
    m);
```

**Parameters**

- **[in]** `handle`: handle to the rocspaire library context queue.
- **[in]** `trans_A`: matrix `A` operation type.

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• [in] trans_B: matrix B operation type.
• [in] m: number of rows of the sparse CSR matrix A.
• [in] n: number of columns of the dense matrix op(B) and C.
• [in] k: number of columns of the sparse CSR matrix A.
• [in] nnz: number of non-zero entries of the sparse CSR matrix A.
• [in] alpha: scalar α.
• [in] descr: descriptor of the sparse CSR matrix A. Currently, only rocsparse_matrix_type_general is supported.
• [in] csr_val: array of nnz elements of the sparse CSR matrix A.
• [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix A.
• [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix A.
• [in] B: array of dimension ldb x n ( op(B) == B) or ldb x k ( op(B) == Bᵀ or op(B) == Bᴴ).
• [in] ldb: leading dimension of B, must be at least max (1, k) ( op(A) == A) or max (1, m) ( op(A) == Aᵀ or op(A) == Aᴴ).
• [inout] C: array of dimension ldc x n.
• [in] ldc: leading dimension of C, must be at least max (1, m) ( op(A) == A) or max (1, k) ( op(A) == Aᵀ or op(A) == Aᴴ).

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m, n, k, nnz, ldb or ldc is invalid.
• rocsparse_status_invalid_pointer: descr, alpha, csr_val, csr_row_ptr, csr_col_ind, B, beta or C pointer is invalid.
• rocsparse_status_arch_mismatch: the device is not supported.
• rocsparse_status_not_implemented: trans_A != rocsparse_operation_none or rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.11 Preconditioner

This module holds all sparse preconditioners.

The sparse preconditioners describe manipulations on a matrix in sparse format to obtain a sparse preconditioner matrix.

2.9.17.11.1 rocsparse_csrilu0_zero_pivot()
rocsparse_csrilu0_zero_pivot returns rocsparse_status_zero_pivot, if either a structural or numerical zero has been found during rocsparse_scsrilu0() or rocsparse_dcsrilu0() computation. The first zero pivot \( j \) at \( A_{j,j} \) is stored in position, using same index base as the CSR matrix.

position can be in host or device memory. If no zero pivot has been found, position is set to -1 and rocsparse_status_success is returned instead.

Note rocsparse_csrilu0_zero_pivot is a blocking function. It might influence performance negatively.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] info: structure that holds the information collected during the analysis step.
- [inout] position: pointer to zero pivot \( j \), can be in host or device memory.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_pointer: info or position pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.
- rocsparse_status_zero_pivot: zero pivot has been found.

2.9.17.11.2 rocsparse_csrilu0_buffer_size()

rocsparse_status rocsparse_scsrilu0_buffer_size (rocsparse_handle handle, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, size_t *buffer_size)

rocsparse_status rocsparse_dcsrilu0_buffer_size (rocsparse_handle handle, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const double *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, size_t *buffer_size)

Incomplete LU factorization with 0 fill-ins and no pivoting using CSR storage format.

rocsparse_csrilu0_buffer_size returns the size of the temporary storage buffer that is required by rocsparse_scsrilu0_analysis(), rocsparse_dcsrilu0_analysis(), rocsparse_scsrilu0() and rocsparse_dcsrilu0(). The temporary storage buffer must be allocated by the user. The size of the temporary storage buffer is identical to the size returned by rocsparse_scsrsv_buffer_size() and rocsparse_dcsrsv_buffer_size() if the matrix sparsity pattern is identical. The user allocated buffer can thus be shared between subsequent calls to those functions.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
• [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
• [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
• [out] info: structure that holds the information collected during the analysis step.
• [in] buffer_size: number of bytes of the temporary storage buffer required by rocsparse_scsrilu0_analysis(), rocsparse_dcsrilu0_analysis(), rocsparse_scsrilu0() and rocsparse_dcsrilu0().

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m or nnz is invalid.
• rocsparse_status_invalid_pointer: descr, csr_val, csr_row_ptr, csr_col_ind, info or buffer_size pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.
• rocsparse_status_not_implemented: trans != rocsparse_operation_none or rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.11.3 rocsparse_csrilu0_analysis()

rocsparse_status rocsparse_scsrilu0_analysis(rocsparse_handle handle, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, rocsparse_analysis_policy analysis, rocsparse_solve_policy solve, void *temp_buffer)

rocsparse_status rocsparse_dcsrilu0_analysis(rocsparse_handle handle, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, const double *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, rocsparse_analysis_policy analysis, rocsparse_solve_policy solve, void *temp_buffer)

Incomplete LU factorization with 0 fill-ins and no pivoting using CSR storage format.

rocsparse_csrilu0_analysis performs the analysis step for rocsparse_scsrilu0() and rocsparse_dcsrilu0(). It is expected that this function will be executed only once for a given matrix and particular operation type. The analysis meta data can be cleared by rocsparse_csrilu0_clear().

rocsparse_csrilu0_analysis can share its meta data with rocsparse_scsrsv_analysis() and rocsparse_dcsrsv_analysis(). Selecting rocsparse_analysis_policy_reuse policy can greatly improve computation performance of meta data. However, the user need to make sure that the sparsity pattern remains unchanged. If this cannot be assured, rocsparse_analysis_policy_force has to be used.

Note If the matrix sparsity pattern changes, the gathered information will become invalid.
Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

- **[in]** handle: handle to the rocsparse library context queue.
- **[in]** m: number of rows of the sparse CSR matrix.
- **[in]** nnz: number of non-zero entries of the sparse CSR matrix.
- **[in]** descr: descriptor of the sparse CSR matrix.
- **[in]** csr_val: array of nnz elements of the sparse CSR matrix.
- **[in]** csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- **[in]** csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
- **[out]** info: structure that holds the information collected during the analysis step.
- **[in]** analysis: rocsparse_analysis_policy_reuse or rocsparse_analysis_policy_force.
- **[in]** solve: rocsparse_solve_policy_auto.
- **[in]** temp_buffer: temporary storage buffer allocated by the user.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m or nnz is invalid.
- rocsparse_status_invalid_pointer: descr, csr_val, csr_row_ptr, csr_col_ind, info or temp_buffer pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.
- rocsparse_status_not_implemented: trans != rocsparse_operation_none or rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.11.4 rocsparse_csrilu0()

rocsparse_status rocsparse_csrilu0 (rocsparse_handle handle, rocsparse_int m, rocsparse_int nnz, const rocsparse_mat_descr descr, float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_mat_info info, rocsparse_solve_policy policy, void *temp_buffer)

Incomplete LU factorization with 0 fill-ins and no pivoting using CSR storage format.

rocsparse_csrilu0 computes the incomplete LU factorization with 0 fill-ins and no pivoting of a sparse $m \times m$ CSR matrix $A$, such that

$$A \approx LU$$
rocsparse_csrilu0 requires a user allocated temporary buffer. Its size is returned by rocsparse_csrilu0_buffer_size() or rocsparse_dcsrilu0_buffer_size(). Furthermore, analysis meta data is required. It can be obtained by rocsparse_scsrilu0_analysis() or rocsparse_dcsrilu0_analysis(). rocsparse_csrilu0 reports the first zero pivot (either numerical or structural zero). The zero pivot status can be obtained by calling rocsparse_csrilu0_zero_pivot().

**Note** The sparse CSR matrix has to be sorted. This can be achieved by calling rocsparse_csrsort().

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** Consider the sparse $m \times m$ matrix $A$, stored in CSR storage format. The following example computes the incomplete LU factorization $M \approx LU$ and solves the preconditioned system $My = x$.

```c
// Create rocSPARSE handle
rocsparse_handle handle;
rocsparse_create_handle(&handle);

// Create matrix descriptor for M
rocsparse_mat_descr descr_M;
rocsparse_create_mat_descr(&descr_M);

// Create matrix descriptor for L
rocsparse_mat_descr descr_L;
rocsparse_create_mat_descr(&descr_L);
rocsparse_set_mat_fill_mode(descr_L, rocsparse_fill_mode_lower);
rocsparse_set_mat_diag_type(descr_L, rocsparse_diag_type_unit);

// Create matrix descriptor for U
rocsparse_mat_descr descr_U;
rocsparse_create_mat_descr(&descr_U);
rocsparse_set_mat_fill_mode(descr_U, rocsparse_fill_mode_upper);
rocsparse_set_mat_diag_type(descr_U, rocsparse_diag_type_non_unit);

// Create matrix info structure
rocsparse_mat_info info;
rocsparse_create_mat_info(&info);

// Obtain required buffer size
size_t buffer_size_M;
size_t buffer_size_L;
size_t buffer_size_U;
rocsparse_dcsrilu0_buffer_size(handle,
    m,
    nnz,
    descr_M,
    csr_val,
    csr_row_ptr,
    csr_col_ind,
    info,
    &buffer_size_M);
rocsparse_dcsrsrv_buffer_size(handle,
    rocsparse_operation_none,
    m,
    nnz,
    descr_L,
    csr_val,
    csr_row_ptr,
    (continues on next page)
csr_col_ind,  
info,  
$buffer_size_L$);

rocsparse_dcsrsv_buffer_size(handle,  
rocsparse_operation_none,  
m,  
nnz,  
descr_U,  
csr_val,  
csr_row_ptr,  
csr_col_ind,  
info,  
$buffer_size_U$);

size_t buffer_size = max(buffer_size_M, max(buffer_size_L, buffer_size_U));

// Allocate temporary buffer
void* temp_buffer;
hipMalloc(&temp_buffer, buffer_size);

// Perform analysis steps, using rocsparse_analysis_policy_reuse to improve  
// computation performance
rocsparse_dcsrilu0_analysis(handle,  
m,  
nnz,  
descr_M,  
csr_val,  
csr_row_ptr,  
csr_col_ind,  
info,  
rocsparse_analysis_policy_reuse,  
rocsparse_solve_policy_auto,  
temp_buffer);

rocsparse_dcsrsv_analysis(handle,  
rocsparse_operation_none,  
m,  
nnz,  
descr_L,  
csr_val,  
csr_row_ptr,  
csr_col_ind,  
info,  
rocsparse_analysis_policy_reuse,  
rocsparse_solve_policy_auto,  
temp_buffer);

rocsparse_dcsrsv_analysis(handle,  
rocsparse_operation_none,  
m,  
nnz,  
descr_U,  
csr_val,  
csr_row_ptr,  
csr_col_ind,  
info,  
rocsparse_analysis_policy_reuse,  
rocsparse_solve_policy_auto,  
temp_buffer);
// Check for zero pivot
rocsparse_int position;
if (rocsparse_status_zero_pivot == rocsparse_csrilu0_zero_pivot(handle, info, &position))
{
    printf("A has structural zero at A(%d,%d)\n", position, position);
}

// Compute incomplete LU factorization
rocsparse_dcsrilu0(handle, m, nnz, descr_M, csr_val, csr_row_ptr, csr_col_ind, info, rocsparse_solve_policy_auto, temp_buffer);

// Check for zero pivot
if (rocsparse_status_zero_pivot == rocsparse_csrilu0_zero_pivot(handle, info, &position))
{
    printf("U has structural and/or numerical zero at U(%d,%d)\n", position, position);
}

// Solve Lz = x
rocsparse_dcsrsv_solve(handle, rocsparse_operation_none, m, nnz, &alpha, descr_L, csr_val, csr_row_ptr, csr_col_ind, info, x, z, rocsparse_solve_policy_auto, temp_buffer);

// Solve Uy = z
rocsparse_dcsrsv_solve(handle, rocsparse_operation_none, m, nnz, &alpha, descr_U, csr_val, csr_row_ptr, csr_row_ptr,
(continued from previous page)

csr_col_ind,
info,
z,
y,
rocsparse_solve_policy_auto,
temp_buffer);

// Clean up
hipFree(temp_buffer);
rocsparse_destroy_mat_info(info);
rocsparse_destroy_mat_descr(descr_M);
rocsparse_destroy_mat_descr(descr_L);
rocsparse_destroy_mat_descr(descr_U);
rocsparse_destroy_handle(handle);

Parameters

• [in] handle: handle to the rocsparse library context queue.
• [in] m: number of rows of the sparse CSR matrix.
• [in] nnz: number of non-zero entries of the sparse CSR matrix.
• [inout] csr_val: array of nnz elements of the sparse CSR matrix.
• [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
• [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
• [in] info: structure that holds the information collected during the analysis step.
• [in] temp_buffer: temporary storage buffer allocated by the user.

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m or nnz is invalid.
• rocsparse_status_invalid_pointer: descr, csr_val, csr_row_ptr or csr_col_ind pointer is invalid.
• rocsparse_status_arch_mismatch: the device is not supported.
• rocsparse_status_internal_error: an internal error occurred.
• rocsparse_status_not_implemented: trans != rocsparse_operation_none or rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.11.5 rocsparse_csrilu0_clear()

rocsparse_status rocsparse_csrilu0_clear(rocsparse_handle handle, rocsparse_mat_info info)
Incomplete LU factorization with 0 fill-ins and no pivoting using CSR storage format.
rocsparse_csrilu0_clear deallocates all memory that was allocated by rocsparse_scsrilu0_analysis() or rocsparse_dcsrilu0_analysis(). This is especially useful, if memory is an issue and the analysis data is not required for further computation.

**Note** Calling rocsparse_csrilu0_clear is optional. All allocated resources will be cleared, when the opaque rocsparse_mat_info struct is destroyed using rocsparse_destroy_mat_info().

**Parameters**

- [in] handle: handle to the rocsparse library context queue.
- [inout] info: structure that holds the information collected during the analysis step.

**Return Value**

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_pointer: info pointer is invalid.
- rocsparse_status_memory_error: the buffer holding the meta data could not be deallocated.
- rocsparse_status_internal_error: an internal error occurred.

### 2.9.17.12 Sparse Conversion Functions

This module holds all sparse conversion routines.

The sparse conversion routines describe operations on a matrix in sparse format to obtain a matrix in a different sparse format.

#### 2.9.17.12.1 rocsparse_csr2coo()

rocsparse_status rocsparse_csr2coo (rocsparse_handle handle, const rocsparse_int *csr_row_ptr, rocsparse_int nnz, rocsparse_int m, rocsparse_int *coo_row_ind, rocsparse_index_base idx_base)

Convert a sparse CSR matrix into a sparse COO matrix.

rocsparse_csr2coo converts the CSR array containing the row offsets, that point to the start of every row, into a COO array of row indices.

**Note** It can also be used to convert a CSC array containing the column offsets into a COO array of column indices.

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** This example converts a CSR matrix into a COO matrix.

```c
    // A =  1  2  0  3  0
    //    0  4  5  0  0
    //    6  0  0  7  8
    rocsparse_int m = 3;
    rocsparse_int n = 5;
    rocsparse_int nnz = 8;
```

(continues on next page)
csr_row_ptr[m+1] = \{0, 3, 5, 8\}; // device memory
csr_col_ind[nnz] = \{0, 1, 3, 1, 2, 0, 3, 4\}; // device memory
csr_val[nnz] = \{1, 2, 3, 4, 5, 6, 7, 8\}; // device memory

// Allocate COO matrix arrays
rocsparse_int* coo_row_ind;
rocsparse_int* coo_col_ind;
float* coo_val;

hipMalloc((void**)&coo_row_ind, sizeof(rocsparse_int) * nnz);
hipMalloc((void**)&coo_col_ind, sizeof(rocsparse_int) * nnz);
hipMalloc((void**)&coo_val, sizeof(float) * nnz);

// Convert the csr row offsets into coo row indices
rocsparse_csr2coo(handle,
csr_row_ptr,
nnz,
m,
coo_row_ind,
rocsparse_index_base_zero);

// Copy the column and value arrays
hipMemcpy(coo_col_ind,
csr_col_ind,
sizeof(rocsparse_int) * nnz,
hipMemcpyDeviceToDevice);

hipMemcpy(coo_val,
csr_val,
sizeof(float) * nnz,
hipMemcpyDeviceToDevice);

### Parameters

- **[in]** handle: handle to the rocsparse library context queue.
- **[in]** csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- **[in]** nnz: number of non-zero entries of the sparse CSR matrix.
- **[in]** m: number of rows of the sparse CSR matrix.
- **[out]** coo_row_ind: array of nnz elements containing the row indices of the sparse COO matrix.
- **[in]** idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

### Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m or nnz is invalid.
- rocsparse_status_invalid_pointer: csr_row_ptr or coo_row_ind pointer is invalid.
- rocsparse_status_arch_mismatch: the device is not supported.
2.9.17.12.2 rocsparse_coo2csr()

rocsparse_status rocsparse_coo2csr (rocsparse_handle handle, const rocsparse_int *coo_row_ind,
rocsparse_int nnz, rocsparse_int m, rocsparse_int *csr_row_ptr,
rocsparse_index_base idx_base)

Convert a sparse COO matrix into a sparse CSR matrix.
rocsparse_coo2csr converts the COO array containing the row indices into a CSR array of row offsets,
that point to the start of every row. It is assumed that the COO row index array is sorted.

Note It can also be used, to convert a COO array containing the column indices into a CSC array of column
offsets, that point to the start of every column. Then, it is assumed that the COO column index array is
sorted, instead.

Note This function is non blocking and executed asynchronously with respect to the host. It may return before
the actual computation has finished.

Example This example converts a COO matrix into a CSR matrix.

```
// 1 2 0 3 0
// A = 0 4 5 0 0
// 6 0 0 7 8
rocsparse_int m = 3;
rocsparse_int n = 5;
rocsparse_int nnz = 8;

coo_row_ind[nnz] = {0, 0, 0, 1, 1, 2, 2, 2}; // device memory
coo_col_ind[nnz] = {0, 1, 3, 1, 2, 0, 3, 4}; // device memory
coo_val[nnz] = {1, 2, 3, 4, 5, 6, 7, 8}; // device memory

// Allocate CSR matrix arrays
rocsparse_int* csr_row_ptr;
rocsparse_int* csr_col_ind;
float* csr_val;
hipMalloc((void**)&csr_row_ptr, sizeof(rocsparse_int) * (m + 1));
hipMalloc((void**)&csr_col_ind, sizeof(rocsparse_int) * nnz);
hipMalloc((void**)&csr_val, sizeof(float) * nnz);

// Convert the coo row indices into csr row offsets
rocsparse_coo2csr(handle,
    coo_row_ind,
    nnz,
    m,
    csr_row_ptr,
    rocsparse_index_base_zero);

// Copy the column and value arrays
hipMemcpy(csr_col_ind,
    coo_col_ind,
    sizeof(rocsparse_int) * nnz,
    hipMemcpyDeviceToDevice);

hipMemcpy(csr_val,
    coo_val,
    sizeof(float) * nnz,
    hipMemcpyDeviceToDevice);
```
Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] coo_row_ind: array of nnz elements containing the row indices of the sparse COO matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] m: number of rows of the sparse CSR matrix.
- [out] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m or nnz is invalid.
- rocsparse_status_invalid_pointer: coo_row_ind or csr_row_ptr pointer is invalid.

### 2.9.17.12.3 rocsparse_csr2csc_buffer_size()

rocsparse_status rocsparse_csr2csc_buffer_size (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_action copy_values, size_t *buffer_size)

Convert a sparse CSR matrix into a sparse CSC matrix.

rocsparse_csr2csc_buffer_size returns the size of the temporary storage buffer required by rocsparse_scsc2csc() and rocsparse_dcsr2csc(). The temporary storage buffer must be allocated by the user.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse CSR matrix.
- [in] n: number of columns of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
- [in] copy_values: rocsparse_action_symbolic or rocsparse_action_numeric.
- [out] buffer_size: number of bytes of the temporary storage buffer required by sparse_csr2csc().

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
• `rocsparse_status_invalid_size`: `m`, `n` or `nnz` is invalid.
• `rocsparse_status_invalid_pointer`: `csr_row_ptr`, `csr_col_ind` or `buffer_size` pointer is invalid.
• `rocsparse_status_internal_error`: an internal error occurred.

### 2.9.17.12.4 rocsparse_csr2csc()

Convert a sparse CSR matrix into a sparse CSC matrix. `rocsparse_csr2csc` converts a CSR matrix into a CSC matrix. `rocsparse_csr2csc` can also be used to convert a CSC matrix into a CSR matrix. `copy_values` decides whether `csc_val` is being filled during conversion (`rocsparse_action_numeric`) or not (`rocsparse_action_symbolic`).

`rocsparse_csr2csc` requires extra temporary storage buffer that has to be allocated by the user. Storage buffer size can be determined by `rocsparse_csr2csc_buffer_size()`.

**Note** The resulting matrix can also be seen as the transpose of the input matrix.

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** This example computes the transpose of a CSR matrix.

```c
// 1 2 0 3 0
// A = 0 4 5 0 0
// 6 0 0 7 8
rocsparse_int m_A = 3;
rocsparse_int n_A = 5;
rocsparse_int nnz_A = 8;
csr_row_ptr_A[m+1] = {0, 3, 5, 8}; // device memory
csr_col_ind_A[nnz] = {0, 1, 3, 1, 2, 0, 3, 4}; // device memory
csr_val_A[nnz] = {1, 2, 3, 4, 5, 6, 7, 8}; // device memory

// Allocate memory for transposed CSR matrix
rocsparse_int m_T = n_A;
rocsparse_int n_T = m_A;
rocsparse_int nnz_T = nnz_A;
rocsparse_int* csr_row_ptr_T;
rocsparse_int* csr_col_ind_T;
float* csr_val_T;
```
hipMalloc((void**)&csr_row_ptr_T, sizeof(rocsparse_int) * (m_T + 1));
hipMalloc((void**)&csr_col_ind_T, sizeof(rocsparse_int) * nnz_T);
hipMalloc((void**)&csr_val_T, sizeof(float) * nnz_T);

// Obtain the temporary buffer size
size_t buffer_size;
rocsparse_csr2csc_buffer_size(handle,
    m_A,
    n_A,
    nnz_A,
    csr_row_ptr_A,
    csr_col_ind_A,
    rocsparse_action_numeric,
    &buffer_size);

// Allocate temporary buffer
void* temp_buffer;
hipMalloc(&temp_buffer, buffer_size);
rocsparse_scsr2csc(handle,
    m_A,
    n_A,
    nnz_A,
    csr_val_A,
    csr_row_ptr_A,
    csr_col_ind_A,
    csr_val_T,
    csr_col_ind_T,
    csr_row_ptr_T,
    rocsparse_action_numeric,
    rocsparse_index_base_zero,
    temp_buffer);

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse CSR matrix.
- [in] n: number of columns of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
- [out] csc_val: array of nnz elements of the sparse CSC matrix.
- [out] csc_row_ind: array of nnz elements containing the row indices of the sparse CSC matrix.
- [out] csc_col_ptr: array of n+1 elements that point to the start of every column of the sparse CSC matrix.
- [in] copy_values: rocsparse_action_symbolic or rocsparse_action_numeric.
• [in] idx_base: rocsparse_index_base_zero or rocsparse_index_base_one.

• [in] temp_buffer: temporary storage buffer allocated by the user, size is returned by rocsparse_csr2csc_buffer_size()

Return Value

• rocsparse_status_success: the operation completed successfully.

• rocsparse_status_invalid_handle: the library context was not initialized.

• rocsparse_status_invalid_size: m, n, or nnz is invalid.

• rocsparse_status_invalid_pointer: csr_val, csr_row_ptr, csr_col_ind, csc_val, csc_row_ind, csc_col_ptr or temp_buffer pointer is invalid.

• rocsparse_status_arch_mismatch: the device is not supported.

• rocsparse_status_internal_error: an internal error occurred.

2.9.17.12.5 rocsparse_csr2ell_width()

rocsparse_status rocsparse_csr2ell_width(rocsparse_handle handle, rocsparse_int m, const rocsparse_mat_descr csr_descr, const rocsparse_int *csr_row_ptr, const rocsparse_mat_descr ell_descr, rocsparse_int *ell_width)

Convert a sparse CSR matrix into a sparse ELL matrix.

rocsparse_csr2ell_width computes the maximum of the per row non-zero elements over all rows, the ELL width, for a given CSR matrix.

Note  This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

• [in] handle: handle to the rocsparse library context queue.

• [in] m: number of rows of the sparse CSR matrix.

• [in] csr_descr: descriptor of the sparse CSR matrix. Currently, only rocsparse_matrix_type_general is supported.

• [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.

• [in] ell_descr: descriptor of the sparse ELL matrix. Currently, only rocsparse_matrix_type_general is supported.

• [out] ell_width: pointer to the number of non-zero elements per row in ELL storage format.

Return Value

• rocsparse_status_success: the operation completed successfully.

• rocsparse_status_invalid_handle: the library context was not initialized.

• rocsparse_status_invalid_size: m is invalid.

• rocsparse_status_invalid_pointer: csr_descr, csr_row_ptr, or ell_width pointer is invalid.

• rocsparse_status_internal_error: an internal error occurred.
• rocsparse_status_not_implemented: rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.12.6 rocsparse_csr2ell()

rocsparse_status rocsparse_csr2ell(rocsparse_handle handle, rocsparse_int m, const rocsparse_mat_descr csr_descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, const rocsparse_matdescr ell_descr, rocsparse_int ell_width, float *ell_val, rocsparse_int *ell_col_ind)

rocsparse_status rocsparse_dcsr2ell(rocsparse_handle handle, rocsparse_int m, const rocsparse_matdescr csr_descr, const double *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, const rocsparse_matdescr ell_descr, rocsparse_int ell_width, double *ell_val, rocsparse_int *ell_col_ind)

Convert a sparse CSR matrix into a sparse ELL matrix.

rocsparse_csr2ell converts a CSR matrix into an ELL matrix. It is assumed, that ell_val and ell_col_ind are allocated. Allocation size is computed by the number of rows times the number of ELL non-zero elements per row, such that $n_{ELL} = m \cdot ell\_width$. The number of ELL non-zero elements per row is obtained by rocsparse_csr2ell_width().

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Example This example converts a CSR matrix into an ELL matrix.

```cpp
// 1 2 0 3 0
// A = 0 4 5 0 0
// 6 0 0 7 8
rocsparse_int m = 3;
rocsparse_int n = 5;
rocsparse_int nnz = 8;

csr_row_ptr[m+1] = {0, 3, 5, 8}; // device memory
csr_col_ind[nnz] = {0, 1, 3, 1, 2, 0, 3, 4}; // device memory
csr_val[nnz] = {1, 2, 3, 4, 5, 6, 7, 8}; // device memory

// Create ELL matrix descriptor
rocsparse_matdescr ell_descr;
rocsparse_create_matdescr(&ell_descr);

// Obtain the ELL width
rocsparse_int ell_width;
rocsparse_csr2ell_width(handle, m, csr_descr, csr_row_ptr, ell_descr, &ell_width);

// Compute ELL non-zero entries
rocsparse_int ell_nnz = m * ell_width;

// Allocate ELL column and value arrays
```

(continues on next page)
rocsparse_int* ell_col_ind;
hipMalloc((void**)&ell_col_ind, sizeof(rocsparse_int) * ell_nnz);

float* ell_val;
hipMalloc((void**)&ell_val, sizeof(float) * ell_nnz);

// Format conversion
rocsparse_scsr2ell(handle,
    m,
    csr_descr,
    csr_val,
    csr_row_ptr,
    csr_col_ind,
    ell_descr,
    ell_width,
    ell_val,
    ell_col_ind);

Parameters

- **[in]** handle: handle to the rocsparse library context queue.
- **[in]** m: number of rows of the sparse CSR matrix.
- **[in]** csr_descr: descriptor of the sparse CSR matrix. Currently, only rocsparse_matrix_type_general is supported.
- **[in]** csr_val: array containing the values of the sparse CSR matrix.
- **[in]** csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- **[in]** csr_col_ind: array containing the column indices of the sparse CSR matrix.
- **[in]** ell_descr: descriptor of the sparse ELL matrix. Currently, only rocsparse_matrix_type_general is supported.
- **[in]** ell_width: number of non-zero elements per row in ELL storage format.
- **[out]** ell_val: array of m times ell_width elements of the sparse ELL matrix.
- **[out]** ell_col_ind: array of m times ell_width elements containing the column indices of the sparse ELL matrix.

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m or ell_width is invalid.
- rocsparse_status_invalid_pointer: csr_descr, csr_val, csr_row_ptr, csr_col_ind, ell_descr, ell_val or ell_col_ind pointer is invalid.
- rocsparse_status_not_implemented: rocsparse_matrix_type != rocsparse_matrix_type_general.
2.9.17.2 rocsparse_ell2csr_nnz()

rocsparse_status rocsparse_ell2csr_nnz(rocsparse_handle handle, rocsparse_int m, rocsparse_int n, const rocsparse_mat_descr ell_descr, rocsparse_int ell_width, const rocsparse_int *ell_col_ind, const rocsparse_mat_descr csr_descr, rocsparse_int *csr_row_ptr, rocsparse_int *csr_nnz)

Convert a sparse ELL matrix into a sparse CSR matrix.

rocsparse_ell2csr_nnz computes the total CSR non-zero elements and the CSR row offsets, that point to the start of every row of the sparse CSR matrix, for a given ELL matrix. It is assumed that csr_row_ptr has been allocated with size m + 1.

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Parameters

• [in] handle: handle to the rocsparse library context queue.
• [in] m: number of rows of the sparse ELL matrix.
• [in] n: number of columns of the sparse ELL matrix.
• [in] ell_descr: descriptor of the sparse ELL matrix. Currently, only rocsparse_matrix_type_general is supported.
• [in] ell_width: number of non-zero elements per row in ELL storage format.
• [in] ell_col_ind: array of m times ell_width elements containing the column indices of the sparse ELL matrix.
• [in] csr_descr: descriptor of the sparse CSR matrix. Currently, only rocsparse_matrix_type_general is supported.
• [out] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
• [out] csr_nnz: pointer to the total number of non-zero elements in CSR storage format.

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m, n or ell_width is invalid.
• rocsparse_status_invalid_pointer: ell_descr, ell_col_ind, csr_descr, csr_row_ptr or csr_nnz pointer is invalid.
• rocsparse_status_not_implemented: rocsparse_matrix_type != rocsparse_matrix_type_general.
2.9.17.12.8 rocsparse_ell2csr()

rocsparse_status rocsparse_csr2csc_buffer_size (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_action copy_values, size_t *buffer_size)

Convert a sparse CSR matrix into a sparse CSC matrix.

rocsparse_csr2csc_buffer_size returns the size of the temporary storage buffer required by rocsparse_scsr2csc() and rocsparse_dcsr2csc(). The temporary storage buffer must be allocated by the user.

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse CSR matrix.
- [in] n: number of columns of the sparse CSR matrix.
- [in] nnz: number of non-zero entries of the sparse CSR matrix.
- [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
- [in] copy_values: rocsparse_action_symbolic or rocsparse_action_numeric.
- [out] buffer_size: number of bytes of the temporary storage buffer required by sparse_csr2csc().

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m, n or nnz is invalid.
- rocsparse_status_invalid_pointer: csr_row_ptr, csr_col_ind or buffer_size pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.

2.9.17.12.9 rocsparse_csr2hyb()

rocsparse_status rocsparse_scsr2hyb (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, const rocsparse_mat_descr descr, const float *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_hyb_mat hyb, rocsparse_int user_ell_width, rocsparse_hyb_partition partition_type)

rocsparse_status rocsparse_dcsr2hyb (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, const rocsparse_mat_descr descr, const double *csr_val, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, rocsparse_hyb_mat hyb, rocsparse_int user_ell_width, rocsparse_hyb_partition partition_type)

Convert a sparse CSR matrix into a sparse HYB matrix.
rocsparse_csr2hyb converts a CSR matrix into a HYB matrix. It is assumed that hyb has been initialized with rocsparse_create_hyb_mat().

**Note** This function requires a significant amount of storage for the HYB matrix, depending on the matrix structure.

**Note** This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** This example converts a CSR matrix into a HYB matrix using user defined partitioning.

```c
// Create HYB matrix structure
rocsparse_hyb_mat hyb;
rocsparse_create_hyb_mat(&hyb);

// User defined ell width
rocsparse_int user_ell_width = 5;

// Perform the conversion
rocsparse_scsr2hyb(handle,
    m,
    n,
    descr,
    csr_val,
    csr_row_ptr,
    csr_col_ind,
    hyb,
    user_ell_width,
    rocsparse_hyb_partition_user);

// Do some work

// Clean up
rocsparse_destroy_hyb_mat(hyb);
```

**Parameters**

- **[in] handle**: handle to the rocsparse library context queue.
- **[in] m**: number of rows of the sparse CSR matrix.
- **[in] n**: number of columns of the sparse CSR matrix.
- **[in] descr**: descriptor of the sparse CSR matrix. Currently, only rocsparse_matrix_type_general is supported.
- **[in] csr_val**: array containing the values of the sparse CSR matrix.
- **[in] csr_row_ptr**: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
- **[in] csr_col_ind**: array containing the column indices of the sparse CSR matrix.
- **[out] hyb**: sparse matrix in HYB format.
- **[in] user_ell_width**: width of the ELL part of the HYB matrix (only required if partition_type == rocsparse_hyb_partition_user).
- **[in] partition_type**: rocsparse_hyb_partition_auto (recommended), rocsparse_hyb_partition_user or rocsparse_hyb_partition_max.

**Return Value**
• `rocsparse_status_success`: the operation completed successfully.
• `rocsparse_status_invalid_handle`: the library context was not initialized.
• `rocsparse_status_invalid_size`: `m`, `n` or `user_ell_width` is invalid.
• `rocsparse_status_invalid_value`: `partition_type` is invalid.
• `rocsparse_status_invalid_pointer`: `descr`, `hyb`, `csr_val`, `csr_row_ptr` or `csr_col_ind` pointer is invalid.
• `rocsparse_status_memory_error`: the buffer for the HYB matrix could not be allocated.
• `rocsparse_status_internal_error`: an internal error occurred.
• `rocsparse_status_not_implemented`: `rocsparse_matrix_type` != `rocsparse_matrix_type_general`.

2.9.17.12.10 `rocsparse_create_identity_permutation()`

```c
rocsparse_status rocsparse_create_identity_permutation(rocsparse_handle handle, rocsparse_int n, rocsparse_int *p)
```

Create the identity map.

`rocsparse_create_identity_permutation` stores the identity map in `p`, such that `p = 0 : 1 : (n - 1)`.

```c
for(i = 0; i < n; ++i)
{
    p[i] = i;
}
```

**Note** This function is non-blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** The following example creates an identity permutation.

```c
rocsparse_int size = 200;

// Allocate memory to hold the identity map
rocsparse_int* perm;
hipMalloc((void**)&perm, sizeof(rocsparse_int) * size);

// Fill perm with the identity permutation
rocsparse_create_identity_permutation(handle, size, perm);
```

**Parameters**
- `[in]` `handle`: handle to the rocsparse library context queue.
- `[out]` `p`: array of `n` integers containing the map.

**Return Value**
- `rocsparse_status_success`: the operation completed successfully.
- `rocsparse_status_invalid_handle`: the library context was not initialized.
- `rocsparse_status_invalid_size`: `n` is invalid.
• rocsparse_status_invalid_pointer: pointer is invalid.

2.9.17.12.11 rocsparse_csrsort_buffer_size()

rocsparse_status rocsparse_csrsort_buffer_size (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, const rocsparse_int *csr_row_ptr, const rocsparse_int *csr_col_ind, size_t *buffer_size)

Sort a sparse CSR matrix.

rocsparse_csrsort_buffer_size returns the size of the temporary storage buffer required by rocsparse_csrsort(). The temporary storage buffer must be allocated by the user.

Parameters

• [in] handle: handle to the rocsparse library context queue.
• [in] m: number of rows of the sparse CSR matrix.
• [in] n: number of columns of the sparse CSR matrix.
• [in] nnz: number of non-zero entries of the sparse CSR matrix.
• [in] csr_row_ptr: array of m+1 elements that point to the start of every row of the sparse CSR matrix.
• [in] csr_col_ind: array of nnz elements containing the column indices of the sparse CSR matrix.
• [out] buffer_size: number of bytes of the temporary storage buffer required by rocsparse_csrsort().

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m, n or nnz is invalid.
• rocsparse_status_invalid_pointer: csr_row_ptr, csr_col_ind or buffer_size pointer is invalid.

2.9.17.12.12 rocsparse_csrsort()

rocsparse_status rocsparse_csrsort (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, const rocsparse_mat_descr descr, const rocsparse_int *csr_row_ptr, rocsparse_int *csr_col_ind, rocsparse_int *perm, void *temp_buffer)

Sort a sparse CSR matrix.

rocsparse_csrsort sorts a matrix in CSR format. The sorted permutation vector perm can be used to obtain sorted csr_val array. In this case, perm must be initialized as the identity permutation, see rocsparse_create_identity_permutation().

rocsparse_csrsort requires extra temporary storage buffer that has to be allocated by the user. Storage buffer size can be determined by rocsparse_csrsort_buffer_size().

Note perm can be NULL if a sorted permutation vector is not required.
**Note** This function is non-blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** The following example sorts a $3 \times 3$ CSR matrix.

```c
// 1 2 3
// A = 4 5 6
// 7 8 9
rocsparse_int m = 3;
rocsparse_int n = 3;
rocsparse_int nnz = 9;

csr_row_ptr[m + 1] = {0, 3, 6, 9}; // device memory
csr_col_ind[nnz] = {2, 0, 1, 0, 1, 2, 0, 2, 1}; // device memory
csr_val[nnz] = {3, 1, 2, 4, 5, 6, 7, 9, 8}; // device memory

// Create permutation vector perm as the identity map
rocsparse_int* perm;
hipMalloc((void**)&perm, sizeof(rocsparse_int) * nnz);
rocsparse_create_identity_permutation(handle, nnz, perm);

// Allocate temporary buffer
size_t buffer_size;
void* temp_buffer;
rocsparse_csrsort_buffer_size(handle, m, n, nnz, csr_row_ptr, csr_col_ind, &buffer_size);
hipMalloc(&temp_buffer, buffer_size);

// Sort the CSR matrix
rocsparse_csrsort(handle, m, n, nnz, descr, csr_row_ptr, csr_col_ind, perm, temp_buffer);

// Gather sorted csr_val array
float* csr_val_sorted;
hipMalloc((void**)&csr_val_sorted, sizeof(float) * nnz);
rocsparse_sgthr(handle, nnz, csr_val, csr_val_sorted, perm, rocsparse_index_base_zero);

// Clean up
hipFree(temp_buffer);
hipFree(perm);
hipFree(csr_val);
```

**Parameters**

- **[in]** handle: handle to the rocsparse library context queue.
- **[in]** m: number of rows of the sparse CSR matrix.
- **[in]** n: number of columns of the sparse CSR matrix.
- **[in]** nnz: number of non-zero entries of the sparse CSR matrix.
- **[in]** descr: descriptor of the sparse CSR matrix. Currently, only `rocsparse_matrix_type_general` is supported.
- **[in]** csr_row_ptr: array of $m+1$ elements that point to the start of every row of the sparse CSR matrix.
- **[inout]** csr_col_ind: array of $nnz$ elements containing the column indices of the sparse CSR matrix.
• [inout] perm: array of nnz integers containing the unsorted map indices, can be NULL.
• [in] temp_buffer: temporary storage buffer allocated by the user, size is returned by rocsparse_csrsort_buffer_size().

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m, n or nnz is invalid.
• rocsparse_status_invalid_pointer: descr, csr_row_ptr, csr_col_ind or temp_buffer pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.
• rocsparse_status_not_implemented: rocsparse_matrix_type != rocsparse_matrix_type_general.

2.9.17.12.13 rocsparse_coosort_buffer_size()

rocsparse_status rocsparse_coosort_buffer_size (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, const rocsparse_int *coo_row_ind, const rocsparse_int *coo_col_ind, size_t *buffer_size)

Sort a sparse COO matrix.

cosort_buffer_size returns the size of the temporary storage buffer that is required by rocsparse_coosort_by_row() and rocsparse_coosort_by_column(). The temporary storage buffer has to be allocated by the user.

Parameters
• [in] handle: handle to the rocsparse library context queue.
• [in] m: number of rows of the sparse COO matrix.
• [in] n: number of columns of the sparse COO matrix.
• [in] nnz: number of non-zero entries of the sparse COO matrix.
• [in] coo_row_ind: array of nnz elements containing the row indices of the sparse COO matrix.
• [in] coo_col_ind: array of nnz elements containing the column indices of the sparse COO matrix.
• [out] buffer_size: number of bytes of the temporary storage buffer required by rocsparse_coosort_by_row() and rocsparse_coosort_by_column().

Return Value
• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m, n or nnz is invalid.
• rocsparse_status_invalid_pointer: coo_row_ind, coo_col_ind or buffer_size pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.
2.9.17.12.14 rocsparse_coosort_by_row()

rocsparse_status rocsparse_coosort_by_row(rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, *coo_row_ind, rocsparse_int *coo_col_ind, rocsparse_int *perm, void *temp_buffer)

Sort a sparse COO matrix by row.

rocsparse_coosort_by_row sorts a matrix in COO format by row. The sorted permutation vector perm can be used to obtain sorted coo_val array. In this case, perm must be initialized as the identity permutation, see rocsparse_create_identity_permutation().

rocsparse_coosort_by_row requires extra temporary storage buffer that has to be allocated by the user. Storage buffer size can be determined by rocsparse_coosort_buffer_size().

Note perm can be NULL if a sorted permutation vector is not required.

Note This function is non blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

Example The following example sorts a $3 \times 3$ COO matrix by row indices.

```c
// 1 2 3
// A = 4 5 6
// 7 8 9
rocsparse_int m = 3;
rocsparse_int n = 3;
rocsparse_int nnz = 9;

coo_row_ind[nnz] = {0, 1, 2, 0, 1, 2, 0, 1, 2}; // device memory
coo_col_ind[nnz] = {0, 0, 0, 1, 1, 1, 2, 2, 2}; // device memory
coo_val[nnz] = {1, 4, 7, 2, 5, 8, 3, 6, 9}; // device memory

// Create permutation vector perm as the identity map
rocsparse_int* perm;
hipMalloc((void**)&perm, sizeof(rocsparse_int) * nnz);
rocsparse_create_identity_permutation(handle, nnz, perm);

// Allocate temporary buffer
size_t buffer_size;
void* temp_buffer;
rocsparse_coosort_buffer_size(handle,
    m,
    n,
    nnz,
    coo_row_ind,
    coo_col_ind,
    &buffer_size);
hipMalloc(&temp_buffer, buffer_size);

// Sort the COO matrix
rocsparse_coosort_by_row(handle,
    m,
    n,
    nnz,
    coo_row_ind,
    coo_col_ind,
    perm,
```

(continues on next page)
temp_buffer);

// Gather sorted coo_val array
float* coo_val_sorted;
hipMalloc((void**)&coo_val_sorted, sizeof(float) * nnz);
rocsparse_sgthr(handle, nnz, coo_val, coo_val_sorted, perm, rocsparse_index_base_zero);

// Clean up
hipFree(temp_buffer);
hipFree(perm);
hipFree(coo_val);

Parameters

- [in] handle: handle to the rocsparse library context queue.
- [in] m: number of rows of the sparse COO matrix.
- [in] n: number of columns of the sparse COO matrix.
- [in] nnz: number of non-zero entries of the sparse COO matrix.
- [inout] coo_row_ind: array of nnz elements containing the row indices of the sparse COO matrix.
- [inout] coo_col_ind: array of nnz elements containing the column indices of the sparse COO matrix.
- [inout] perm: array of nnz integers containing the unsorted map indices, can be NULL.
- [in] temp_buffer: temporary storage buffer allocated by the user, size is returned by rocsparse_coosort_buffer_size().

Return Value

- rocsparse_status_success: the operation completed successfully.
- rocsparse_status_invalid_handle: the library context was not initialized.
- rocsparse_status_invalid_size: m, n or nnz is invalid.
- rocsparse_status_invalid_pointer: coo_row_ind, coo_col_ind or temp_buffer pointer is invalid.
- rocsparse_status_internal_error: an internal error occurred.

2.9.17.12.15 rocsparse_coosort_by_column()

rocsparse_status rocsparse_coosort_by_column (rocsparse_handle handle, rocsparse_int m, rocsparse_int n, rocsparse_int nnz, rocsparse_int *coo_row_ind, rocsparse_int *coo_col_ind, rocsparse_int *perm, void *temp_buffer)

Sort a sparse COO matrix by column.

rocsparse_coosort_by_column sorts a matrix in COO format by column. The sorted permutation vector perm can be used to obtain sorted coo_val array. In this case, perm must be initialized as the identity permutation, see rocsparse_create_identity_permutation().

rocsparse_coosort_by_column requires extra temporary storage buffer that has to be allocated by the user. Storage buffer size can be determined by rocsparse_coosort_buffer_size().
**Note** perm can be NULL if a sorted permutation vector is not required.

**Note** This function is non-blocking and executed asynchronously with respect to the host. It may return before the actual computation has finished.

**Example** The following example sorts a $3 \times 3$ COO matrix by column indices.

```c
// 1 2 3
// A = 4 5 6
// 7 8 9
rocsparse_int m = 3;
rocsparse_int n = 3;
rocsparse_int nnz = 9;

coo_row_ind[nnz] = {0, 0, 0, 1, 1, 1, 2, 2, 2}; // device memory
coo_col_ind[nnz] = {0, 1, 2, 0, 1, 2, 0, 1, 2}; // device memory
coo_val[nnz] = {1, 2, 3, 4, 5, 6, 7, 8, 9}; // device memory

// Create permutation vector perm as the identity map
rocsparse_int* perm;
hipMalloc((void**)&perm, sizeof(rocsparse_int) * nnz);
rocsparse_create_identity_permutation(handle, nnz, perm);

// Allocate temporary buffer
size_t buffer_size;
void* temp_buffer;
rocsparse_coosort_buffer_size(handle,
    m,
    n,
    nnz,
    coo_row_ind,
    coo_col_ind,
    &buffer_size);
hipMalloc(&temp_buffer, buffer_size);

// Sort the COO matrix
rocsparse_coosort_by_column(handle,
    m,
    n,
    nnz,
    coo_row_ind,
    coo_col_ind,
    perm,
    temp_buffer);

// Gather sorted coo_val array
float* coo_val_sorted;
hipMalloc((void**)&coo_val_sorted, sizeof(float) * nnz);
rocsparse_sgthr(handle, nnz, coo_val, coo_val_sorted, perm, rocsparse_index_base_zero);

// Clean up
hipFree(temp_buffer);
hipFree(perm);
hipFree(coo_val);
```

**Parameters**

- `[in] handle`: handle to the rocsparse library context queue.
• [in] m: number of rows of the sparse COO matrix.
• [in] n: number of columns of the sparse COO matrix.
• [in] nnz: number of non-zero entries of the sparse COO matrix.
• [inout] coo_row_ind: array of nnz elements containing the row indices of the sparse COO matrix.
• [inout] coo_col_ind: array of nnz elements containing the column indices of the sparse COO matrix.
• [inout] perm: array of nnz integers containing the unsorted map indices, can be NULL.
• [in] temp_buffer: temporary storage buffer allocated by the user, size is returned by `roc-sparse_coosort_buffer_size()`.

Return Value

• rocsparse_status_success: the operation completed successfully.
• rocsparse_status_invalid_handle: the library context was not initialized.
• rocsparse_status_invalid_size: m, n or nnz is invalid.
• rocsparse_status_invalid_pointer: coo_row_ind, coo_col_ind or temp_buffer pointer is invalid.
• rocsparse_status_internal_error: an internal error occurred.

2.10 ROCm

2.10.1 GCN

• ROCm-Native-ISA

2.10.2 ROCm

• ROCm-Codeobj-format

2.10.3 ROCm

2.10.3.1 OVERVIEW

This repository contains the following libraries:

<table>
<thead>
<tr>
<th>Name</th>
<th>Comments</th>
<th>Dependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>irif</td>
<td>Interface to LLVM IR</td>
<td></td>
</tr>
<tr>
<td>ocml</td>
<td>Open Compute Math library(ocml)</td>
<td>irif</td>
</tr>
<tr>
<td>oclc</td>
<td>Open Compute library controls (documentation)</td>
<td></td>
</tr>
<tr>
<td>ockl</td>
<td>Open Compute Kernel library.</td>
<td>irif</td>
</tr>
<tr>
<td>opencl</td>
<td>OpenCL built-in library</td>
<td>ocml, ockl</td>
</tr>
<tr>
<td>hc</td>
<td>Heterogeneous Compute built-in library</td>
<td>ocml, ockl</td>
</tr>
</tbody>
</table>

All libraries are compiled to LLVM Bitcode which can be linked. Note that libraries use specific AMDGPU intrinsics.
2.10.3.2 BUILDING

To build it, use RadeonOpenCompute LLVM/LLD/Clang. Default branch on these repositories is “amd-common”, which may contain AMD-specific codes yet upstreamed.

```bash
git clone git@github.com:RadeonOpenCompute/llvm.git llvm_amd-common
cd llvm_amd-common/tools
git clone git@github.com:RadeonOpenCompute/lld.git lld
git clone git@github.com:RadeonOpenCompute/clang.git clang
cd ..
mkdir -p build
cd build
cmake \
-DCMAKE_BUILD_TYPE=Release \ 
-DCMAKE_INSTALL_PREFIX=/opt/rocm/llvm \ 
-DLLVM_TARGETS_TO_BUILD="AMDGPU;X86" \ ..
```

Testing also requires amdhsacod utility from ROCm Runtime.

Use out-of-source CMake build and create separate directory to run CMake.

The following build steps are performed:

```bash
mkdir -p build
cd build
export LLVM_BUILD=... (path to LLVM build)
CC=$LLVM_BUILD/bin/clang cmake -DLLVM_DIR=$LLVM_BUILD -DAMDHSACOD=$HSA_DIR/bin/x86_64/amdhsacod ..
make
```

It is also possible to use compiler that only has AMDGPU target enabled if you build prepare-builtins separately with host compiler and pass explicit target option to CMake:

```bash
export LLVM_BUILD=... (path to LLVM build)
# Build prepare-builtins
cd utils
mkdir build
cd build
cmake -DLLVM_DIR=$LLVM_BUILD ..
make
# Build bitcode libraries
cd ..../
mkdir build
cd build
CC=$LLVM_BUILD/bin/clang cmake -DLLVM_DIR=$LLVM_BUILD -DAMDHSACOD=$HSA_DIR/bin/x86_64/amdhsacod -DCMAKE_C_FLAGS="-target amdgcn--amdhsa" -DCMAKE_CXX_FLAGS="-target amdgcn--amdhsa" -DPREPARE_BUILTINS=`cd ../utils/build/prepare-builtins/; pwd`/prepare-builtins ..
```

To install artifacts: make install

To run offline tests: make test

To create packages for the library: make package
2.10.3.3 USING BITCODE LIBRARIES

The bitcode libraries should be linked to user bitcode (obtained from source) before final code generation with `llvm-link` or `-mlink-bitcode-file` option of clang.

For OpenCL, the list of bitcode libraries includes `opencl`, its dependencies (`ocml`, `ockl`, `irif`) and oclc control libraries selected according to OpenCL compilation mode. Assuming that the build of this repository was done in `/srv/git/ROCm-Device-Libs/build`, the following command line shows how to compile simple OpenCL source test.cl into code object test.so:

```bash
clang -x cl -Xclang -finclude-default-header \
    -target amdgcn--amdhsa -mcpu=fiji \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/opencl/opencl. \
    amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/ocml/ocml. \
    amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/ockl/ockl. \
    amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/oclc/oclc_correctly_rounded_sqrt_off.amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/oclc/oclc_daz_off.amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/oclc/oclc_finite_only_off.amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/oclc/oclc_isa_version_803.amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/oclc/oclc_unsafe_math_off.amdgcn.bc \ 
    -Xclang -mlink-bitcode-file -Xclang /srv/git/ROCm-Device-Libs/build/irif/irif. \
    amdgcn.bc \ 
    test.cl -o test.so
```

2.10.3.4 TESTING

Currently all tests are offline:

- OpenCL source is compiled to LLVM bitcode
- Test bitcode is linked to library bitcode with `llvm-link`
- Clang OpenCL compiler is run on resulting bitcode, producing code object.
- Resulting code object is passed to `llvm-objdump` and `amdh sac -test`.

The output of tests (which includes AMDGPU disassembly) can be displayed by running `ctest -VV` in build directory.

Tests for OpenCL conformance kernels can be enabled by specifying `-DOCL_CONFORMANCE_HOME=` to CMake, for example, `cmake ... -DOCL_CONFORMANCE_HOME=/srv/hsa/drivers/opencl/tests/extra/hsa/ocl/conformance/1.2`

2.10.4 ROCr Runtime

Github link of ROCr Runtime check [Here](#)
This repository includes the user-mode API interfaces and libraries necessary for host applications to launch compute kernels to available HSA ROCm kernel agents. Reference source code for the core runtime is also available. Initial target platform requirements:

- CPU: Intel Haswell or newer, Core i5, Core i7, Xeon E3 v4 & v5; Xeon E5 v3
- GPU: Fiji ASIC (AMD R9 Nano, R9 Fury and R9 Fury X)
- GPU: Polaris ASIC (AMD RX480)

The HSA core runtime source code for the ROCR runtime is located in the src subdirectory. Please consult the associated README.md file for contents and build instructions.

Pre-built binaries are available for installation from the ROCm package repository. For ROCR, they include:

- HSA include files to support application development on the HSA runtime for the ROCR runtime
- A 64-bit version of AMD’s HSA core runtime for the ROCR runtime

Runtime extension package:

- A 64-bit version of AMD’s finalizer extension for ROCR runtime
- A 64-bit version of AMD’s runtime tools library
- A 64-bit version of AMD’s runtime image library, which supports the HSAIL image implementation only.

The contents of these packages are installed in /opt/rocm/hsa and /opt/rocm by default. The core runtime package depends on the hsakmt-roct-dev package.

Installation instructions can be found in the ROCm Documentation.

The HSA runtime is a thin, user-mode API that exposes the necessary interfaces to access and interact with graphics hardware driven by the AMDGPU driver set and the ROCK kernel driver. Together they enable programmers to directly harness the power of AMD discrete graphics devices by allowing host applications to launch compute kernels directly to the graphics hardware.

The capabilities expressed by the HSA Runtime API are:

- Error handling
- Runtime initialization and shutdown
- System and agent information
- Signals and synchronization
- Architected dispatch
- Memory management
- HSA runtime fits into a typical software architecture stack.
The HSA runtime provides direct access to the graphics hardware to give the programmer more control of the execution. An example of low level hardware access is the support of one or more user mode queues provides programmers with a low-latency kernel dispatch interface, allowing them to develop customized dispatch algorithms specific to their application.

The HSA Architected Queuing Language is an open standard, defined by the HSA Foundation, specifying the packet syntax used to control supported AMD/ATI Radeon (c) graphics devices. The AQL language supports several packet types, including packets that can command the hardware to automatically resolve inter-packet dependencies (barrier AND & barrier OR packet), kernel dispatch packets and agent dispatch packets.

In addition to user mode queues and AQL, the HSA runtime exposes various virtual address ranges that can be accessed by one or more of the system’s graphics devices, and possibly the host. The exposed virtual address ranges either support a fine grained or a coarse grained access. Updates to memory in a fine grained region are immediately visible to all devices that can access it, but only one device can have access to a coarse grained allocation at a time. Ownership of a coarse grained region can be changed using the HSA runtime memory APIs, but this transfer of ownership must be explicitly done by the host application.

Programmers should consult the HSA Runtime Programmer’s Reference Manual for a full description of the HSA Runtime APIs, AQL and the HSA memory policy.

2.10.4.5 Sample

The simplest way to check if the kernel, runtime and base development environment are installed correctly is to run a simple sample. A modified version of the vector_copy sample was taken from the HSA-Runtime-AMD repository and added to the ROCR repository to facilitate this. Build the sample and run it, using this series of commands:

```bash
cd ROCR-Runtime/sample && make && ./vector_copy
```

If the sample runs without generating errors, the installation is complete.

2.10.4.6 Known issues

- The image extension is currently not supported for discrete GPUs. An image extension library is not provided in the binary package. The standard hsa_ext_image.h extension include file is provided for reference.
- Each HSA process creates and internal DMA queue, but there is a system-wide limit of four DMA queues. The fifth simultaneous HSA process will fail hsa_init() with HSA_STATUS_ERROR_OUT_OF_RESOURCES. To run an unlimited number of simultaneous HSA processes, set the environment variable HSA_ENABLE_SDMA=0.

Disclaimer

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2.11 ROCm System Management

2.11.1 ROCm-SMI

ROCm System Management Interface

This repository includes the rocm-smi tool. This tool exposes functionality for clock and temperature management of your ROCm enabled system.

Installation

You may find rocm-smi at the following location after installing the rocm package:

```
/opt/rocm/bin/rocm-smi
```

Alternatively, you may clone this repository and run the tool directly.

Usage

For detailed and up to date usage information, we recommend consulting the help:

```
/opt/rocm/bin/rocm-smi -h
```

For convenience purposes, following is a quick excerpt:


AMD ROCm System Management Interface

optional arguments:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-h, --help</td>
<td>show this help message and exit</td>
</tr>
<tr>
<td>--load FILE</td>
<td>Load Clock, Fan, Performance and Profile settings</td>
</tr>
<tr>
<td>--save FILE</td>
<td>Save Clock, Fan, Performance and Profile settings</td>
</tr>
</tbody>
</table>

-d DEVICE [DEVICE . . . ], --device DEVICE [DEVICE . . . ] Execute command on specified device

-1, --showid | Show GPU ID.

-v, --showvbios | Show VBIOS version.

-showhw | Show Hardware details.

-t, --showtemp | Show current temperature.

-c, --showclocks | Show current clock frequencies.

-g, --showgpuclocks | Show current GPU clock frequencies.

-f, --showfan | Show current fan speed.

-p, --showperlevel | Show current PowerPlay Performance Level.

-P, --showpower | Show current GPU ASIC power consumption.

-o, --showoverdrive | Show current OverDrive level.

-m, --showmemoverdrive | Show current GPU Memory Clock OverDrive level.
### Table 1 – continued from previous page

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-M, --showmaxpower</code></td>
<td>Show maximum graphics package power this GPU will consume</td>
</tr>
<tr>
<td><code>-l, --showprofile</code></td>
<td>Show Compute Profile attributes</td>
</tr>
<tr>
<td><code>-s, --showclfkfq</code></td>
<td>Show supported GPU and Memory Clock</td>
</tr>
<tr>
<td><code>-u, --showuse</code></td>
<td>Show current GPU use</td>
</tr>
<tr>
<td><code>--showmemuse</code></td>
<td>Show current GPU memory used</td>
</tr>
<tr>
<td><code>-b, --showbw</code></td>
<td>Show estimated PCIe use</td>
</tr>
<tr>
<td><code>--showreplaycount</code></td>
<td>Show PCIe Replay Count</td>
</tr>
<tr>
<td><code>-S, --showclkvolt</code></td>
<td>Show supported GPU and Memory Clocks and Voltages</td>
</tr>
<tr>
<td><code>--showvoltage</code></td>
<td>Show current GPU voltage</td>
</tr>
<tr>
<td><code>--showrasinfo BLOCK [BLOCK . . . ]</code></td>
<td>Show RAS enablement information and error counts for the specified block(s)</td>
</tr>
<tr>
<td><code>--showfwinfo [BLOCK [BLOCK . . . ] ]</code></td>
<td>Show FW information</td>
</tr>
<tr>
<td><code>--showproductname</code></td>
<td>Show SKU/Vendor name</td>
</tr>
<tr>
<td><code>-a, --showallinfo</code></td>
<td>Show all SMI-supported values values</td>
</tr>
<tr>
<td><code>--showmeminfo TYPE [TYPE . . . ]</code></td>
<td>Show Memory usage information for given block(s) TYPE</td>
</tr>
<tr>
<td><code>--showdriverversion</code></td>
<td>Show kernel driver version</td>
</tr>
<tr>
<td><code>--shownuniqueid</code></td>
<td>Show GPU’s Unique ID</td>
</tr>
<tr>
<td><code>--showpids</code></td>
<td>Show current running KFD PIDs</td>
</tr>
<tr>
<td><code>--alldevices</code></td>
<td>Execute command on non-AMD devices as well as AMD devices</td>
</tr>
<tr>
<td><code>-r, --resetclocks</code></td>
<td>Reset clocks to OverDrive to default</td>
</tr>
<tr>
<td><code>--setclk LEVEL [LEVEL . . . ]</code></td>
<td>Set GPU Clock Frequency Level Level(s) (requires manual Perf level)</td>
</tr>
<tr>
<td><code>--setmclk LEVEL [LEVEL . . . ]</code></td>
<td>Set GPU Memory Clock Frequency Level(s) (requires manual Perf level)</td>
</tr>
<tr>
<td><code>--setpcie LEVEL [LEVEL . . . ]</code></td>
<td>Set PCIe Clock Frequency Level(s) (requires manual Perf level)</td>
</tr>
<tr>
<td><code>--setlevel SCLKLEVEL SCLK SVOLT</code></td>
<td>Change GPU Clock frequency (MHz) and Voltage (mV) for a specific Level</td>
</tr>
<tr>
<td><code>--setmlevel MCLKLEVEL MCLK MVOLT</code></td>
<td>Change GPU Memory clock frequency (MHz) and Voltage for (mV) a specific Level</td>
</tr>
<tr>
<td><code>--resetfans</code></td>
<td>Reset fans to automatic (driver) control</td>
</tr>
<tr>
<td><code>--setfan LEVEL</code></td>
<td>Set GPU Fan Speed Level</td>
</tr>
<tr>
<td><code>--setperfllevel LEVEL</code></td>
<td>Set PowerPlay Performance Level</td>
</tr>
<tr>
<td><code>--setoverdrive</code></td>
<td>Set GPU OverDrive level</td>
</tr>
<tr>
<td><code>--setmemoverdrive %</code></td>
<td>Set GPU Memory Overclock OverDrive level (requires manual</td>
</tr>
<tr>
<td><code>--setpoweroverdrive WATTS</code></td>
<td>Set the maximum GPU power using Power OverDrive in Watts</td>
</tr>
<tr>
<td><code>--resetpoweroverdrive</code></td>
<td>Set the maximum GPU power back to the device deault state</td>
</tr>
<tr>
<td><code>--setprofile SETPROFILE</code></td>
<td>Specify Power Profile level (#) or a quoted string of CUSTOM Profile attributes “# # # #. . . ”</td>
</tr>
<tr>
<td><code>--resetprofile</code></td>
<td>Reset Power Profile back to default</td>
</tr>
<tr>
<td><code>--rasenable BLOCK ERRTYPE</code></td>
<td>Enable RAS for specified block and error type</td>
</tr>
<tr>
<td><code>--rasdisable BLOCK ERRTYPE</code></td>
<td>Disable RAS for specified block and error type</td>
</tr>
<tr>
<td><code>--rasinject BLOCK</code></td>
<td>Inject RAS poison for specified block (ONLY WORKS ON UNSECURE BOARDS)</td>
</tr>
<tr>
<td><code>--gpureset</code></td>
<td>Reset specified GPU (One GPU must be specified)</td>
</tr>
<tr>
<td><code>--autorespond RESPONSE</code></td>
<td>Response to automatically provide for all prompts (NOT RECOMMENDED)</td>
</tr>
<tr>
<td><code>--logfile ILEVEL</code></td>
<td>How much output will be printed for what program is doing, one of debug/info/warning</td>
</tr>
<tr>
<td><code>--json</code></td>
<td>Print output in JSON format</td>
</tr>
</tbody>
</table>

#### Detailed Option Descriptions

```
--setsclk/-setmclk #[# # . . . ]: This allows you to set a mask for the levels. For example, if a GPU has 8 clock levels, you can set a mask to use levels 0, 5, 6 and 7 with --setsclk 0 5 6 7. This will only use the base level, and the top 3 clock levels. This will allow you to keep the GPU at base level when there is no GPU load, and the top 3 levels when the GPU load increases.

--setfan LEVEL: This sets the fan speed to a value ranging from 0 to 255 (not from 0-100%). If the level ends with a %, the fan speed is calculated as pct*maxlevel/100 (maxlevel is usually 255, but is determined by the ASIC) . NOTE:
While the hardware is usually capable of overriding this value when required, it is
```

(continues on next page)
recommended to **not set** the fan level lower than the default value for extended periods of time

---

**setperflevel LEVEL:** This lets you use the pre-defined Performance Level values, which can include: auto (Automatically change PowerPlay values based on GPU workload) low (Keep PowerPlay values low, regardless of workload) high (Keep PowerPlay values high, regardless of workload) manual (Only use values defined in sysfs values)

**setoverdrive/setmemoverdrive #:** **DEPRECATED IN NEWER KERNEL VERSIONS** (use

**setlevel/setmlevel instead**) This sets the percentage above maximum for the max Performance Level. For example, setoverdrive 20 will increase the top sclk level by 20%. If the maximum sclk level is 1000MHz, then

setoverdrive 20 will increase the maximum sclk to 1200MHz

**setpoweroverdrive/resetpoweroverdrive #:** This allows users to change the maximum power available to a GPU package. The input value is in Watts. This limit is enforced by the hardware, and some cards allow users to set it to a higher value than the default that ships with the GPU. This Power OverDrive mode allows the GPU to run at higher frequencies for longer periods of time, though this may mean the GPU uses more power than it is allowed to use per power supply specifications. Each GPU has a model-specific maximum Power OverDrive that is will take; attempting to set a higher limit than that will cause this command to fail.

**setprofile SETPROFILE:** The Compute Profile accepts 1 or n parameters, either the Profile to select (see

**showprofile** for a list of preset Power Profiles) or a quoted string of values for the CUSTOM profile. NOTE: These values can vary based on the ASIC, and may include: SCLK_PROFILE_ENABLE - Whether or not to apply the 3 following SCLK settings (0=disable,1=enable) NOTE: This is a hidden field. If set to 0, the following 3 values are displayed as ‘-’ SCLK_UP_HYST - Delay before sclk is increased (in milliseconds) SCLK_DOWN_HYST - Delay before sclk is decreed (in milliseconds) SCLK_ACTIVE_LEVEL - Workload required before sclk levels change (in %) MCLK_PROFILE_ENABLE - Whether or not to apply the 3 following MCLK settings (0=disable,1=enable) NOTE: This is a hidden field. If set to 0, the following 3 values are displayed as ‘-’ MCLK_UP_HYST - Delay before mclk is increased (in milliseconds) MCLK_DOWN_HYST - Delay before mclk is decreed (in milliseconds) MCLK_ACTIVE_LEVEL - Workload required before mclk levels change (in %)

BUSY_SET_POINT - Threshold for raw activity level before levels change

FPS - Frames Per Second

USE_RLC_BUSY - When set to 1, DPM is switched up as long as RLC busy message is received

MINACTIVE_LEVEL - Workload required before levels change (in %)

**Note:** When a compute queue is detected, these values will be automatically applied to the system Compute Power Profiles are only applied when the Performance Level is set to “auto”

The CUSTOM Power Profile is only applied when the Performance Level is set to “manual” so using this flag will automatically set the performance level to “manual”

It is not possible to modify the non-CUSTOM Profiles. These are hard-coded by the kernel

**-P, --showpower:** Show Average Graphics Package power consumption

“Graphics Package” refers to the GPU plus any HBM (High-Bandwidth memory) modules, if present

**-M, --showmaxpower:** Show the maximum Graphics Package power that the GPU will attempt to consume. This limit is enforced by the hardware.

**-loglevel:** This will allow the user to set a logging level for the SMI’s actions. Currently this is only implemented for sysfs writes, but can easily be expanded upon in the future to log other things from the SMI

**--showmeminfo:** This allows the user to see the amount of used and total memory for a given block (vram, vis_vram, gtt). It returns the number of bytes used and total number of bytes for each block ‘all’ can be passed as a field to return all blocks, otherwise a quoted-string is used for multiple values (e.g. “vram vis_vram”) vram refers to the
Video RAM, or graphics memory, on the specified device vis_vram refers to Visible VRAM, which is the CPU-accessible video memory on the device gtt refers to the Graphics Translation Table

\textbf{--showbw:} This shows an approximation of the number of bytes received and sent by the GPU over the last second through the PCIe bus. Note that this will not work for APUs since data for the GPU portion of the APU goes through the memory fabric and does not enter/exit the chip via the PCIe interface, thus no accesses are generated, and the performance counters can’t count accesses that are not generated. NOTE: It is not possible to easily grab the size of every packet that is transmitted in real time, so the kernel estimates the bandwidth by taking the maximum payload size (mps), which is the max size that a PCIe packet can be, and multiplies it by the number of packets received and sent. This means that the SMI will report the maximum estimated bandwidth, the actual usage could (and likely will be) less

\textbf{--showrasinfo:} This shows the RAS information for a given block. This includes enablement of the block (currently GFX, SDMA and UMC are the only supported blocks) and the number of errors ue - Uncorrectable errors ce - Correctable errors

\textbf{Clock Type Descriptions}

DCEFCLK - DCE (Display) FCLK - Data fabric (VG20 and later) - Data flow from XGMI, Memory, PCIe SCLK - GFXCLK (Graphics core)

\textbf{Note:} SOCCCLK split from SCLK as of Vega10. Pre-Vega10 they were both controlled by SCLK

MCLK - GPU Memory (VRAM) PCLK - PCIe bus

\textbf{Note:} This gives 2 speeds, PCIe Gen1 x1 and the highest available based on the hardware

SOCCCLK - System clock (VG10 and later) - Data Fabric (DF), MM HUB, AT HUB, SYSTEM HUB, OSS, DFD Note - DF split from SOCCCLK as of Vega20. Pre-Vega20 they were both controlled by SOCCCLK

\textbf{--gpureset:} This flag will attempt to reset the GPU for a specified device. This will invoke the GPU reset through the kernel debugfs file amdgpu_gpu_recover. Note that GPU reset will not always work, depending on the manner in which the GPU is hung.

\textbf{--showdriverversion:} This flag will print out the AMDGPU module version for amdgpu-pro or ROCK kernels. For other kernels, it will simply print out the name of the kernel (uname)

\textbf{OverDrive settings}

For OverDrive functionality, the OverDrive bit (bit 14) must be enabled (by default, the OverDrive bit is disabled on the ROCK and upstream kernels). This can be done by setting amdgpu.ppfeaturemask accordingly in the kernel parameters, or by changing the default value inside amdgpu_drv.c (if building your own kernel).

As an example, if the ppfeaturemask is set to 0xffffffff (11111111111111111111111111111111), then enabling the OverDrive bit would make it 0xffffffff (11111111111111111111111111111111).

\textbf{Testing changes}

After making changes to the SMI, run the test script to ensure that all functionality remains intact before uploading the patch. This can be done using:

```
./test-rocm-smi.sh /opt/rocm/bin/rocm-smi
```

The test can run all flags for the SMI, or specific flags can be tested with the \texttt{-s} option.

Any new functionality added to the SMI should have a corresponding test added to the test script.

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2.11.1.1 Programing

2.11.2 SYSFS

2.11.2.1 Naming and data format standards for sysfs files

The libsensors library offers an interface to the raw sensors data through the sysfs interface. Since lm-sensors 3.0.0, libsensors is completely chip-independent. It assumes that all the kernel drivers implement the standard sysfs interface described in this document. This makes adding or updating support for any given chip very easy, as libsensors, and applications using it, do not need to be modified.

Note that motherboards vary widely in the connections to sensor chips. There is no standard that ensures connection of sensor to CPU, variation in external resistor value and conversion calculation we can not hard code this into the driver and have to be done in user space.

Each chip gets its own directory in the sysfs /sys/devices tree. To find all sensor chips, it is easier to follow the device symlinks from /sys/class/hwmon/hwmon*. This document briefly describes the standards that the drivers follow, so that an application program can scan for entries and access this data in a simple and consistent way. That said, such programs will have to implement conversion, labeling and hiding of inputs.

Up to lm-sensors 3.0.0, libsensors looks for hardware monitoring attributes in the “physical” device directory. Since lm-sensors 3.0.1, attributes found in the hwmon “class” device directory are also supported. Complex drivers (e.g. drivers for multifunction chips) may want to use this possibility to avoid namespace pollution. The only drawback will be that older versions of lib sensors won’t support the driver in question.

All sysfs values are fixed point numbers.

There is only one value per file, unlike the older /proc specification. The common scheme for files naming is: <type><number>_<item>. Usual types for sensor chips are “in” (voltage), “temp” (temperature) and “fan” (fan). Usual items are “input” (measured value), “max” (high threshold), “min” (low threshold). Numbering usually starts from 1, except for voltages which start from 0 (because most data sheets use this). A number is always used for elements that can be present more than once, even if there is a single element of the given type on the specific chip. Other files do not refer to a specific element, so they have a simple name, and no number.

Alarms are direct indications read from the chips. The drivers do NOT make comparisons of readings to thresholds. This allows violations between readings to be caught and alarmed. The exact definition of an alarm (for example, whether a threshold must be met or must be exceeded to cause an alarm) is chip-dependent.

When setting values of hwmon sysfs attributes, the string representation of the desired value must be written, note that strings which are not a number are interpreted as 0! For more on how written strings are interpreted see the “sysfs attribute writes interpretation” section at the end of this file.
Read/write values may be read-only for some chips, depending on the hardware implementation.
All entries (except name) are optional, and should only be created in a given driver if the chip has the feature.

### 2.11.2.1.1 Global attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>The chip name. This should be a short, lowercase string, not containing whitespace, dashes, or the wildcard character ‘*’. This attribute represents the chip name. It is the only mandatory attribute. I2C devices get this attribute created automatically. RO</td>
</tr>
<tr>
<td>update_interval</td>
<td>The interval at which the chip will update readings. Unit: millisecond RW Some devices have a variable update rate or interval. This attribute can be used to change it to the desired value.</td>
</tr>
</tbody>
</table>
## 2.11.2.1.2 Voltages

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>in[0-9]_min</code></td>
<td>Voltage min value. Unit: millivolt</td>
</tr>
<tr>
<td></td>
<td><strong>RW</strong></td>
</tr>
<tr>
<td></td>
<td>Voltage min value.</td>
</tr>
<tr>
<td><code>in[0-9]_lcrit</code></td>
<td>Voltage critical min value. Unit: millivolt</td>
</tr>
<tr>
<td></td>
<td><strong>RW</strong></td>
</tr>
<tr>
<td></td>
<td>If voltage drops to or below this limit, the system may take drastic action</td>
</tr>
<tr>
<td></td>
<td>such as power down or reset. At the very least, it should report a fault.</td>
</tr>
<tr>
<td><code>in[0-9]_max</code></td>
<td>Voltage max value. Unit: millivolt</td>
</tr>
<tr>
<td></td>
<td><strong>RW</strong></td>
</tr>
<tr>
<td><code>in[0-9]_crit</code></td>
<td>Voltage critical max value. Unit: millivolt</td>
</tr>
<tr>
<td></td>
<td><strong>RW</strong></td>
</tr>
<tr>
<td></td>
<td>If voltage reaches or exceeds this limit, the system may take drastic action</td>
</tr>
<tr>
<td></td>
<td>such as power down or reset. At the very least, it should report a fault.</td>
</tr>
<tr>
<td><code>in[0-9]_input</code></td>
<td>Voltage input value. Unit: millivolt</td>
</tr>
<tr>
<td></td>
<td><strong>RO</strong></td>
</tr>
<tr>
<td></td>
<td>Voltage measured on the chip pin. Actual voltage depends on the scaling</td>
</tr>
<tr>
<td></td>
<td>resistors on the motherboard, as recommended in the chip datasheet. This</td>
</tr>
<tr>
<td></td>
<td>varies by chip and by motherboard. Because of this variation, values are</td>
</tr>
<tr>
<td></td>
<td>generally NOT scaled by the chip driver, and must be done by the</td>
</tr>
<tr>
<td></td>
<td>application. However, some drivers (notably lm87 and via686a) do scale,</td>
</tr>
<tr>
<td></td>
<td>because of internal resistors built into a chip. These drivers will output</td>
</tr>
<tr>
<td></td>
<td>the actual voltage. Rule of thumb: drivers should report the voltage values</td>
</tr>
<tr>
<td></td>
<td>at the “pins” of the chip.</td>
</tr>
<tr>
<td><code>in[0-9]_average</code></td>
<td>Average voltage. Unit: millivolt</td>
</tr>
<tr>
<td><code>in[0-9]_lowest</code></td>
<td>Historical minimum voltage.</td>
</tr>
<tr>
<td><code>in[0-9]_highest</code></td>
<td>Historical maximum voltage.</td>
</tr>
<tr>
<td><code>in[0-9]_reset_history</code></td>
<td>Reset inX_lowest and inX_highest for all sensors</td>
</tr>
<tr>
<td><code>in_reset_history</code></td>
<td>Reset inX_lowest and inX_highest for all sensors</td>
</tr>
</tbody>
</table>

**2.11. ROCm System Management**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>cpu[0-9]_vid</code></td>
<td>CPU core reference voltage. Unit: millivolt</td>
</tr>
<tr>
<td></td>
<td><strong>RO</strong></td>
</tr>
<tr>
<td></td>
<td>Not always correct.</td>
</tr>
<tr>
<td><code>vrm</code></td>
<td>Voltage Regulator Module version number. <strong>RW</strong> (but changing it should no</td>
</tr>
<tr>
<td></td>
<td>more be necessary)</td>
</tr>
<tr>
<td></td>
<td>Originally the VRM standard version multiplied by 10, but now an arbitrary</td>
</tr>
<tr>
<td></td>
<td>number, as not all standards have a version number. Affects the way the</td>
</tr>
<tr>
<td></td>
<td>driver calculates the CPU core reference voltage from the vid pins.</td>
</tr>
</tbody>
</table>
Also see the Alarms section for status flags associated with voltages.
## 2.11.2.1.3 Fans

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
</table>
| fan[1-..]_min | Fan minimum value  
Unit: revolution/min (RPM)  
RW                                                                                                           |
| fan[1-..]_max | Fan maximum value  
Unit: revolution/min (RPM)  
Only rarely supported by the hardware.  
RW                                                                                                           |
| fan[1-..]_input | Fan input value.  
Unit: revolution/min (RPM)  
RO                                                                                                           |
| fan[1-..]_div | Fan divisor.  
Integer value in powers of two (1, 2, 4, 8, 16, 32, 64, 128).  
RW  
Some chips only support values 1, 2, 4 and 8. Note that this is actually an internal clock divisor, which affects the measurable speed range, not the read value. |
| fan[1-..]_pulses | Number of tachometer pulses per fan revolution.  
Integer value, typically between 1 and 4.  
RW  
This value is a characteristic of the fan connected to the device’s input, so it has to be set in accordance with the fan model. Should only be created if the chip has a register to configure the number of pulses. In the absence of such a register (and thus attribute) the value assumed by all devices is 2 pulses per fan revolution. |
| fan[1-..]_target | Desired fan speed  
Unit: revolution/min (RPM)  
RW  
Only makes sense if the chip supports closed-loop fan speed control based on the measured fan speed. |
| fan[1-..]_label | Suggested fan channel label. Should only be created if the driver has hints about what this fan channel is being used for, and user-space doesn’t. In all other cases, the label is provided by user-space. |
Also see the Alarms section for status flags associated with fans.
### 2.11.2.1.4 PWM

| **pwm[1-]** | Pulse width modulation fan control.  
| Integer value in the range 0 to 255  
| RW  
| 255 is max or 100%. |

| **pwm[1-]**_enable | Fan speed control method:  
| 0: no fan speed control (i.e. fan at full speed)  
| 1: manual fan speed control enabled (using pwm[1-])  
| 2+: automatic fan speed control enabled  
| Check individual chip documentation files for automatic mode details.  
| RW |

| **pwm[1-]**_mode | 0: DC mode (direct current)  
| 1: PWM mode (pulse-width modulation)  
| RW |

| **pwm[1-]**_freq | Base PWM frequency in Hz.  
| Only possibly available when pwmN_mode is PWM, but not always present even then.  
| RW |

| **pwm[1-]**_auto_channels_temp | Select which temperature channels affect this PWM output in auto mode. Bitfield,  
| 1 is temp1, 2 is temp2, 4 is temp3 etc…  
| Which values are possible depend on the chip used.  
| RW |

| **pwm[1-]**_auto_point[1-]_pwm  
| **pwm[1-]**_auto_point[1-]_temp  
| **pwm[1-]**_auto_point[1-]_temp_hyst | Define the PWM vs temperature curve. Number of trip points is chip-dependent. Use this for chips which associate trip points to PWM output channels.  
| RW |

| **temp[1-]**_auto_point[1-]_pwm  
| **temp[1-]**_auto_point[1-]_temp  
| **temp[1-]**_auto_point[1-]_temp_hyst | Define the PWM vs temperature curve. Number of trip points is chip dependent. Use this for chips which associate trip points to temperature channels.  
| RW |
There is a third case where trip points are associated to both PWM output channels and temperature channels: the PWM values are associated to PWM output channels while the temperature values are associated to temperature channels. In that case, the result is determined by the mapping between temperature inputs and PWM outputs. When several temperature inputs are mapped to a given PWM output, this leads to several candidate PWM values. The actual result is up to the chip, but in general the highest candidate value (fastest fan speed) wins.
### 2.11.2.1.5 Temperatures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>temp[1-]*_type</strong></td>
<td>Sensor type selection. Integers 1 to 6 RW 1: CPU embedded diode 2: 3904 transistor 3: thermal diode 4: thermistor 5: AMD AMDSI 6: Intel PECI Not all types are supported by all chips</td>
</tr>
<tr>
<td><strong>temp[1-]*_max</strong></td>
<td>Temperature max value. Unit: millidegree Celsius (or millivolt, see below) RW</td>
</tr>
<tr>
<td><strong>temp[1-]*_min</strong></td>
<td>Temperature min value. Unit: millidegree Celsius RW</td>
</tr>
<tr>
<td><strong>temp[1-]*_max_hyst</strong></td>
<td>Temperature hysteresis value for max limit. Unit: millidegree Celsius Must be reported as an absolute temperature, NOT a delta from the max value. RW</td>
</tr>
<tr>
<td><strong>temp[1-]*_min_hyst</strong></td>
<td>Temperature hysteresis value for min limit. Unit: millidegree Celsius Must be reported as an absolute temperature, NOT a delta from the min value. RW</td>
</tr>
<tr>
<td><strong>temp[1-]*_input</strong></td>
<td>Temperature input value. Unit: millidegree Celsius RO</td>
</tr>
<tr>
<td><strong>temp[1-]*_crit</strong></td>
<td>Temperature critical max value, typically greater than corresponding temp_max values. Unit: millidegree Celsius</td>
</tr>
<tr>
<td><strong>temp[1-]*_crit_hyst</strong></td>
<td>Temperature hysteresis value for critical limit.</td>
</tr>
<tr>
<td><strong>temp[1-]*_label</strong></td>
<td>Suggested temperature channel label. Text string Should only be created if the driver has hints about what this temperature channel is being used for, and user-space doesn’t. In all other cases, the label is provided by user-space. RO</td>
</tr>
<tr>
<td><strong>temp[1-]*_lowest</strong></td>
<td>Historical minimum temperature Unit: millidegree Celsius RO</td>
</tr>
<tr>
<td><strong>temp[1-]*_highest</strong></td>
<td>Historical maximum temperature Unit: millidegree Celsius RO</td>
</tr>
<tr>
<td><strong>temp_reset_history</strong></td>
<td>Reset temp_lowest and temp_highest for all sensors WO</td>
</tr>
</tbody>
</table>

---

**Chapter 2. Solid Compilation Foundation and Language Support**
Some chips measure temperature using external thermistors and an ADC, and report the temperature measurement as a voltage. Converting this voltage back to a temperature (or the other way around for limits) requires mathematical functions not available in the kernel, so the conversion must occur in user space. For these chips, all temp* files described above should contain values expressed in millivolt instead of millidegree Celsius. In other words, such temperature channels are handled as voltage channels by the driver.

Also see the Alarms section for status flags associated with temperatures.
### 2.11.2.1.6 Currents

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Read/Write</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>curr&lt;1-9&gt;_max</code></td>
<td>Current max value</td>
<td>RW</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_min</code></td>
<td>Current min value</td>
<td>RW</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_lcrit</code></td>
<td>Current critical low value</td>
<td>RW</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_crit</code></td>
<td>Current critical high value</td>
<td>RW</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_input</code></td>
<td>Current input value</td>
<td>RO</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_average</code></td>
<td>Average current use</td>
<td>RO</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_lowest</code></td>
<td>Historical minimum current</td>
<td>RO</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_highest</code></td>
<td>Historical maximum current</td>
<td>RO</td>
</tr>
<tr>
<td></td>
<td>Unit: milliampere</td>
<td></td>
</tr>
<tr>
<td><code>curr&lt;1-9&gt;_reset_history</code></td>
<td>Reset currX_lowest and currXHighest</td>
<td>WO</td>
</tr>
<tr>
<td><code>curr_reset_history</code></td>
<td>Reset currX_lowest and currX_Highest for all sensors</td>
<td>WO</td>
</tr>
</tbody>
</table>
Also see the Alarms section for status flags associated with currents.
### 2.11.2.1.7 Power

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
</table>
| power[1-*]_average | Average power use  
Unit: microWatt  
RO |
| power[1-*]_average_interval | Power use averaging interval. A poll notification is sent to this file if the hardware changes the averaging interval.  
Unit: milliseconds  
RW |
| power[1-*]_average_interval_max | Maximum power use averaging interval  
Unit: milliseconds  
RO |
| power[1-*]_average_interval_min | Minimum power use averaging interval  
Unit: milliseconds  
RO |
| power[1-*]_average_highest | Historical average maximum power use  
Unit: microWatt  
RO |
| power[1-*]_average_lowest | Historical average minimum power use  
Unit: microWatt  
RO |
| power[1-*]_average_max | A poll notification is sent to power[1-*]_average when power use rises above this value.  
Unit: microWatt  
RW |
| power[1-*]_average_min | A poll notification is sent to power[1-*]_average when power use sinks below this value.  
Unit: microWatt  
RW |
| power[1-*]_input | Instantaneous power use  
Unit: microWatt  
RO |
| power[1-*]_input_highest | Historical maximum power use  
Unit: microWatt  
RO |
| power[1-*]_input_lowest | Historical minimum power use  
Unit: microWatt  
RO |
| power[1-*]_reset_history | Reset input_highest, input_lowest, average_highest and average_lowest.  
WO |
| power[1-*]_accuracy | Accuracy of the power meter.  
Unit: Percent  
RO |
| power[1-*]_cap | If power use rises above this limit, the system should take action to reduce power use. A poll notification is sent to this file if the cap is changed by the hardware. The *_cap files only appear if the cap is known to be enforced by hardware.  
Unit: microWatt  
RW |
| power[1-*]_cap_hyst | Margin of hysteresis built around capping and notification.  
Unit: microWatt  
RW |
| power[1-*]_cap_max | Maximum cap that can be set.  
Unit: microWatt  
RO |
| power[1-*]_cap_min | Minimum cap that can be set.  
Unit: microWatt  
RO |
| power[1-*]_max | Maximum power.  
Unit: microWatt  
RW |
| power[1-*]_crit | Critical maximum power. If power rises to or above this limit, the system is expected to take drastic action to reduce power consumption, such as a system shutdown or a forced power down of some devices.  
Unit: microWatt  
RW |
Also see the Alarms section for status flags associated with power readings.

### 2.11.2.1.8 Energy

| energy[1-*]_input | Cumulative energy use  
|                  | Unit: microJoule  
|                  | RO  |

### 2.11.2.1.9 Humidity

| humidity[1-*]_input | Humidity  
|                    | Unit: milli-percent (per cent mille, pcm)  
|                    | RO  |

### 2.11.2.1.10 Alarms

Each channel or limit may have an associated alarm file, containing a boolean value. 1 means than an alarm condition exists, 0 means no alarm.

Usually a given chip will either use channel-related alarms, or limit-related alarms, not both. The driver should just reflect the hardware implementation.

| in[0-*]_alarm  
| curr[1-*]_alarm  
| power[1-*]_alarm  
| fan[1-*]_alarm  
| temp[1-*]_alarm | Channel alarm  
|                  | 0: no alarm  
|                  | 1: alarm  
|                  | RO  |

OR
Each input channel may have an associated fault file. This can be used to notify open diodes, unconnected fans etc. where the hardware supports it. When this boolean has value 1, the measurement for that channel should not be trusted.

<table>
<thead>
<tr>
<th>fan[1-]*_fault</th>
<th>Input fault condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp[1-]*_fault</td>
<td>0: no fault occurred</td>
</tr>
<tr>
<td></td>
<td>1: fault condition</td>
</tr>
<tr>
<td></td>
<td>RO</td>
</tr>
</tbody>
</table>

Some chips also offer the possibility to get beeped when an alarm occurs:

<table>
<thead>
<tr>
<th>beep_enable</th>
<th>Master beep enable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0: no beeps</td>
</tr>
<tr>
<td></td>
<td>1: beeps</td>
</tr>
<tr>
<td></td>
<td>RW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>in[0-]*_beep</th>
<th>Channel beep</th>
</tr>
</thead>
<tbody>
<tr>
<td>curr[1-]*_beep</td>
<td>0: disable</td>
</tr>
<tr>
<td>fan[1-]*_beep</td>
<td>1: enable</td>
</tr>
<tr>
<td>temp[1-]*_beep</td>
<td>RW</td>
</tr>
</tbody>
</table>
In theory, a chip could provide per-limit beep masking, but no such chip was seen so far.

Old drivers provided a different, non-standard interface to alarms and beeps. These interface files are deprecated, but will be kept around for compatibility reasons:

| alarms  | Alarm bitmask.  
|         | RO  
|         | Integer representation of one to four bytes.  
|         | A ‘1’ bit means an alarm.  
|         | Chips should be programmed for ‘comparator’ mode so that the alarm will ‘come back’ after you read the register if it is still valid.  
|         | Generally a direct representation of a chip’s internal alarm registers; there is no standard for the position of individual bits. For this reason, the use of this interface file for new drivers is discouraged. Use individual *_alarm and _fault files instead.  
|         | Bits are defined in kernel/include/sensors.h.  

| beep_mask | Bitmask for beep.  
|           | Same format as ‘alarms’ with the same bit locations, use discouraged for the same reason. Use individual *_beep files instead.  
|           | RW  

2.11. ROCm System Management

357
intrusion[0-]*_alarm

Chassis intrusion detection
0: OK
1: intrusion detected
RW
Contrary to regular alarm flags which clear themselves automatically when read, this one sticks until cleared by
the user. This is done by writing 0 to the file. Writing other values is unsupported.

intrusion[0-]*_beep

Chassis intrusion beep
0: disable
1: enable
RW

2.11.2.11.1 sysfs attribute writes interpretation

hwmon sysfs attributes always contain numbers, so the first thing to do is to convert the input to a number, there are 2
ways todo this depending whether the number can be negative or not:

unsigned long u = simple_strtoul(buf, NULL, 10);
long s = simple_strtol(buf, NULL, 10);

With buf being the buffer with the user input being passed by the kernel. Notice that we do not use the second
argument of strto[u]l, and thus cannot tell when 0 is returned, if this was really 0 or is caused by invalid input. This is
done deliberately as checking this everywhere would add a lot of code to the kernel.

Notice that it is important to always store the converted value in an unsigned long or long, so that no wrap around can
happen before any further checking.

After the input string is converted to an (unsigned) long, the value should be checked if its acceptable. Be careful
with further conversions on the value before checking it for validity, as these conversions could still cause a wrap
around before the check. For example do not multiply the result, and only add/subtract if it has been divided before
the add/subtract.

What to do if a value is found to be invalid, depends on the type of the sysfs attribute that is being set. If it is a
continuous setting like a tempX_max or inX_max attribute, then the value should be clamped to its limits using
clamp_val(value, min_limit, max_limit). If it is not continuous like for example a tempX_type, then when an invalid
value is written, -EINVAL should be returned.

Example1, temp1_max, register is a signed 8 bit value (-128 - 127 degrees):

long v = simple_strtol(buf, NULL, 10) / 1000;
v = clamp_val(v, -128, 127);
/* write v to register */

Example2, fan divider setting, valid values 2, 4 and 8:
```c
unsigned long v = simple_strtoul(buf, NULL, 10);

switch (v) {
    case 2: v = 1; break;
    case 4: v = 2; break;
    case 8: v = 3; break;
    default:
        return -EINVAL;
}
/* write v to register */
```

### 2.11.2.12 Performance

The `pcie_bw` sysfs file will report the usage of the PCIe bus over the last second, as a string with 3 integers: “bytes-received bytes-sent mps”. As there is no efficient way to calculate the size of each packet transmitted to and from the GPU in real time, the maximum payload size (mps), or the largest size of a PCIe packet, is included. The estimated bandwidth can then be calculated using by “bytes-received*mps + bytes-sent*mps” sed and multiplied by the number of packets received and sent.

### 2.11.3 KFD Topology

Application software needs to understand the properties of the underlying hardware to leverage the performance capabilities of the platform for feature utilization and task scheduling. The sysfs topology exposes this information in a loosely hierarchal order. The information is populated by the KFD driver is gathered from ACPI (CRAT) and AMDGPU base driver.

The sysfs topology is arranged hierarchically as following. The root directory of the topology is `/sys/devices/virtual/kfd/kfd/topology/nodes/`

Based on the platform inside this directory there will be sub-directories corresponding to each HSA Agent. A system with N HSA Agents will have N directories as shown below.

```
/sys/devices/virtual/kfd/kfd/topology/nodes/0/
/sys/devices/virtual/kfd/kfd/topology/nodes/1/
...
/sys/devices/virtual/kfd/kfd/topology/nodes/N-1/
```

### 2.11.3.1 HSA Agent Information

The HSA Agent directory and the sub-directories inside that contains all the information about that agent. The following are the main information available.
2.11.3.2 Node Information

This is available in the root directory of the HSA agent. This provides information about the compute capabilities of the agent which includes number of cores or compute units, SIMD count and clock speed.

2.11.3.3 Memory

The memory bank information attached to this agent is populated in “mem_banks” subdirectory.

/sys/devices/virtual/kfd/kfd/topology/nodes/N/mem_banks

2.11.3.4 Cache

The caches available for this agent is populated in “cache” subdirectory

/sys/devices/virtual/kfd/kfd/topology/nodes/N/cache

2.11.3.5 IO-LINKS

The IO links provides HSA agent interconnect information with latency (cost) between agents. This is useful for peer-to-peer transfers.

2.11.3.6 How to use topology information

The information provided in sysfs should not be directly used by application software. Application software should always use Thunk library API (libhsakmt) to access topology information. Please refer to Thunk API for more information.

The data are associated with a node ID, forming a per-node element list which references the elements contained at relative offsets within that list. A node associates with a kernel agent or agent. Node ID’s should be 0-based, with the “0” ID representing the primary elements of the system (e.g., “boot cores”, memory) if applicable. The enumeration order and—if applicable—values of the ID should match other information reported through mechanisms outside of the scope of the requirements;

For example, the data and enumeration order contained in the ACPI SRAT table on some systems should match the memory order and properties reported through HSA. Further detail is out of the scope of the System Architecture and outlined in the Runtime API specification.
Each of these nodes is interconnected with other nodes in more advanced systems to the level necessary to adequately describe the topology.

Where applicable, the node grouping of physical memory follows NUMA principles to leverage memory locality in software when multiple physical memory blocks are available in the system and agents have a different “access cost” (e.g., bandwidth/latency) to that memory.

2.11. ROCm System Management
KFD Topology structure for AMDGPU:

sysfsclasskfd
sysfsclasskfdtopology
sysfsclasskfdtopologynodes0
sysfsclasskfdtopologynodes0iolinks01
sysfsclasskfdtopologynodes0membanks0
sysfs-class-kfd-topology-nodes-N-caches

2.12 ROCm Virtualization & Containers

2.12.1 PCIe Passthrough on KVM

The following KVM-based instructions assume a headless host with an input/output memory management unit (IOMMU) to pass peripheral devices such as a GPU to guest virtual machines. If you know your host supports IOMMU but the below command does not find “svm” or “vxm”, you may need to enable IOMMU in your BIOS.

```
cat /proc/cpuinfo | grep -E “svm|vxm”
```

2.12.1.1 Ubuntu 16.04

Assume we use an intel system that support VT-d, with fresh ubuntu 16.04 installed

a. Install necessary packages and prepare for pass through device

1. `sudo apt-get install qemu-kvm qemu-system bridge-utils virt-manager ubuntu-vm-builder libvirt-dev`

2. add following modules into /etc/modules

   vfi
   vfi_iommu_type1
   vfi_pci
   kvm
   kvm_intel

   add intel_iommu=on in /etc/default/grub

   GRUB_CMDLINE_LINUX_DEFAULT=”quiet splash intel_iommu=on”

   sudo update-grub

3. Blacklist amdgpu by adding the following line to /etc/modprobe.d/blacklist.conf

   blacklist amdgpu

b. Bind pass through device to vfi-pci

1. Create a script file (vfio-bind) under /usr/bin. The script file has the following content:

   ```bash
   #!/bin/bash
   modprobe vfio-pci
   for dev in "$@"; do
     vendor=$(cat /sys/bus/pci/devices/$dev/vendor)
     device=$(cat /sys/bus/pci/devices/$dev/device)
   ```

(continues on next page)
if [ -e /sys/bus/pci/devices/$dev/driver ]; then
  echo $dev > /sys/bus/pci/devices/$dev/driver/unbind
fi
echo $vendor $device > /sys/bus/pci/drivers/vfio-pci/new_id
done

2. Make it executable by enter the command

```bash
chmod 755 vfio-bind
```

3. Bind the device to vfio by running the command for the three pass through devices

```bash
lspci -n -d 1002:
  83:00.0 0300: 1002:7300 (rev ca)
vfio.bind 0000:83:00.0
```

4. sudo reboot

**c. Pass through device to guest VM**

1. Start VMM by running “virt-manager” as root. Follow the on screen instruction to create one virtual machine (VM), make sure CPU copy host CPU configuration, network use bridge mode.

2. Add Hardware –> Select PCI Host device, select the appropriate device to pass through. ex:0000:83:00.0

3. sudo setpci -s 83:00.0 CAP_EXP+28.l=40

4. sudo reboot

After reboot, start virt-manager and then start the VM, inside the VM, lspci -d 1002: should shows the pass throughed device.

### 2.12.1.2 Fedora 27 or CentOS 7 (1708)

From a fresh install of Fedora 27 or CentOS 7 (1708)

**a. Install necessary packages and prepare for pass through device**

1. Identity the vendor and device id(s) for the PCIe device(s) you wish to passthrough, e.g., 1002:6861 and 1002:aaf8 for an AMD

```bash
lspci -nnk
```

2. **Install virtualization packages** sudo dnf install @virtualization sudo usermod -G libvirt -a $(whoami)

3. **Enable IOMMU in the GRUB_CMDLINE_LINUX variable for your target kernel**
   a. **For an AMD CPU** sudo sed ’s/quiet/quiet amd_iommu=on iommu=pt/’ etc/sysconfig/grub
   b. **For an Intel CPU** sudo sed ‘s/quiet/quiet intel_iommu=on iommu=pt/’ etc/sysconfig/grub

4. **Preempt the host claiming the device by loading a stub driver**

```bash
echo "options vfio-pci ids=1002:6861,1002:aaf8" | sudo tee -a /etc/modprobe.d/vfio.conf
echo "options vfio-pci disable_vga=1"
"l sudo tee -a /etc/modprobe.d/vfio.conf
```

5. **Update the kernel boot settings**

```bash
sudo grub2-mkconfig -o /etc/grub2-efi.cfg
```

6. **Reboot and verify that vfio-pci driver has been loaded**

```bash
lspci -nnk
```
c. Pass through device to guest VM

1. Within virt-manager the device should now appear in the list of available PCI devices

Note: To pass a device within a particular IOMMU group, all devices within that IOMMU group must also be passed. You may wish to refer to https://wiki.archlinux.org/index.php/PCI_passthrough_via_OVMF for more details, such as the following script that lists all IOMMU groups and the devices within them.

```bash
#!/bin/bash
shopt -s nullglob
for d in /sys/kernel/iommu_groups/; do
    n=${d#*/iommu_groups/}; n=${n%%/}
    printf 'IOMMU Group %s
    lspci -nns"${d##*/}"
    done;
```

2.12.2 ROCm-Docker

Radeon Open Compute Platform for docker

Please refer ROCm-Docker

This repository contains a framework for building the software layers defined in the Radeon Open Compute Platform into portable docker images. The following are docker dependencies, which should be installed on the target machine.

- Docker on Ubuntu systems or Fedora systems
- Highly recommended: Docker-Compose to simplify container management

2.12.2.1 Docker

Looking for an easy start with ROCm + Docker? The rocm/rocm-terminal image is hosted on Docker Hub. After the ROCm kernel is installed, pull the image from Docker Hub and create a new instance of a container.

```
sudo docker pull rocm/rocm-terminal
sudo docker run -it --device=/dev/kfd --device=/dev/dri --group-add video rocm/rocm-terminal
```

2.12.2.2 ROCm-docker

Installation instructions and asciicasts demos are available to help users quickly get running with rocm-docker. Visit the set up guide to read more.

F.A.Q

When working with the ROCm containers, the following are common and useful docker commands:

- A new docker container typically does not house apt repository meta-data. Before trying to install new software using apt, make sure to run sudo apt update first
- A message like the following typically means your user does not have permissions to execute docker; use sudo or add your user to the docker group.
- Cannot connect to the Docker daemon. Is the docker daemon running on this host?
- Open another terminal into a running container
- sudo docker exec -it <CONTAINER-NAME> bash -l
- Copy files from host machine into running docker container
  - sudo docker cp HOST_PATH <CONTAINER-NAME>:/PATH
• **Copy files from running docker container onto host machine**
  
  ```bash
  sudo docker cp <CONTAINER-NAME>:/PATH/TO/FILE HOST_PATH
  ```

• If receiving messages about no space left on device when pulling images, check the storage driver in use by the docker engine. If its ‘device mapper’, that means the image size limits imposed by the ‘device mapper’ storage driver are a problem. Follow the documentation in the quickstart for a solution to change to the storage driver.

### Saving work in a container

Docker containers are typically ephemeral, and are discarded after closing the container with the ‘–rm’ flag to docker run. However, there are times when it is desirable to close a container that has arbitrary work in it, and serialize it back into a docker image. This may be to create a checkpoint in a long and complicated series of instructions, or it may be desired to share the image with others through a docker registry, such as docker hub.

```bash
sudo docker ps -a  # Find container of interest
sudo docker commit <container-name> <new-image-name>
sudo docker images  # Confirm existence of a new image
```

#### 2.12.2.3 Details

Docker does not virtualize or package the linux kernel inside of an image or container. This is a design decision of docker to provide lightweight and fast containerization. The implication for this on the ROCm compute stack is that in order for the docker framework to function, the ROCm kernel and corresponding modules must be installed on the host machine. Containers share the host kernel, so the ROCm KFD component ROCK-Kernel-Driver1 functions outside of docker.

**Installing ROCK on the host machine.**

An **apt-get repository** is available to automate the installation of the required kernel and kernel modules.

#### 2.12.2.4 Building

There are two ways to install rocm components:

1. Install from the rocm apt/rpm repository (repo.radeon.com)

2. Build the components from source and run install scripts

The first method produces docker images with the smallest footprint and best building speed. The footprint is smaller because no developer tools need to be installed in the image, an the images build speed is fastest because typically downloading binaries is much faster than downloading source and then invoking a build process. Of course, building components allows much greater flexibility on install location and the ability to step through the source with debug builds. ROCm-docker supports making images either way, and depends on the flags passed to the setup script.

The setup script included in this repository is provides some flexibility to how docker containers are constructed. Unfortunately, Dockerfiles do not have a preprocessor or template language, so typically build instructions are hardcoded. However, the setup script allows us to write a primitive ‘template’, and after running it instantiates baked dockerfiles with environment variables substituted in. For instance, if you wish to build release images and debug images, first run the setup script to generate release dockerfiles and build the images. Then, run the setup script again and specify debug dockerfiles and build new images. The docker images should generate unique image names and not conflict with each other.

**setup.sh**

Currently, the setup.sh scripts checks to make sure that it is running on an **Ubuntu system**, as it makes a few assumptions about the availability of tools and file locations. If running rocm on a Fedora machine, inspect the source of setup.sh and issue the appropriate commands manually. There are a few parameters to setup.sh of a generic nature.
that affects all images built after running. If no parameters are given, built images will be based off of Ubuntu 16.04 with rocm components installed from debians downloaded from packages.amd.com. Supported parameters can be queried with ./setup --help.

<table>
<thead>
<tr>
<th>setup.sh parameters</th>
<th>parameter [default]</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--ubuntu</td>
<td>xx.yy [16.04]</td>
<td>Ubuntu version for to inherit base image</td>
</tr>
<tr>
<td>--install-docker-compose</td>
<td></td>
<td>helper to install the docker-compose tool</td>
</tr>
</tbody>
</table>

The following parameters are specific to building containers that compile rocm components from source.

<table>
<thead>
<tr>
<th>setup.sh parameters</th>
<th>parameter [default]</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--tag</td>
<td>string ['master']</td>
<td>string representing a git branch name</td>
</tr>
<tr>
<td>--branch</td>
<td>string ['master']</td>
<td>alias for tag</td>
</tr>
<tr>
<td>--debug</td>
<td>string ['master']</td>
<td>build code with debug flags</td>
</tr>
</tbody>
</table>

./setup generates finalized Dockerfiles from textual template files ending with the .template suffix. Each sub-directory of this repository corresponds to a docker ‘build context’ responsible for a software layer in the ROCm stack. After running the script, each directory contains generated dockerfiles for building images from debians and from source.

2.12.2.5 Docker compose

/setup prepares an environment to be controlled with Docker Compose. While docker-compose is not necessary for proper operation, it is highly recommended. setup.sh does provide a flag to simplify the installation of this tool. Docker-compose coordinates the relationships between the various ROCm software layers, and it remembers flags that should be passed to docker to expose devices and import volumes.

Example of using docker-compose

docker-compose.yml provides services that build and run containers. YAML is structured data, so it’s easy to modify and extend. The setup.sh script generates a .env file that docker-compose reads to satisfy the definitions of the variables in the .yml file.

- docker-compose run --rm rocm – Run container using rocm packages
- docker-compose run --rm rocm-from-src – Run container with rocm built from source

<table>
<thead>
<tr>
<th>Docker-compose</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>docker-compose</td>
<td>docker compose executable</td>
</tr>
<tr>
<td>run</td>
<td>sub-command to bring up interactive container</td>
</tr>
<tr>
<td>--rm</td>
<td>when shutting the container down, delete it</td>
</tr>
<tr>
<td>rocm</td>
<td>application service defined in docker-compose.yml</td>
</tr>
</tbody>
</table>

rocm-user has root privileges by default

The dockerfile that serves as a ‘terminal’ creates a non-root user called rocm-user. This container is meant to serve as a development environment (therefore apt-get is likely needed), the user has been added to the linux sudo group. Since it is somewhat difficult to set and change passwords in a container (often requiring a rebuild), the password prompt has been disabled for the sudo group. While this is convenient for development to be able sudo apt-get install packages, it does imply lower security in the container.

To increase container security:

1. Eliminate the sudo-nopasswd COPY statement in the dockerfile and replace with
2. Your own password with RUN echo ‘account:password’ | chpasswd
Footnotes:

[1] It can be installed into a container, it just doesn’t do anything because containers do not go through the traditional boot process. We actually do provide a container for ROCK-Kernel-Driver, but it not used by the rest of the docker images. It does provide isolation and a reproducible environment for kernel development.

2.13 Remote Device Programming

2.13.1 ROCmRDMA

ROCmRDMA is the solution designed to allow third-party kernel drivers to utilize DMA access to the GPU memory. It allows direct path for data exchange (peer-to-peer) using the standard features of PCI Express. Currently ROCmRDMA provides the following benefits:

- Direct access to ROCm memory for 3rd party PCIe devices
- Support for PeerDirect(c) interface to offloads the CPU when dealing with ROCm memory for RDMA network stacks;

2.13.1.1 Restrictions and limitations

To fully utilize ROCmRDMA the number of limitation could apply impacting either performance or functionality in the whole:

- It is recommended that devices utilizing ROCmRDMA share the same upstream PCI Express root complex. Such limitation depends on PCIe chipset manufacturses and outside of GPU controls;
- To provide peer-to-peer DMA access all GPU local memory must be exposed via PCI memory BARs (so called large-BAR configuration);
- It is recommended to have IOMMU support disabled or configured in pass-through mode due to limitation in Linux kernel to support local PCIe device memory for any form transition others then 1:1 mapping.

2.13.1.2 ROCmRDMA interface specification

The implementation of ROCmRDMA interface could be found in [amd_rdma.h] file.

2.13.1.3 Data structures

```c
/**
 * Structure describing information needed to P2P access from another device
 * to specific location of GPU memory
 */
struct amd_p2p_info {
    uint64_t va;  /* Specify user virt. address */
    uint64_t size;  /* Specify total size of allocation */
}
```

(continues on next page)
struct pid *pid; /**< Specify process pid to which */
   /* virtual address belongs */

struct sg_table *pages; /**< Specify DMA/Bus addresses */

void *priv; /**< Pointer set by AMD kernel */
   /* driver */

};

/**
 * Structure providing function pointers to support rdma/p2p requirements.
 * to specific location of GPU memory
 */

struct amd_rdma_interface {
   int (*get_pages)(uint64_t address, uint64_t length, struct pid *pid,
       struct amd_p2p_info **amd_p2p_data,
       void (*free_callback)(void *client_priv),
       void *client_priv);
   int (*put_pages)(struct amd_p2p_info **amd_p2p_data);
   int (*is_gpu_address)(uint64_t address, struct pid *pid);
   int (*get_page_size)(uint64_t address, uint64_t length, struct pid *pid,
       unsigned long *page_size);
};

2.13.1.4 The function to query ROCmRDMA interface

/**
 * amdkfd_query_rdma_interface - Return interface (function pointers table) for
 * rdma interface
 *
 * \param interface - OUT: Pointer to interface
 * \return 0 if operation was successful.
 */
int amdkfd_query_rdma_interface(const struct amd_rdma_interface **rdma);

2.13.1.5 The function to query ROCmRDMA interface

/**
 * amdkfd_query_rdma_interface - Return interface (function pointers table) for rdma_
 * interface
 * \param interface - OUT: Pointer to interface
 * \return 0 if operation was successful.
 */
int amdkfd_query_rdma_interface(const struct amd_rdma_interface **rdma);
### ROCmRDMA Interface Functions Description

**get_pages**

```c
int get_pages(uint64_t address, uint64_t length, struct pid *pid, struct amd_p2p_info **amd_p2p_data, void ( *free_callback)(void *client_priv), void *client_priv);
```

- This function makes the pages underlying a range of GPU virtual memory accessible for DMA operations from another PCIe device.
- **address** - The start address in the Unified Virtual Address space in the specified process.
- **length** - The length of requested mapping.
- **pid** - Pointer to structure pid to which address belongs.
- **amd_p2p_data** - On return: Pointer to structure describing underlying pages/locations.
- **free_callback** - Pointer to callback which will be called when access to such memory must be stopped immediately: Memory was freed, GECC events, etc.
- **client_priv** - Pointer to be passed as parameter on 'free_callback'; 

**Return**

0 if operation was successful.

**put_pages**

```c
int put_pages(struct amd_p2p_info **p_p2p_data)
```

- This function release resources previously allocated by get_pages() call.
- **p_p2p_data** - A pointer to pointer to amd_p2p_info entries allocated by get_pages() call.

**Return**

0 if operation was successful.

**is_gpu_address**

```c
int is_gpu_address(uint64_t address, struct pid *pid);
```

- Check if given address belongs to GPU address space.
- **address** - Address to check
- **pid** - Process to which given address belongs.
- **client_priv** - Could be NULL if current one.

**Return**

0 - This is not GPU address managed by AMD driver
1 - This is GPU address managed by AMD driver

---

**2.13. Remote Device Programming**

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2.13.2 UCX

2.13.2.1 Introduction

2.13.2.2 UCX Quick start

Compiling UCX

```
% ./autogen.sh
% ./contrib/configure-release --prefix=$PWD/install
% make -j8 install
```

2.13.2.3 UCX API usage examples

https://github.com/openucx/ucx/tree/master/test/examples

2.13.2.4 Running UCX

2.13.2.4.1 UCX internal performance tests

This infrastructure provided a function which runs a performance test (in the current thread) on UCX communication APIs. The purpose is to allow a developer make optimizations to the code and immediately test their effects. The infrastructure provides both an API, and a standalone tool which uses that API - ucx_perftest. The API is also used for unit tests. Location: src/tools/perf

Features of the library:

- uct_perf_test_run() is the function which runs the test. (currently only UCT API is supported)
- No need to do any resource allocation - just pass the testing parameters to the API
- Requires running the function on 2 threads/processes/nodes - by passing RTE callbacks which are used to bootstrap the connections.
- Two testing modes - ping-pong and unidirectional stream (TBD bi-directional stream)
- Configurable message size, and data layout (short/bcopy/zcopy)
• Supports: warmup cycles, unlimited iterations.
• UCT Active-messages stream is measured with simple flow-control.
• Tests driver is written in C++ (C linkage), to take advantage of templates.
• Results are reported to callback function at the specified intervals, and also returned from the API call.
  – Including: latency, message rate, bandwidth - iteration average, and overall average.

Features of ucx_perftest:

• Have pre-defined list of tests which are valid combinations of operation and testing mode.
• Can be run either as client-server application, as MPI application, or using libRTE.
• Supports: CSV output, numeric formatting.
• Supports “batch mode” - write the lists of tests to run to a text file (see example in contrib/perf) and run them one after another.
  – “Cartesian” mode: if several batch files are specified, all possible combinations are executed!

$ ucx_perftest -h
Usage: ucx_perftest [ server-hostname ] [ options ]

This test can be also launched as an MPI application
Common options:

Test options:       Test to run.
 -t <test>          am_lat : active message latency.
                     put_lat : put latency.
                     add_lat : atomic add latency.
                     get : get latency / bandwidth / message rate.
                     fadd : atomic fetch-and-add latency / message rate.
                     swap : atomic swap latency / message rate.
                     cswap : atomic compare-and-swap latency / message rate.
                     am_bw : active message bandwidth / message rate.
                     put_bw : put bandwidth / message rate.
                     add_mr : atomic add message rate.

-D <layout>        Data layout.
                    short : Use short messages API (cannot used for get).
                    bcopy : Use copy-out API (cannot used for atomics).
                    zcopy : Use zero-copy API (cannot used for atomics).

-d <device>       Device to use for testing.
-x <tl>           Transport to use for testing.
-c <cpu>          Set affinity to this CPU. (off)
-n <iters>        Number of iterations to run. (1000000)
-s <size>         Message size. (8)
-H <size>         AM Header size. (8)
-w <iters>        Number of warm-up iterations. (10000)
-W <count>        Flow control window size, for active messages. (128)
-O <count>        Maximal number of uncompleted outstanding sends. (1)
-N                Use numeric formatting - thousands separator.
-f                Print only final numbers.
-v                Print CSV-formatted output.
-p <port>         TCP port to use for data exchange. (13337)
-b <batchfile>    Batch mode. Read and execute tests from a file.
                    Every line of the file is a test to run. The first word is the
---

**Example - using mpi as a launcher**

When using mpi as the launcher to run ucx_perftest, please make sure that your ucx library was configured with mpi. Add the following to your configure line:

```
--with-mpi=/path/to/mpi/home
```

```
salloc -N2 --ntasks-per-node=1 mpirun --bind-to core --display-map ucx_perftest -d,
    -mlx5_1:1:1 \  
    -x rc_mlx5 -t put_lat
```

```
salloc: Granted job allocation 6991
salloc: Waiting for resource configuration
salloc: Nodes clx-orion-[001-002] are ready for job
Data for JOB [62403,1] offset 0
```

```
+--------------+-----------------------------+---------------------+------------------+
| # iterations | latency (usec) | bandwidth (MB/s) | message rate (msg/s) |
+--------------+---------+---------+---------+----------+----------+-----------+------
586527        0.845   0.852   0.852   4.47    4.47    586527                586527
586527        1000000 0.844   0.848   0.851   4.50    4.48    589339                587686
```

---

**2.13.2.4.2 OpenMPI and OpenSHMEM with UCX**

**UCX installation**

Requirements: Autoconf 2.63 and above.

1. Get latest version of the UCX code

```
$ git clone https://github.com/openucx/ucx.git ucx
$ cd ucx
```

2. Run autogen:
3. This step is only required for OpenPOWER platforms - Power 8 On Ubuntu platform the config.guess file is a bit outdated and does not have support for power. In order to resolve the issue you have to download an updated config.guess. From the root of the project:

```bash
$ wget https://github.com/shamisp/ucx/raw/topic/power8-config/config.guess
```

4. Configure:

```bash
$ mkdir build
$ cd build
$ ../configure --prefix=/your_install_path
```

Note: For best performance configuration, use ../contrib/configure-release. This will strip all debugging and profiling code.

5. Build and install:

```bash
$ make
$ make install
```

6. Running unit tests (using google test). This only work if gtest was installed and detected on your platform, and --enable-gtest was passed to configure:

```bash
$ make -C test/gtest test
```

2.13.2.5 Interface to ROCm

- https://github.com/openucx/ucx/tree/master/src/uct/rocm

2.13.2.6 Documentation

- Slides
- API documentation (v1.5)

2.13.2.6.1 High Level Design

UCX code consists of 3 parts:

- Protocol Layer - UCP
- Transport Layer - UCT
- Services - UCS

Protocol Layer

Supports all functionality described in the API, and does not require knowledge of particular hardware. It would try to provide best “out-of-box” performance, combining different hardware mechanisms and transports. It may emulate features which are not directly supported in hardware, such as one-sided operations. In addition, it would support common software protocols which are not implemented in hardware, such as tag matching and generic active messages. More details UCP-Design
Transport Layer

Provides direct access to hardware capabilities, without decision logic which would prefer one hardware mechanism over another. Some functionality may not be supported, due to hardware limitations. The capabilities are exposed in the interface. More details UCT-Design

Services

Collection of generic services, data structures, debug aids, etc.

Responsibilities of each layer

<table>
<thead>
<tr>
<th>What</th>
<th>Where</th>
<th>Why</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tag matching</td>
<td>High level</td>
<td>Software protocol</td>
</tr>
<tr>
<td>RMA/AMO emulation</td>
<td>High level</td>
<td>Software protocol</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>High level</td>
<td>Software protocol</td>
</tr>
<tr>
<td>Pending queue</td>
<td>High level</td>
<td>Stateful</td>
</tr>
<tr>
<td>Multi-transport/channel/rail</td>
<td>High level</td>
<td>OOB optimization</td>
</tr>
<tr>
<td>Select inline/bcopy/zcopy</td>
<td>High level</td>
<td>optimization logic</td>
</tr>
<tr>
<td>Reliability (e.g UD)</td>
<td>Low level</td>
<td>Transport specific</td>
</tr>
<tr>
<td>DMA buffer ownership</td>
<td>Low level</td>
<td>Transport specific</td>
</tr>
<tr>
<td>Memory registration cache</td>
<td>Low level</td>
<td>Transport dependent</td>
</tr>
</tbody>
</table>

See also:

- sideprogresscompletion
- DesignDiscuss

2.13.2.6.2 Infrastructure and Tools

Tools

- PrintUCXinfo
- findUCPendpoint
- Malloc hooks
- Performance measurement
- Testing
- UCXenv

Infrastructure library (UCS)

- Async
- Configuration parsing
- Memory hooks

Data structures:

- Double linked list
- Single linked queue
- Fragment list - reordering
- Memory pool
• Index/Pointer array
• SGLIB

• Debugging:
  – Resolving address to file name and line number
  – Handling faults
  – Attaching a debugger to self
  – logging
  – Assertions (compile-time and run-time)
  – Tracking memory used by different components
  – profiling

• statistic

• Fast time measurement
  – Read CPU timer
  – Convert time to sec/msec/usec/nsec
  – Timer queue
  – Timer wheel

• Data types:
  – Callback
  – Class infrastructure
  – Component infrastructure
  – Spinlock
  – Error codes

• System services:
  – Atomic operations
  – Fast bit operations (find first set bit, integer log2)
  – Get hostname
  – Generate UUID
  – Get CPU affinity
  – Read a whole file
  – Get page / huge page size
  – Allocate memory with SystemV
  – Get memory region access flags (from /proc/$$/maps)
  – Modify file flags with fcntl
  – Get process command line
  – Get CPU model, clock frequency
  – Get thread ID
2.13.2.7 FAQ

What is UCX?
UCX is a framework (collection of libraries and interfaces) that provides efficient and relatively easy way to construct widely used HPC protocols: MPI tag matching, RMA operations, rendezvous protocols, stream, fragmentation, remote atomic operations, etc.

How do I get in touch with UCX developers?
Please join our mailing list: https://elist.ornl.gov/mailman/listinfo/ucx-group

What is UCP, UCT, UCS

• UCT is a transport layer that abstracts the differences across various hardware architectures and provides a low-level API that enables the implementation of communication protocols. The primary goal of the layer is to provide direct and efficient access to hardware network resources with minimal software overhead. For this purpose UCT relies on low-level drivers provided by vendors such as InfiniBand Verbs, Cray’s uGNI, libfabrics, etc. In addition, the layer provides constructs for communication context management (thread-based and application level), and allocation and management of device-specific memories including those found in accelerators. In terms of communication APIs, UCT defines interfaces for immediate (short), buffered copy-and-send (bcopy), and zero-copy (zcopy) communication operations. The short operations are optimized for small messages that can be posted and completed in place. The bcopy operations are optimized for medium size messages that are typically sent through a so-called bouncing-buffer. Finally, the zcopy operations expose zero-copy memory-to-memory communication semantics.

• UCP implements higher-level protocols that are typically used by message passing (MPI) and PGAS programming models by using lower-level capabilities exposed through the UCT layer. UCP is responsible for the following functionality: initialization of the library, selection of transports for communication, message fragmentation, and multi-rail communication. Currently, the API has the following classes of interfaces: Initialization, Remote Memory Access (RMA) communication, Atomic Memory Operations (AMO), Active Message, Tag-Matching, and Collectives.

• UCS is a service layer that provides the necessary functionality for implementing portable and efficient utilities.

What are the key features of UCX?

• Open source framework supported by vendors The UCX framework is maintained and supported by hardware vendors in addition to the open source community. Every pull-request is tested and multiple hardware platforms supported by vendors community.

• Performance, performance, performance... The framework design, data structures, and components are design to provide highly optimized access to the network hardware.

• High level API for a broad range HPC programming models. UCX provides a high level API implemented in software ‘UCP’ to fill in the gaps across interconnects. This allows to use a single set of APIs in a library to implement multiple interconnects. This reduces the level of complexities when implementing libraries such as Open MPI or OpenSHMEM. Because of this, UCX performance portable because a single implementation (in Open MPI or OpenSHMEM) will work efficiently on multiple interconnects. (e.g. uGNI, Verbs, libfabrics, etc).

• Support for interaction between multiple transports (or providers) to deliver messages. For example, UCX has the logic (in UCP) to make ‘GPUDirect’, IB and share memory work together efficiently to deliver the data where is needed without the user dealing with this.

• Cross-transport multi-rail capabilities

What protocols are supported by UCX?

UCP implements RMA put/get, send/receive with tag matching, Active messages, atomic operations. In near future we plan to add support for commonly used collective operations.

Is UCX replacement for GASNET?
No. GASNET exposes high level API for PGAS programming management that provides symmetric memory management capabilities and build in runtime environments. These capabilities are out of scope of UCX project. Instead, GASNET can leverage UCX framework for fast end efficient implementation of GASNET for the network technologies support by UCX.

**What is the relation between UCX and network drivers ?**

UCX framework does not provide drivers, instead it relies on the drivers provided by vendors. Currently we use:

- OFA VERBs,
- Cray's UGNI,
- NVIDIA CUDA.

**What is the relation between UCX and OFA Verbs or Libfabrics ?**

UCX, is a middleware communication layer that relies on vendors provided user level drivers including OFA Verbs or libfabrics (or any other drivers provided by another communities or vendors) to implement high-level protocols which can be used to close functionality gaps between various vendors drivers including various libfabrics providers: coordination across various drivers, multi-rail capabilities, software based RMA, AMOs, tag-matching for transports and drivers that do not support such capabilities natively.

**Is UCX a user level driver ?**

No. Typically, Drivers aim to expose fine-grain access to the network architecture specific features. UCX abstracts the differences across various drivers and fill-in the gaps using software protocols for some of the architectures that don’t provide hardware level support for all the operations.

**Does UCX depend on an external runtime environment ?**

UCX does not depend on an external runtime environment.

`ucx_perftest` (UCX based application/benchmark) can be linked with an external runtime environment that can be used for remote `ucx_perftest` launch, but this an optional configuration which is only used for environments that do not provide direct access to compute nodes. By default this option is disabled.

**How to install UCX and OpenMPI ?**

See How to install UCX and OpenMPI

**How can I contribute ?**

1. Fork
2. Fix bug or implement a new feature
3. Open Pull Request

### 2.13.3 MPI

**OpenMPI and OpenSHMEM installation**

1. Get latest-and-gratest OpenMPI version:

   ```bash
   $ git clone https://github.com/open-mpi/ompi.git
   ```

2. Autogen:

   ```bash
   $ cd ompi
   $ ./autogen.pl
   ```

3. Configure with UCX

   ```bash
   $ mkdir build
   $ cd build
   $ ./configure --prefix=/your_install_path/ --with-ucx=/path_to_ucx_installation
   ```
4. Build:

```bash
$ make
$ make install
```

**Running Open MPI with UCX**

Example of the command line (for InfiniBand RC + shared memory):

```bash
$ mpirun -np 2 -mca pml ucx -x UCX_NET_DEVICES=mlx5_0:1 -x UCX_TLS=rc,sm ./app
```

**Open MPI runtime optimizations for UCX**

- By default OpenMPI enables build-in transports (BTLs), which may result in additional software overheads in the OpenMPI progress function. In order to workaround this issue you may try to disable certain BTLs.

```bash
$ mpirun -np 2 -mca pml ucx --mca btl ^vader,tcp,openib -x UCX_NET_DEVICES=mlx5_0:1 -x UCX_TLS=rc,sm ./app
```

- OpenMPI version [https://github.com/open-mpi/ompi/commit/066370202dcad8e302f2baf8921e9ef0df17dfc](https://github.com/open-mpi/ompi/commit/066370202dcad8e302f2baf8921e9ef0df17dfc) leverages more efficient timer mechanism and therefore reduces software overheads in OpenMPI progress.

**MPI and OpenSHMEM release versions tested with UCX master**

1. UCX current tarball: [https://github.com/openucx/ucx/archive/master.zip](https://github.com/openucx/ucx/archive/master.zip)
2. The table of MPI and OpenSHMEM distributions that are tested with the HEAD of UCX master

<table>
<thead>
<tr>
<th>MPI/OpenSHMEM</th>
<th>project</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenMPI/OSHMEM</td>
<td>2.1.0</td>
</tr>
<tr>
<td>MPICH</td>
<td>Latest</td>
</tr>
</tbody>
</table>

### 2.13.4 IPC

**2.13.4.1 Introduction**

**New datatypes**

```c
hsa_amd_ipc_memory_handle_t

//** IPC memory handle to be passed from one process to another */
typedef struct hsa_amd_ipc_memory_handle_s {
    uint64_t handle;
} hsa_amd_ipc_memory_handle_t;

hsa_amd_ipc_signal_handle_t

//** IPC signal handle to be passed from one process to another */
typedef struct hsa_amd_ipc_signal_handle_s {
    uint64_t handle;
} hsa_amd_ipc_signal_handle_t;
```

**Memory sharing API**

Allows sharing of HSA allocated memory between different processes.

```c
hsa_amd_ipc_get_memory_handle
```
The purpose of this API is to get / export an IPC handle for an existing allocation from pool.

**hsa_status_t HSA_API**

hsa_amd_ipc_get_memory_handle(void *ptr, hsa_amd_ipc_memory_handle_t *ipc_handle);

where:

IN: ptr - Pointer to memory previously allocated via hsa_amd_memory_pool_allocate() call

OUT: ipc_handle - Unique IPC handle to be used in IPC.

Application must pass this handle to another process.

hsa_amd_ipc_close_memory_handle
Close IPC memory handle previously received via “hsa_amd_ipc_get_memory_handle()” call.

**hsa_status_t HSA_API**

hsa_amd_ipc_close_memory_handle(hsa_amd_ipc_memory_handle_t ipc_handle);

where:

IN: ipc_handle - IPC Handle to close

hsa_amd_ipc_open_memory_handle
Open / import an IPC memory handle exported from another process and return address to be used in the current process.

**hsa_status_t HSA_API**

hsa_amd_ipc_open_memory_handle(hsa_amd_ipc_memory_handle_t ipc_handle, void **ptr);

where:

IN: ipc_handle - IPC Handle

OUT: ptr - Address which could be used in the given process for access to the memory

Client should call hsa_amd_memory_pool_free() when access to this resource is not needed any more.

**Signal sharing API**

Allows sharing of HSA signals between different processes.

hsa_amd_ipc_get_signal_handle
The purpose of this API is to get / export an IPC handle for an existing signal.

**hsa_status_t HSA_API**
hsa_amd_ipc_get_signal_handle(hsa_signal_t signal, hsa_amd_ipc_signal_handle_t *ipc_handle);
where:
   IN: signal - Signal handle created as the result of hsa_signal_create() call.
   OUT: ipc_handle - Unique IPC handle to be used in IPC.
       Application must pass this handle to another process.

hsa_amd_ipc_close_signal_handle
Close IPC signal handle previously received via “hsa_amd_ipc_get_signal_handle()” call.

hsa_status_t HSA_API

hsa_amd_ipc_close_signal_handle(hsa_amd_ipc_signal_handle_t ipc_handle);
where:
   IN: ipc_handle - IPC Handle to close

hsa_amd_ipc_open_signal_handle
Open / import an IPC signal handle exported from another process and return address to be used in the current process.

hsa_status_t HSA_API

hsa_amd_ipc_open_signal_handle(hsa_amd_ipc_signal_handle_t ipc_handle, hsa_signal_t &signal);
where:
   IN: ipc_handle - IPC Handle
   OUT: signal - Signal handle to be used in the current process

Client should call hsa_signal_destroy() when access to this resource is not needed any more.

Query API

Query memory information

Allows query information about memory resource based on address. It is partially overlapped with the following requirement Memory info interface so it may be possible to merge those two interfaces.

typedef enum hsa_amd_address_info_s {
    /* Return uint32_t / boolean if address was allocated via HSA stack */
    HSA_AMD_ADDRESS_HSA_ALLOCATED = 0x1,

    /* Return agent where such memory was allocated */
    HSA_AMD_ADDRESS_AGENT = 0x2,

    /* Return pool from which this address was allocated */
    HSA_AMD_ADDRESS_POOL = 0x3,

} (continues on next page)
```c
/** Return size of allocation */
HSA_AMD_ADDRESS_ALLOC_SIZE = 0x4

} hsa_amd_address_info_t;
```

hsa_status_t HSA_API
hsa_amd_get_address_info(void *ptr, hsa_amd_address_info_t attribute, void *value);

where:
- `ptr` - Address information about which to query
- `attribute` - Attribute to query

## 2.14 Deep Learning on ROCm

### 2.14.1 TensorFlow

#### 2.14.1.1 ROCm TensorFlow v2.0 Release

We are excited to announce the release of ROCm enabled TensorFlow v2.0 for AMD GPUs. This includes the enhanced compilation toolchain and a set of bug fixes to support TensorFlow 2.0 features natively.

#### 2.14.1.2 Tensorflow Installation

First, you’ll need to install the open-source ROCm 2.6 stack. Details can be found [here](#).

Then, install these other relevant ROCm packages:

```bash
sudo apt update
sudo apt install rocm-libs miopen-hip cxlactivitylogger
```

And finally, install TensorFlow itself (via the Python Package Index):

```bash
sudo apt install wget python3-pip
# Pip3 install the whl package from PyPI
pip3 install --user tensorflow-rocm
```

Now that TensorFlow v2.0 is installed!

### 2.14.1.3 Tensorflow More Resources

Tensorflow docker images are also publicly available, more details can be found [here](#).

The official github repository is [here](#).
2.14.2 MIOpen

2.14.2.1 ROCm MIOpen v2.0 Release

Announcing our new Foundation for Deep Learning acceleration MIOpen 2.0 which introduces support for Convolution Neural Network (CNN) acceleration — built to run on top of the ROCm software stack!

This release includes the following:

- This release contains several new features including an immediate mode for selecting convolutions, bfloat16 support, new layers, modes, and algorithms.
- MIOpenDriver, a tool for benchmarking and developing kernels is now shipped with MIOpen.
- BFloat16 now supported in HIP requires an updated rocBLAS as a GEMM backend.
- Immediate mode API now provides the ability to quickly obtain a convolution kernel.
- MIOpen now contains HIP source kernels and implements the ImplicitGEMM kernels. This is a new feature and is currently disabled by default. Use the environmental variable “MIOPEN_DEBUG_CONV_IMPLICIT_GEMM=1” to activation this feature. ImplicitGEMM requires an up to date HIP version of at least 1.5.9211.
- A new “loss” category of layers has been added, of which, CTC loss is the first. See the API reference for more details.
- 2.0 is the last release of active support for gfx803 architectures. In future releases, MIOpen will not actively debug and develop new features specifically for gfx803.
- System Find-Db in memory cache is disabled by default. Please see build instructions to enable this feature.
- Source code

- Documentation
  - MIOpen
  - MIOpenGemm

2.14.2.2 Porting from cuDNN to MIOpen

The porting guide highlights the key differences between the current cuDNN and MIOpen APIs.

2.14.2.3 The ROCm 2.6 has prebuilt packages for MIOpen

Install the ROCm MIOpen implementation (assuming you already have the ‘rocml’ and ‘rocml-opencl-dev” package installed):

```
apt-get
```

MIOpen can be installed on Ubuntu using

```
sudo apt-get install miopengemm miopen-opencl
```

For just OpenCL development

For HIP development
Currently both the backends cannot be installed on the same system simultaneously. If a different backend other than what currently exists on the system is desired, please uninstall the existing backend completely and then install the new backend.

2.14.3 PyTorch

2.14.3.1 Building

This is a quick guide to setup PyTorch with ROCm support inside a docker container. Assumes a .deb based system. See ROCm install for supported operating systems and general information on the ROCm software stack. A ROCm install version 2.6 is required currently.

1. Install or update rocm-dev on the host system:

```
sudo apt-get install rocm-dev
or
sudo apt-get update
sudo apt-get upgrade
```

2.14.3.2 Recommended: Install using published PyTorch ROCm docker image:

2. Obtain docker image:

```
docker pull rocm/pytorch:rocm2.1
```

3. Clone PyTorch repository on the host:

```
cd ~
git clone https://github.com/pytorch/pytorch.git
cd pytorch
git submodule init
git submodule update
```

4. Start a docker container using the downloaded image:

```
sudo docker run -it -v $HOME:/data --privileged --rm --device=/dev/kfd --device=/dev/dri --group-add video rocm/pytorch:rocm2.1
```

Note: This will mount your host home directory on /data in the container.

5. Change to previous PyTorch checkout from within the running docker:

```
cd /data/pytorch
```

6. Build PyTorch for ROCm:

```
Unless you are running a gfx900/Vega10-type GPU (MI25, Vega56, Vega64,...), explicitly export the GPU architecture to build for, e.g.: export HCC_AMDGPU_TARGET=gfx906
then
```
This will first hipify the PyTorch sources and then compile using 4 concurrent jobs, needing 16 GB of RAM to be available to the docker image.

7. Confirm working installation:

```
PYTORCH_TEST_WITH_ROCM=1 python test/run_test.py --verbose
```

No tests will fail if the compilation and installation is correct.

8. Install torchvision:

```
pip install torchvision
```

This step is optional but most PyTorch scripts will use torchvision to load models. E.g., running the pytorch examples requires torchvision.

9. Commit the container to preserve the pytorch install (from the host):

```
sudo docker commit <container_id> -m 'pytorch installed'
```

### 2.14.3.3 Option 2: Install using PyTorch upstream docker file

2. Clone PyTorch repository on the host:

```
cd ~
git clone https://github.com/pytorch/pytorch.git
cd pytorch
git submodule init
git submodule update
```

3. Build PyTorch docker image:

```
cd pytorch/docker/caffe2/jenkins
./build.sh py2-clang7-rocmdeb-ubuntu16.04
```

This should complete with a message “Successfully built <image_id>” Note here that other software versions may be chosen, such setups are currently not tested though!

4. Start a docker container using the new image:

```
sudo docker run -it -v $HOME:/data --privileged --rm --device=/dev/kfd --device=/dev/dri --group-add video <image_id>
```

Note: This will mount your host home directory on /data in the container.

5. Change to previous PyTorch checkout from within the running docker:

```
cd /data/pytorch
```

6. Build PyTorch for ROCm:

```
Unless you are running a gfx900/Vega10-type GPU (MI25, Vega56, Vega64,...), explicitly export the GPU architecture to build for, e.g.: export HCC_AMDGPU_TARGET=gfx906
then
```
.jenkins/pytorch/build.sh

This will first hipify the PyTorch sources and then compile using 4 concurrent jobs, needing 16 GB of RAM to be available to the docker image.

7. Confirm working installation:

```
PYTORCH_TEST_WITH_ROCM=1 python test/run_test.py --verbose
```

No tests will fail if the compilation and installation is correct.

8. Install torchvision:

```
pip install torchvision
```

This step is optional but most PyTorch scripts will use torchvision to load models. E.g., running the pytorch examples requires torchvision.

9. Commit the container to preserve the pytorch install (from the host):

```
sudo docker commit <container_id> -m 'pytorch installed'
```

---

### 2.14.3.4 Option 3: Install using minimal ROCm docker file

2. Download pytorch dockerfile:

```
Dockerfile
```

3. Build docker image:

```
cd pytorch_docker
sudo docker build .
```

This should complete with a message “Successfully built <image_id>”

4. Start a docker container using the new image:

```
sudo docker run -it -v $HOME:/data --privileged --rm --device=/dev/kfd --device=/dev/ →dri --group-add video <image_id>
```

Note: This will mount your host home directory on /data in the container.

5. Clone pytorch master (on to the host):

```
cd ~
git clone https://github.com/pytorch/pytorch.git or git clone https://github.com/ →ROCmSoftwarePlatform/pytorch.git
cd pytorch
git submodule init
git submodule update
```

6. Run “hipify” to prepare source code (in the container):

```
cd /data/pytorch/
python tools/amd_build/build_pytorch_amd.py
python tools/amd_build/build_caffe2_amd.py
```

7. Build and install pytorch:
Unless you are running a gfx900/Vega10-type GPU (MI25, Vega56, Vega64, ...), explicitly export the GPU architecture to build for, e.g.: export HCC_AMDGPU_TARGET=gfx906

```
USE_ROCM=1 MAX_JOBS=4 python setup.py install --user
```

Use MAX_JOBS=n to limit peak memory usage. If building fails try falling back to fewer jobs. 4 jobs assume available main memory of 16 GB or larger.

8. Confirm working installation:
```
PYTORCH_TEST_WITH_ROCM=1 python test/run_test.py --verbose
```

No tests will fail if the compilation and installation is correct.

9. Install torchvision:
```
pip install torchvision
```

This step is optional but most PyTorch scripts will use torchvision to load models. E.g., running the pytorch examples requires torchvision.

10. Commit the container to preserve the pytorch install (from the host):
```
sudo docker commit <container_id> -m 'pytorch installed'
```

### 2.14.3.5 Try PyTorch examples

1. Clone the PyTorch examples repository:
```
git clone https://github.com/pytorch/examples.git
```

2. Run individual example: MNIST
```
cd examples/mnist
```

Follow instructions in README.md, in this case:
```
pip install -r requirements.txt python main.py
```

3. Run individual example: Try ImageNet training
```
cd ../imagenet
```

Follow instructions in README.md.

### 2.14.4 Caffe2

#### 2.14.4.1 Building Caffe2 for ROCm

This is a quick guide to setup Caffe2 with ROCm support inside docker container and run on AMD GPUs. Caffe2 with ROCm support offers complete functionality on a single GPU achieving great performance on AMD GPUs using both native ROCm libraries and custom hip kernels. This requires your host system to have rocm-2.6s drivers installed. Please refer to ROCm install to install ROCm software stack. If your host system doesn’t have docker
This guide provides two options to run Caffe2.

1. Launch the docker container using a docker image with Caffe2 installed.
2. Build Caffe2 from source inside a Caffe2 ROCm docker image.

### Option 1: Docker image with Caffe2 installed

This option provides a docker image which has Caffe2 installed. Users can launch the docker container and train/run deep learning models directly. This docker image will run on both gfx900(Vega10-type GPU - MI25, Vega56, Vega64,...) and gfx906(Vega20-type GPU - MI50, MI60).

1. Launch the docker container
   ```bash
docker run -it --network=host --device=/dev/kfd --device=/dev/dri --group-add video --rocm/pytorch:rocm2.1_caffe2
   ```
   This will automatically download the image if it does not exist on the host. You can also pass -v argument to mount any data directories on to the container.

### Option 2: Install using Caffe2 ROCm docker image

1. Clone PyTorch repository on the host:
   ```bash
cd ~
git clone --recursive-submodules https://github.com/pytorch/pytorch.git
cd pytorch
   ```
   git submodule update --init --recursive

2. Launch the docker container
   ```bash
docker pull rocm/pytorch:rocm2.1
   docker run -it --network=host --device=/dev/kfd --device=/dev/dri --group-add video -v $PWD:/pytorch rocm/pytorch:rocm2.1
   ```

3. Build Caffe2 from source
   ```bash
   cd /pytorch
   ```
   If running on gfx900/vega10-type GPU(MI25, Vega56, Vega64,...)
   ```bash
   .jenkins/caffe2/build.sh
   ```
   If running on gfx906/vega20-type GPU(MI50, MI60)
   ```bash
   HCC_AMDGPU_TARGET=gfx906 .jenkins/caffe2/build.sh
   ```

### Test the Caffe2 Installation

To validate Caffe2 installation, run

1. Test Command
2. Running unit tests in Caffe2

```
cd ~ && python -c 'from caffe2.python import core' 2>/dev/null && echo "Success" || echo "Failure"
```

2.14.4.5 Run benchmarks

Caffe2 benchmarking script supports the following networks MLP, AlexNet, OverFeat, VGGA, Inception

To run benchmarks for networks MLP, AlexNet, OverFeat, VGGA, Inception run the command from pytorch home directory replacing `<name_of_the_network>` with one of the networks.

```
python caffe2/python/convnet_benchmarks.py --batch_size 64 --model <name_of_the_network> --engine MIOPEN
```

2.14.4.6 Running example scripts

Please refer to the example scripts in `caffe2/python/examples`. It currently has `resnet50_trainer.py` which can run ResNet’s, ResNeXt’s with various layer, groups, depth configurations and `char_rnn.py` which uses RNNs to do character level prediction.

2.14.4.7 Building own docker images

After cloning the pytorch repository, you can build your own Caffe2 ROCm docker image. Navigate to pytorch repo and run

```
cd docker/caffe2/jenkins
./build.sh py2-clang7-rocmdeb-ubuntu16.04
```

This should complete with a message “Successfully built <image_id>” which can then be used to install Caffe2 as in Option 2 above.
### 2.14.5 Deep Learning Framework support for ROCm

<table>
<thead>
<tr>
<th>Framework</th>
<th>Status</th>
<th>MIOpen Enabled</th>
<th>Upstreamed</th>
<th>Current Repository</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caffe</td>
<td>Public</td>
<td>Yes</td>
<td></td>
<td><a href="https://github.com/ROCmSoftwarePlatform/hipCaffe">https://github.com/ROCmSoftwarePlatform/hipCaffe</a></td>
</tr>
<tr>
<td>Tensorflow</td>
<td>Development</td>
<td>Yes</td>
<td>CLA inProgress</td>
<td>Notes: Working on NCCL and XLA enablement, Running</td>
</tr>
<tr>
<td>Caffe2</td>
<td>Upstreaming</td>
<td>Yes</td>
<td>CLA inProgress</td>
<td></td>
</tr>
<tr>
<td>Torch</td>
<td>HIP</td>
<td>Upstreaming</td>
<td>Development inProgress</td>
<td><a href="https://github.com/ROCmSoftwarePlatform/cutorch_hip">https://github.com/ROCmSoftwarePlatform/cutorch_hip</a></td>
</tr>
<tr>
<td>PyTorch</td>
<td>Development</td>
<td>Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MxNet</td>
<td>Development</td>
<td>Development</td>
<td></td>
<td><a href="https://github.com/ROCmSoftwarePlatform/mxnet">https://github.com/ROCmSoftwarePlatform/mxnet</a></td>
</tr>
<tr>
<td>CNTK</td>
<td>Development</td>
<td>Development</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2.14.6 Tutorials

- hipCaffe
  - caffe
  - MXNet
  - mxnet

### 2.15 System Level Debug

#### 2.15.1 ROCm Language & System Level Debug, Flags and Environment Variables

Kernel options to avoid Ethernet port getting renamed every time you change graphics cards
```
net.ifnames=0 biosdevname=0
```

#### 2.15.1.1 ROCr Error Code

- 2 Invalid Dimension
- 4 Invalid Group Memory
- 8 Invalid (or Null) Code
- 32 Invalid Format </li>
- 64 Group is too large
- 128 Out of VGPR’s
- 0x80000000 Debug Trap
2.15.1.2 Command to dump firmware version and get Linux Kernel version

- `sudo cat /sys/kernel/debug/dri/1/amdgpu_firmware_info`
- `uname -a`

2.15.1.3 Debug

Debug messages when developing/debugging base ROCm driver. You could enable the printing from libhsakmt.so by setting an environment variable, `HSAKMT_DEBUG_LEVEL`. Available debug levels are 3~7. The higher level you set, the more messages will print.

- `export HSAKMT_DEBUG_LEVEL=3` : only `pr_err()` will print.
- `export HSAKMT_DEBUG_LEVEL=4` : `pr_err()` and `pr_warn()` will print.
- `export HSAKMT_DEBUG_LEVEL=5` : We currently don’t implement “notice”. Setting to 5 is same as setting to 4.
- `export HSAKMT_DEBUG_LEVEL=6` : `pr_err()`, `pr_warn()`, and `pr_info` will print.
- `export HSAKMT_DEBUG_LEVEL=7` : Everything including `pr_debug` will print.

2.15.1.4 ROCr level env variable for debug

- `HSA_ENABLE_SDMA=0`
- `HSA_ENABLE_INTERRUPT=0`
- `HSA_SVM_GUARD_PAGES=0`
- `HSA_DISABLE_CACHE=1`

2.15.1.5 Turn Off Page Retry on GFX9/Vega devices

- `sudo –s`
- `echo 1 > /sys/module/amdkfd/parameters/noretry`
| HCC_PRINT_ENV=1 | will print usage and current values for the HCC and HIP env variables. |
| HCC_PRINT_ENV = 1 | Print values of HCC environment variables |
| HCC_SERIALIZE_KERNEL= 0 | 0x1=pre-serialize before each kernel launch, 0x2=post-serialize after each kernel launch, 0x3=both |
| HCC_SERIALIZE_COPY= 0 | 0x1=pre-serialize before each data copy, 0x2=post-serialize after each data copy, 0x3=both |
| HCC_DB = 0 | Enable HCC trace debug |
| HCC_OPT_FLUSH = 1 | Perform system-scope acquire/release only at CPU sync boundaries (rather than after each kernel) |
| HCC_MAX_QUEUES= 20 | Set max number of HSA queues this process will use. accelerator_views will share the allotted queues and steal from each other as necessary |
| HCC_UNPINNED_COPY_MODE = 2 | Select algorithm for unpinned copies. 0=ChooseBest(see thresholds), 1=PinInPlace, 2=StagingBuffer, 3=Memcpy |
| HCC_CHECK_COPY = 0 | Check dst == src after each copy operation. Only works on large-bar systems. |
| HCC_H2D_STAGING_THRESHOLD = 64 | Min size (in KB) to use staging buffer algorithm for H2D copy if ChooseBest algorithm selected |
| HCC_H2D_PININPLACE_THRESHOLD = 4096 | Min size (in KB) to use pin-in-place algorithm for H2D copy if ChooseBest algorithm selected |
| HCC_D2H_PININPLACE_THRESHOLD = 1024 | Min size (in KB) to use pin-in-place for D2H copy if ChooseBest algorithm selected |
| HCC_PROFILE = 0 | Enable HCC kernel and data profiling. 1=summary, 2=trace |
| HCC_PROFILE_VERBOSE = 31 | Bitmark to control profile verbosity and format. 0x1=default, 0x2=show begin/end, 0x4=show barrier |
### 2.15.1.7 HIP Environment Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIP_PRINT_ENV=1</td>
<td>Print HIP environment variables.</td>
</tr>
<tr>
<td>HIP_LAUNCH_BLOCKING=0</td>
<td>Make HIP kernel launches ‘host-synchronous’, so they block until any kernel launches. Alias: CUDA_LAUNCH_BLOCKING</td>
</tr>
<tr>
<td>HIP_LAUNCH_BLOCKING KERNELS=</td>
<td>Comma-separated list of kernel names to make host-synchronous, so they block until completed.</td>
</tr>
<tr>
<td>HIP_API_BLOCKING= 0</td>
<td>Make HIP APIs ‘host-synchronous’, so they block until completed. Impacts hipMemcpyAsync, hipMemsetAsync</td>
</tr>
<tr>
<td>HIP_HIDDEN_FREE_MEM= 256</td>
<td>Amount of memory to hide from the free memory reported by hipMemGetInfo, specified in MB. Impacts hipMemGetInfo</td>
</tr>
<tr>
<td>HIP_DB = 0</td>
<td>Print debug info. Bitmask (HIP_DB=0xff) or flags separated by ‘+’ (HIP_DB=api+sync+mem+copy)</td>
</tr>
<tr>
<td>HIP_TRACE_API=0</td>
<td>Trace each HIP API call. Print function name and return code to stderr as program executes.</td>
</tr>
<tr>
<td>HIP_TRACE_API_COLOR= green</td>
<td>Color to use for HIP_API. None/Red/Green/Yellow/Blue/Magenta/Cyan/White</td>
</tr>
<tr>
<td>HIP_PROFILE_API = 0</td>
<td>Add HIP API markers to ATP file generated with CodeXL. 0x1=short API name, 0x2=full API name including args</td>
</tr>
<tr>
<td>HIP_DB_START_API =</td>
<td>Comma-separated list of tid.api_seq_num for when to start debug and profiling.</td>
</tr>
<tr>
<td>HIP_DB_STOP_API =</td>
<td>Comma-separated list of tid.api_seq_num for when to stop debug and profiling.</td>
</tr>
<tr>
<td>HIP_VISIBLE_DEVICES = 0</td>
<td>Only devices whose index is present in the sequence are visible to HIP applications and they are enumerated in the order of sequence</td>
</tr>
<tr>
<td>HIP_WAIT_MODE = 0</td>
<td>Force synchronization mode. 1= force yield, 2=force spin, 0=defaults specified in application</td>
</tr>
<tr>
<td>HIP_FORCE_P2P_HOST = 0</td>
<td>Force use of host/staging copy for peer-to-peer copies. 1=always use copies, 2=always return false for hipDeviceCanAccessPeer</td>
</tr>
<tr>
<td>HIP_FORCE_SYNC_COPY = 0</td>
<td>Force all copies (even hipMemcpyAsync) to use sync copies</td>
</tr>
<tr>
<td>HIP_FAIL_SOC = 0</td>
<td>Fault on Sub-Optimal-Copy, rather than use a slower but functional implementation. Bit 0x1=Fail on async copy with unpinned memory. Bit 0x2=Fail peer copy rather than use staging buffer copy</td>
</tr>
</tbody>
</table>

### 2.15. System Level Debug
2.15.1.8 OpenCL Debug Flags

- AMD_OCL_WAIT_COMMAND=1 (0 = OFF, 1 = On)

2.15.1.9 PCIe-Debug

Refer here for PCIe-Debug
There’s some more information here on how to debug and profile HIP applications

- HIP-Debugging
- HIP-Profiling

2.16 Tutorial

- caffe How use Caffe on ROCm
- Vector-Add example ussing the HIP Programing Language
- mininbody This sample demonstrates the use of the HIP API for a mini n-body problem.
- GCN-asm-tutorial Assembly Sample The Art of AMDGCN Assembly:How to Bend the Machine to Your Will. This tutorial demonstrates GCN assembly with ROCm application development.
- Optimizing-Dispatches ROCm With Rapid Harmony: Optimizing HSA Dispatch: This tutorial shows how to optimize HSA dispatch performance for ROCm application development.
- rocnclroc ROCm With Harmony: Combining OpenCL Kernels, HCC and HSA in a Single Program. This tutorial demonstrates how to compile OpenCL kernels using the CL offline compiler (CLOC) and integrate them with HCC C++ compiled ROCm applications.
- The AMD GCN Architecture - A Crash Course, by Layla Mah
- AMD GCN Architecture White paper
- ROCm-MultiGPU

2.17 ROCm

**ROCm** ROCm runtime The HSA runtime is a thin, user-mode API that exposes the necessary interfaces to access and interact with graphics hardware driven by the AMDGPU driver set and the ROCK kernel driver. Together they enable programmers to directly harness the power of AMD discrete graphics devices by allowing host applications to launch compute kernels directly to the graphics hardware.

HCC (Heterogeneous Compute Compiler): HCC is an Open Source, Optimizing C++ Compiler for Heterogeneous Compute. It supports heterogeneous offload to AMD APUs and discrete GPUs via HSA enabled runtimes and drivers. It is based on Clang, the LLVM Compiler Infrastructure and the ‘libc++’ C++ standard library. The goal is to implement a compiler that takes a program that conforms to a parallel programming standard such as C++ AMP, HC, C++ 17 ParallelSTL, or OpenMP, and transforms it into the AMD GCN ISA.

**Accelerator Modes Supported:**

- HC C++ API
- HIP
- C++AMP
• C++ Parallel STL
• OpenMP

**HIP (Heterogeneous Interface for Portability)**: Heterogeneous Interface for Portability is a C++ runtime API and kernel language that allows developers to create portable applications that can run on AMD and other GPU’s. It provides a C-style API and a C++ kernel language. The first big feature available in the HIP is porting apps that use the CUDA Driver API.

**OpenCL**: Open Computing Language (OpenCL) is a framework for writing programs that execute across heterogeneous platforms consisting of central processing units (CPUs), graphics processing units (GPUs), digital signal processors (DSPs), field-programmable gate arrays (FPGAs) and other processors or hardware accelerators.

OpenCL provides a standard interface for parallel computing using task- and data-based parallelism. The programming language that is used to write compute kernels is called OpenCL C and is based on C99, but adapted to fit the device model in OpenCL. OpenCL consists of a set of headers and a shared object that is loaded at runtime. As of 2016 OpenCL runs on Graphics processing units, CPUs with SIMD instructions, FPGAs, Movidius Myriad 2, Adapteva epiphany and DSPs.

**PCIe Platform Atomics**: PCI Express (PCIe) was developed as the next generation I/O system interconnect after PCI, designed to enable advanced performance and features in connected devices while remaining compatible with the PCI software environment. Today, atomic transactions are supported for synchronization without using an interrupt mechanism. In emerging applications where math co-processing, visualization and content processing are required, enhanced synchronization would enable higher performance.

**Queue**: A Queue is a runtime-allocated resource that contains a packet buffer and is associated with a packet processor. The packet processor tracks which packets in the buffer have already been processed. When it has been informed by the application that a new packet has been enqueued, the packet processor is able to process it because the packet format is standard and the packet contents are self-contained – they include all the necessary information to run a command. A queue has an associated set of high-level operations defined in “HSA Runtime Specification” (API functions in host code) and “HSA Programmer Reference Manual Specification” (kernel code).

**HSA (Heterogeneous System Architecture)**: HSA provides a unified view of fundamental computing elements. HSA allows a programmer to write applications that seamlessly integrate CPUs (called latency compute units) with GPUs (called throughput compute units), while benefiting from the best attributes of each. HSA creates an improved processor design that exposes the benefits and capabilities of mainstream programmable compute elements, working together seamlessly. HSA is all about delivering new, improved user experiences through advances in computing architectures that deliver improvements across all four key vectors: improved power efficiency; improved performance; improved programmability; and broad portability across computing devices. For more on HSA.

**AQL Architectured Queuing Language**: The Architected Queuing Language (AQL) is a standard binary interface used to describe commands such as a kernel dispatch. An AQL packet is a user-mode buffer with a specific format that encodes one command. AQL allows agents to build and enqueue their own command packets, enabling fast, low-power dispatch. AQL also provides support for kernel agent queue submissions: the kernel agent kernel can write commands in AQL format.
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