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Python implementations of commonly used sensitivity analysis methods, including Sobol, Morris, and FAST methods. Useful in systems modeling to calculate the effects of model inputs or exogenous factors on outputs of interest.
CHAPTER 1

Supported Methods

• Sobol Sensitivity Analysis ([Sobol 2001], [Saltelli 2002], [Saltelli et al. 2010])
• Method of Morris, including groups and optimal trajectories ([Morris 1991], [Campolongo et al. 2007])
• Fourier Amplitude Sensitivity Test (FAST) ([Cukier et al. 1973], [Saltelli et al. 1999])
• Random Balance Designs - Fourier Amplitude Sensitivity Test (RBD-FAST) ([Tarantola et al. 2006 <https://hal.archives-ouvertes.fr/hal-01065897/file/Tarantola06RESS_HAL.pdf>], [Elmar Plischke 2010], [Tissot et al. 2012])
• Delta Moment-Independent Measure ([Borgonovo 2007], [Plischke et al. 2013])
• Derivative-based Global Sensitivity Measure (DGSM) ([Sobol and Kucherenko 2009])
• Fractional Factorial Sensitivity Analysis ([Saltelli et al. 2008])

1.1 Getting Started

1.1.1 Installing SALib

To install the latest stable version of SALib using pip, together with all the dependencies, run the following command:

```
pip install SALib
```

To install the latest development version of SALib, run the following commands. Note that the development version may be unstable and include bugs. We encourage users use the latest stable version.

```
git clone https://github.com/SALib/SALib.git
cd SALib
python setup.py develop
```
1.1.2 Installing Prerequisite Software

SALib requires NumPy, SciPy, and matplotlib installed on your computer. Using pip, these libraries can be installed with the following command:

```
pip install numpy
pip install scipy
pip install matplotlib
```

The packages are normally included with most Python bundles, such as Anaconda and Canopy. In any case, they are installed automatically when using pip or setuptools to install SALib.

1.1.3 Testing Installation

To test your installation of SALib, run the following command

```
python setup.py test
```

Alternatively, if you’d like also like a taste of what SALib provides, start a new interactive Python session and copy/paste the code below.

```
from SALib.sample import saltelli
from SALib.analyze import sobol
from SALib.test_functions import Ishigami
import numpy as np

# Define the model inputs
problem = {
    'num_vars': 3,
    'names': ['x1', 'x2', 'x3'],
    'bounds': [(-3.14159265359, 3.14159265359),
               (-3.14159265359, 3.14159265359),
               (-3.14159265359, 3.14159265359)]
}

# Generate samples
param_values = saltelli.sample(problem, 1000)

# Run model (example)
Y = Ishigami.evaluate(param_values)

# Perform analysis
Si = sobol.analyze(problem, Y, print_to_console=True)

# Print the first-order sensitivity indices
print Si['S1']
```

If installed correctly, the last line above will print three values, similar to `[ 0.30644324 0.44776661 -0.00104936]`. 
1.2 Basics

1.2.1 What is Sensitivity Analysis?

According to Wikipedia, sensitivity analysis is “the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs.” The sensitivity of each input is often represented by a numeric value, called the sensitivity index. Sensitivity indices come in several forms:

1. First-order indices: measures the contribution to the output variance by a single model input alone.
2. Second-order indices: measures the contribution to the output variance caused by the interaction of two model inputs.
3. Total-order index: measures the contribution to the output variance caused by a model input, including both its first-order effects (the input varying alone) and all higher-order interactions.

1.2.2 What is SALib?

SALib is an open source library written in Python for performing sensitivity analysis. SALib provides a decoupled workflow, meaning it does not directly interface with the mathematical or computational model. Instead, SALib is responsible for generating the model inputs, using one of the sample functions, and computing the sensitivity indices from the model outputs, using one of the analyze functions. A typical sensitivity analysis using SALib follows four steps:

1. Determine the model inputs (parameters) and their sample range.
2. Run the sample function to generate the model inputs.
3. Evaluate the model using the generated inputs, saving the model outputs.
4. Run the analyze function on the outputs to compute the sensitivity indices.

SALib provides several sensitivity analysis methods, such as Sobol, Morris, and FAST. There are many factors that determine which method is appropriate for a specific application, which we will discuss later. However, for now, just remember that regardless of which method you choose, you need to use only two functions: sample and analyze. To demonstrate the use of SALib, we will walk you through a simple example.

1.2.3 An Example

In this example, we will perform a Sobol’ sensitivity analysis of the Ishigami function, shown below. The Ishigami function is commonly used to test uncertainty and sensitivity analysis methods because it exhibits strong nonlinearity and nonmonotonicity.

\[ f(x) = \sin(x_1) + a\sin^2(x_2) + bx_3^4\sin(x_1) \]

Importing SALib

The first step is the import the necessary libraries. In SALib, the sample and analyze functions are stored in separate Python modules. For example, below we import the saltelli sample function and the sobol analyze function. We also import the Ishigami function, which is provided as a test function within SALib. Lastly, we import numpy, as it is used by SALib to store the model inputs and outputs in a matrix.
from SALib.sample import saltelli
from SALib.analyze import sobol
from SALib.test_functions import Ishigami
import numpy as np

Defining the Model Inputs

Next, we must define the model inputs. The Ishigami function has three inputs, \( x_1, x_2, x_3 \) where \( x_i \in [-\pi, \pi] \). In SALib, we define a dict defining the number of inputs, the names of the inputs, and the bounds on each input, as shown below:

```python
problem = {
    'num_vars': 3,
    'names': ['x1', 'x2', 'x3'],
    'bounds': 
        [[-3.14159265359, 3.14159265359],
        [-3.14159265359, 3.14159265359],
        [-3.14159265359, 3.14159265359]]
}
```

Generate Samples

Next, we generate the samples. Since we are performing a Sobol’ sensitivity analysis, we need to generate samples using the Saltelli sampler, as shown below:

```python
param_values = saltelli.sample(problem, 1000)
```

Here, `param_values` is a NumPy matrix. If we run `param_values.shape`, we see that the matrix is 8000 by 3. The Saltelli sampler generated 8000 samples. The Saltelli sampler generates \( N \times (2D + 2) \) samples, where in this example \( N \) is 1000 (the argument we supplied) and \( D \) is 3 (the number of model inputs). The keyword argument `calc_second_order=False` will exclude second-order indices, resulting in a smaller sample matrix with \( N \times (D + 2) \) rows instead.

Run Model

As mentioned above, SALib is not involved in the evaluation of the mathematical or computational model. If the model is written in Python, then generally you will loop over each sample input and evaluate the model:

```python
Y = np.zeros((param_values.shape[0]))
for i, X in enumerate(param_values):
    Y[i] = evaluate_model(X)
```

If the model is not written in Python, then the samples can be saved to a text file:

```python
np.savetxt("param_values.txt", param_values)
```

Each line in `param_values.txt` is one input to the model. The output from the model should be saved to another file with a similar format: one output on each line. The outputs can then be loaded with:

```python
Y = np.loadtxt("outputs.txt", float)
```

In this example, we are using the Ishigami function provided by SALib. We can evaluate these test functions as shown below:
Perform Analysis

With the model outputs loaded into Python, we can finally compute the sensitivity indices. In this example, we use `sobol.analyze`, which will compute first, second, and total-order indices.

```python
Si = sobol.analyze(problem, Y)
```

`Si` is a Python dict with the keys "S1", "S2", "ST", "S1_conf", "S2_conf", and "ST_conf". The `_conf` keys store the corresponding confidence intervals, typically with a confidence level of 95%. Use the keyword argument `print_to_console=True` to print all indices. Or, we can print the individual values from `Si` as shown below.

```python
print Si['S1']
[ 0.30644324 0.44776661 -0.00104936 ]
```

Here, we see that x1 and x2 exhibit first-order sensitivities but x3 appears to have no first-order effects.

```python
print Si['ST']
[ 0.56013728 0.4387225 0.24284474]
```

If the total-order indices are substantially larger than the first-order indices, then there is likely higher-order interactions occurring. We can look at the second-order indices to see these higher-order interactions:

```python
print "x1-x2:", Si['S2'][0,1]
print "x1-x3:", Si['S2'][0,2]
print "x2-x3:", Si['S2'][1,2]
```

```
x1-x2: 0.0155279
x1-x3: 0.25484902
x2-x3: -0.00995392
```

We can see there are strong interactions between x1 and x3. Some computing error will appear in the sensitivity indices. For example, we observe a negative value for the x2-x3 index. Typically, these computing errors shrink as the number of samples increases.

1.3 Concise API Reference

This page documents the sensitivity analysis methods supported by SALib.

1.3.1 FAST - Fourier Amplitude Sensitivity Test

```python
SALib.sample.fast_sampler.sample(problem, N, M=4, seed=None)
```

Generate model inputs for the Fourier Amplitude Sensitivity Test (FAST).

Returns a NumPy matrix containing the model inputs required by the Fourier Amplitude sensitivity test. The resulting matrix contains N * D rows and D columns, where D is the number of parameters. The samples generated are intended to be used by `SALib.analyze.fast.analyze()`.

Parameters
• **problem (dict)** – The problem definition
• **N (int)** – The number of samples to generate
• **M (int)** – The interference parameter, i.e., the number of harmonics to sum in the Fourier series decomposition (default 4)

SALib.analyze.fast.analyze (problem, Y, M=4, print_to_console=False, seed=None)
Performs the Fourier Amplitude Sensitivity Test (FAST) on model outputs.
Returns a dictionary with keys ‘S1’ and ‘ST’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

Parameters

• **problem (dict)** – The problem definition
• **Y (numpy.array)** – A NumPy array containing the model outputs
• **M (int)** – The interference parameter, i.e., the number of harmonics to sum in the Fourier series decomposition (default 4)
• **print_to_console (bool)** – Print results directly to console (default False)

References

Examples

```python
>>> X = fast_sampler.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = fast.analyze(problem, Y, print_to_console=False)
```

### 1.3.2 RBD-FAST - Random Balance Designs Fourier Amplitude Sensitivity Test

SALib.sample.latin.sample (problem, N, seed=None)
Generate model inputs using Latin hypercube sampling (LHS).
Returns a NumPy matrix containing the model inputs generated by Latin hypercube sampling. The resulting matrix contains N rows and D columns, where D is the number of parameters.

Parameters

• **problem (dict)** – The problem definition
• **N (int)** – The number of samples to generate

SALib.analyze.rbd_fast.analyze (problem, X, Y, M=10, print_to_console=False, seed=None)
Performs the Random Balanced Design - Fourier Amplitude Sensitivity Test (RBD-FAST) on model outputs.
Returns a dictionary with keys ‘S1’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

Parameters

• **problem (dict)** – The problem definition
• **X (numpy.array)** – A NumPy array containing the model inputs
• **Y (numpy.array)** – A NumPy array containing the model outputs
• **M (int)** – The interference parameter, i.e., the number of harmonics to sum in the Fourier series decomposition (default 10)
• **print_to_console** (*bool*) – Print results directly to console (default False)

**References**

**Examples**

```python
>>> X = latin.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = rbd_fast.analyze(problem, X, Y, print_to_console=False)
```

### 1.3.3 Method of Morris

**SALib.sample.morris.sample** (*problem*, *N*, *num_levels=4*, *optimal_trajectories=None*, *local_optimization=True*)

Generate model inputs using the Method of Morris

Returns a NumPy matrix containing the model inputs required for Method of Morris. The resulting matrix has 
\((G+1)*T \) rows and \(D \) columns, where \( D \) is the number of parameters, \( G \) is the number of groups (if no groups are selected, the number of parameters). \( T \) is the number of trajectories \( N \), or *optimal_trajectories* if selected. These model inputs are intended to be used with *SALib.analyze.morris.analyze()*.

**Parameters**

- **problem** (*dict*) – The problem definition
- **N** (*int*) – The number of trajectories to generate
- **num_levels** (*int*, *default=4*) – The number of grid levels
- **optimal_trajectories** (*int*) – The number of optimal trajectories to sample (between 2 and \( N \))
- **local_optimization** (*bool*, *default=True*) – Flag whether to use local optimization according to Ruano et al. (2012) Speeds up the process tremendously for bigger \( N \) and num_levels. If set to False brute force method is used, unless gurobipy is available

**Returns** *sample* – Returns a numpy.ndarray containing the model inputs required for Method of Morris. The resulting matrix has \((G/D + 1) * N/T\) rows and \(D \) columns, where \( D \) is the number of parameters.

**Return type** *numpy.ndarray*

**SALib.analyze.morris.analyze** (*problem*, *X*, *Y*, *num_resamples=1000*, *conf_level=0.95*,
*print_to_console=False*, *num_levels=4*, *seed=None*)

Perform Morris Analysis on model outputs.

Returns a dictionary with keys ‘mu’, ‘mu_star’, ‘sigma’, and ‘mu_star_conf’, where each entry is a list of parameters containing the indices in the same order as the parameter file.

**Parameters**

- **problem** (*dict*) – The problem definition
- **X** (*numpy.matrix*) – The NumPy matrix containing the model inputs of dtype=float
- **Y** (*numpy.array*) – The NumPy array containing the model outputs of dtype=float
- **num_resamples** (*int*) – The number of resamples used to compute the confidence intervals (default 1000)
- **conf_level** (*float*) – The confidence interval level (default 0.95)
**print_to_console** *(bool)* – Print results directly to console (default False)

**num_levels** *(int)* – The number of grid levels, must be identical to the value passed to `SALib.sample.morris` (default 4)

**Returns**

`Si` – A dictionary of sensitivity indices containing the following entries.

- **mu** - the mean elementary effect
- **mu_star** - the absolute of the mean elementary effect
- **sigma** - the standard deviation of the elementary effect
- **mu_star_conf** - the bootstrapped confidence interval
- **names** - the names of the parameters

**Return type** *dict*

**References**

**Examples**

```python
>>> X = morris.sample(problem, 1000, num_levels=4)
>>> Y = Ishigami.evaluate(X)
>>> Si = morris.analyze(problem, X, Y, conf_level=0.95,
>>>                      print_to_console=True, num_levels=4)
```

### 1.3.4 Sobol Sensitivity Analysis

**SALib.sample.saltelli.sample** *(problem, N, calc_second_order=True, seed=None)*

Generates model inputs using Saltelli’s extension of the Sobol sequence.

Returns a NumPy matrix containing the model inputs using Saltelli’s sampling scheme. Saltelli’s scheme extends the Sobol sequence in a way to reduce the error rates in the resulting sensitivity index calculations. If `calc_second_order` is False, the resulting matrix has \( N \times (D + 2) \) rows, where \( D \) is the number of parameters. If `calc_second_order` is True, the resulting matrix has \( N \times (2D + 2) \) rows. These model inputs are intended to be used with `SALib.analyze.sobol.analyze()`.

**Parameters**

- **problem** *(dict)* – The problem definition
- **N** *(int)* – The number of samples to generate
- **calc_second_order** *(bool)* – Calculate second-order sensitivities (default True)

**SALib.analyze.sobol.analyze** *(problem, Y, calc_second_order=True, num_resamples=100, conf_level=0.95, print_to_console=False, parallel=False, n_processors=None, seed=None)*

Perform Sobol Analysis on model outputs.

Returns a dictionary with keys ‘S1’, ‘S1_conf’, ‘ST’, and ‘ST_conf’, where each entry is a list of size \( D \) (the number of parameters) containing the indices in the same order as the parameter file. If `calc_second_order` is True, the dictionary also contains keys ‘S2’ and ‘S2_conf’.

**Parameters**

- **problem** *(dict)* – The problem definition
- \(Y(\text{numpy.array})\) – A NumPy array containing the model outputs
- \(\text{calc_second_order(} bool\text{)}\) – Calculate second-order sensitivities (default True)
- \(\text{num_resamples(} int\text{)}\) – The number of resamples (default 100)
- \(\text{conf_level(} float\text{)}\) – The confidence interval level (default 0.95)
- \(\text{print_to_console(} bool\text{)}\) – Print results directly to console (default False)

## References

### Examples

```python
>>> X = saltelli.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = sobol.analyze(problem, Y, print_to_console=True)
```

### 1.3.5 Delta Moment-Independent Measure

SALib.sample.latin.sample (\texttt{problem, N, seed=None})

Generate model inputs using Latin hypercube sampling (LHS).

Returns a NumPy matrix containing the model inputs generated by Latin hypercube sampling. The resulting matrix contains \(N\) rows and \(D\) columns, where \(D\) is the number of parameters.

#### Parameters

- \texttt{problem (dict)} – The problem definition
- \texttt{N (int)} – The number of samples to generate

SALib.analyze.delta.analyze (\texttt{problem, X, Y, num_resamples=10, conf_level=0.95, print_to_console=False, seed=None})

Perform Delta Moment-Independent Analysis on model outputs.

Returns a dictionary with keys ‘delta’, ‘delta_conf’, ‘S1’, and ‘S1_conf’, where each entry is a list of size \(D\) (the number of parameters) containing the indices in the same order as the parameter file.

#### Parameters

- \texttt{problem (dict)} – The problem definition
- \texttt{X (numpy.matrix)} – A NumPy matrix containing the model inputs
- \texttt{Y (numpy.array)} – A NumPy array containing the model outputs
- \texttt{num_resamples (int)} – The number of resamples when computing confidence intervals (default 10)
- \texttt{conf_level (float)} – The confidence interval level (default 0.95)
- \texttt{print_to_console (bool)} – Print results directly to console (default False)

## References

1.3. Concise API Reference
Examples

```python
>>> X = latin.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = delta.analyze(problem, X, Y, print_to_console=True)
```

1.3.6 Derivative-based Global Sensitivity Measure (DGSM)

SALib.analyze.dgsm.analyze(problem, X, Y, num_resamples=1000, conf_level=0.95, print_to_console=False, seed=None)

Calculates Derivative-based Global Sensitivity Measure on model outputs.

Returns a dictionary with keys `vi`, `vi_std`, `dgsm`, and `dgsm_conf`, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

Parameters

- **problem (dict)** – The problem definition
- **X (numpy.matrix)** – The NumPy matrix containing the model inputs
- **Y (numpy.array)** – The NumPy array containing the model outputs
- **num_resamples (int)** – The number of resamples used to compute the confidence intervals (default 1000)
- **conf_level (float)** – The confidence interval level (default 0.95)
- **print_to_console (bool)** – Print results directly to console (default False)

References

1.3.7 Fractional Factorial

SALib.sample.ff.sample(problem, seed=None)

Generates model inputs using a fractional factorial sample

Returns a NumPy matrix containing the model inputs required for a fractional factorial analysis. The resulting matrix has D columns, where D is smallest power of 2 that is greater than the number of parameters. These model inputs are intended to be used with `SALib.analyze.ff.analyze()`.

The problem file is padded with a number of dummy variables called `dummy_0` required for this procedure. These dummy variables can be used as a check for errors in the analyze procedure.

This algorithm is an implementation of that contained in [Saltelli et al. 2008]

Parameters **problem (dict)** – The problem definition

Returns sample

Return type numpy.array

SALib.analyze.ff.analyze(problem, X, Y, second_order=False, print_to_console=False, seed=None)

Perform a fractional factorial analysis

Returns a dictionary with keys `ME` (main effect) and `IE` (interaction effect). The techniques bulks out the number of parameters with dummy parameters to the nearest $2^n$. Any results involving dummy parameters could indicate a problem with the model runs.

Parameters
• **problem** *(dict)* – The problem definition
• **X** *(numpy.matrix)* – The NumPy matrix containing the model inputs
• **Y** *(numpy.array)* – The NumPy array containing the model outputs
• **second_order** *(bool, default=False)* – Include interaction effects
• **print_to_console** *(bool, default=False)* – Print results directly to console

**Returns**

Si – A dictionary of sensitivity indices, including main effects ME, and interaction effects IE (if second_order is True)

**Return type** *dict*

**Examples**

```python
>>> X = sample(problem)
>>> Y = X[:, 0] + (0.1 * X[:, 1]) + ((1.2 * X[:, 2]) * (0.2 + X[:, 0]))
>>> analyze(problem, X, Y, second_order=True, print_to_console=True)
```

1.4 License

The MIT License (MIT)

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1.5 Developers

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• Chris Mutel
• Bernardo Trindade
1.6 Projects that use SALib

If you would like to use our software, please cite it using the following:


If you use Bibtex, cite using the following entry:

@article{Herman2017, doi = {10.21105/joss.00097}, url = {https://doi.org/10.21105/joss.00097}, year = {2017}, month = {jan}, publisher = {The Open Journal}, volume = {2}, number = {9}, author = {Jon Herman and Will Usher}, title = {{SALib}: An open-source Python library for Sensitivity Analysis}, journal = {The Journal of Open Source Software} }

Many projects now use the Global Sensitivity Analysis features provided by SALib. Here are a selection:

1.6.1 Software

• The City Energy Analyst
• pynoddy
• savvy
• rhodium
• pySur
• EMA workbench
• Brain/Circulation Model Developer
• DAE Tools

1.6.2 Blogs

• Sensitivity Analysis in Python
• Sensitivity Analysis with SALib
• Running Sobol using SALib
• Extensions of SALib for more complex sensitivity analyses
1.6.3 Videos

- PyData Presentation on SALib

If you would like to be added to this list, please submit a pull request, or create an issue.
Many thanks for using SALib.

1.7 Changelog

1.7.1 Version 1.1.0

New Features:
- Refactored Method of Morris so the Ruano et al. local approach is default

Bug Fixes:
- Inputs to morris.analyze are provided as floats
- Removed calls to standard random library as inconsistent between Python 2 & 3
- First row in Sobol sequences should be zero, not empty

Documentation:
- Added a Code of Conduct
- Added DAETools, BCMD and others to citations - thanks for using SALib!
- Removed misleading keyword arguments in docs and readme examples
- Updated documentation for Method of Morris following refactor
- Improved existing documentation where lacking e.g. for fractional factorial method

Development Features:
- Implemented automatic deployment to PyPi
- Fixed a bug preventing automatic deployment to PyPi upon tagging a branch
- Removed postgres from travis config

1.7.2 Version 1.0.0

Release of our stable version of SALIB to coincide with an submission to JOSS:
- Added a paper for submission to the Journal of Open-source Software
- Updated back-end for documentation on read-the-docs
- Updated the back-end for version introspection using PyScaffold, rather than versioneer
- Updated the Travis-CI scripts
- Moved the tests out of the SALib package and migrated to using pytest
1.7.3 Version 0.7.1

Improvements to Morris sampling and Sobol groups/distributions

- Adds improved sampling for the Morris method
  (thanks to @JoerivanEngelen) and group sampling/analysis for the Sobol method (thanks to @calvinwhealton).
  @calvinwhealton has also added non-uniform distributions to the Sobol sampling. This will be a baseline for adding this to the other methods in the future.
- Also includes several minor bug fixes.

1.7.4 Version 0.7.0

New documentation, doc strings and installation requirements

- @dhadka has kindly contributed a wealth of documentation to the project, including doc strings in every module
- no longer test for numpy <1.8.0 and matplotlib < 1.4.3, and these requirements are implemented in a new setup script.

1.7.5 Version 0.6.3

Parallel option for Sobol method

- New option to run analyze.sobol function in parallel using multiprocessing

1.7.6 Version 0.6.2

This release does not contain any new functionality, but SALib now is citable using a Digital Object Identifier (DOI), which can be found in the readme.

Some minor updates are included:

- morris: sigma has been removed from the grouped-morris results and plots, replaced by mu_star_conf - a bootstrapped confidence interval. Mu_star_conf is not equivalent to sigma when used in the non-grouped method of morris, but its all we have when using groups. - some minor updates to the tests in the plotting module

1.7.7 Version 0.6.0

- Set up to include and test plotting functions
- Specific plotting functions for Morris
- Fractional Factorial SA from Saltelli et al.
- Repo transferred to SALib organization, update setup and URLs
- Small bugfixes
1.7.8  Version 0.5.0

- Vectorized bootstrap calculations for Morris and Sobol
- Optional trajectory optimization with Gurobi, and tests for it
- Several minor bugfixes
- Starting with v0.5, SALib is released under the MIT license.

1.7.9  Version 0.4.0

- Better Python API without requiring file read/write to the OS. Consistent functional API to sampling methods so that they return numpy matrices. Analysis methods now accept numpy matrices instead of data file names. This does not change the CLI at all, but makes it much easier to use from native Python.
- Also expanded tests for regression and the Sobol method.

1.7.10 Version 0.3.0

Improvements to Morris sampling and analysis methods, some bugfixes to make consistent with previous versions of the methods.

1.7.11 Version 0.2.0

Improvements to Morris sampling methods (support for group sampling, and optimized trajectories). Much better test coverage, and fixed Python 3 compatibility.

1.7.12 Version 0.1.0

First numbered release. Contains reasonably well-tested versions of the Sobol, Morris, and FAST methods. Also contains newer additions of DGSM and delta methods which are not as well-tested yet. Contains setup.py for installation.

1.8  SALib

1.8.1  SALib package

Subpackages

SALib.analyze package

Submodules

SALib.analyze.common_args module

SALib.analyze.common_args.create(cli_parser=None)
SALib.analyze.common_args.run_cli(cli_parser, run_analysis, known_args=None)
SALib.analyze.common_args.setup(parser)
SALib Documentation, Release 1.3.8.post0.dev3+g32e33c4

SALib.analyze.delta module

SALib.analyze.delta.analyze(problem, X, Y, num_resamples=10, conf_level=0.95, print_to_console=False, seed=None)

Perform Delta Moment-Independent Analysis on model outputs.

Returns a dictionary with keys ‘delta’, ‘delta_conf’, ‘S1’, and ‘S1_conf’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

Parameters

- **problem (dict)** – The problem definition
- **X (numpy.matrix)** – A NumPy matrix containing the model inputs
- **Y (numpy.array)** – A NumPy array containing the model outputs
- **num_resamples (int)** – The number of resamples when computing confidence intervals (default 10)
- **conf_level (float)** – The confidence interval level (default 0.95)
- **print_to_console (bool)** – Print results directly to console (default False)

References

Examples

```python
>>> X = latin.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = delta.analyze(problem, X, Y, print_to_console=True)
```

SALib.analyze.delta.bias_reduced_delta(Y, Ygrid, X, m, num_resamples, conf_level)

SALib.analyze.delta.calc_delta(Y, Ygrid, X, m)

SALib.analyze.delta.cli_action(args)

SALib.analyze.delta.cli_parse(parser)

SALib.analyze.delta.sobol_first(Y, X, m)

SALib.analyze.delta.sobol_first_conf(Y, X, m, num_resamples, conf_level)

SALib.analyze.dgsm module

SALib.analyze.dgsm.analyze(problem, X, Y, num_resamples=1000, conf_level=0.95, print_to_console=False, seed=None)

Calculates Derivative-based Global Sensitivity Measure on model outputs.

Returns a dictionary with keys ‘vi’, ‘vi_std’, ‘dgsm’, and ‘dgsm_conf’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

Parameters

- **problem (dict)** – The problem definition
- **X (numpy.matrix)** – The NumPy matrix containing the model inputs
- **Y (numpy.array)** – The NumPy array containing the model outputs
• **num_resamples** *(int)* – The number of resamples used to compute the confidence intervals (default 1000)
• **conf_level** *(float)* – The confidence interval level (default 0.95)
• **print_to_console** *(bool)* – Print results directly to console (default False)

**References**

SALib.analyze.dgsm.```calc_dgsm(base, perturbed, x_delta, bounds, num_resamples, conf_level)```  
SALib.analyze.dgsm.```calc_vi(base, perturbed, x_delta)```  
SALib.analyze.dgsm.```cli_action(args)```  
SALib.analyze.dgsm.```cli_parse(parser)```  

**SALib.analyze.fast module**

SALib.analyze.fast.```analyze(problem, Y, M=4, print_to_console=False, seed=None)```  
Performs the Fourier Amplitude Sensitivity Test (FAST) on model outputs.  
Returns a dictionary with keys ‘S1’ and ‘ST’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

**Parameters**

• **problem** *(dict)* – The problem definition
• **Y** *(numpy.array)* – A NumPy array containing the model outputs
• **M** *(int)* – The interference parameter, i.e., the number of harmonics to sum in the Fourier series decomposition (default 4)
• **print_to_console** *(bool)* – Print results directly to console (default False)

**References**

**Examples**

```python
>>> X = fast_sampler.sample(problem, 1000)  
>>> Y = Ishigami.evaluate(X)  
>>> Si = fast.analyze(problem, Y, print_to_console=False)
```  
SALib.analyze.fast.```cli_action(args)```  
SALib.analyze.fast.```compute_first_order(outputs, N, M, omega)```  
SALib.analyze.fast.```compute_total_order(outputs, N, omega)```  

**SALib.analyze.ff module**

Created on 30 Jun 2015

@author: will2
SALib.**analyze**(**problem**, **X**, **Y**, **second_order=False**, **print_to_console=False**, **seed=None**)

Perform a fractional factorial analysis

Returns a dictionary with keys ‘ME’ (main effect) and ‘IE’ (interaction effect). The techniques bulks out the number of parameters with dummy parameters to the nearest 2**n. Any results involving dummy parameters could indicate a problem with the model runs.

**Parameters**

- **problem** (*dict*) – The problem definition
- **X** (*numpy.matrix*) – The NumPy matrix containing the model inputs
- **Y** (*numpy.array*) – The NumPy array containing the model outputs
- **second_order** (*bool, default=False*) – Include interaction effects
- **print_to_console** (*bool, default=False*) – Print results directly to console

**Returns**

- **Si** – A dictionary of sensitivity indices, including main effects ME, and interaction effects IE (if second_order is True)

**Return type** dict

**Examples**

```python
>>> X = sample(problem)
>>> Y = X[:, 0] + (0.1 * X[:, 1]) + ((1.2 * X[:, 2]) * (0.2 + X[:, 0]))
>>> analyze(problem, X, Y, second_order=True, print_to_console=True)
```

SALib.**cli_action**(**args**)

SALib.**cli_parse**(**parser**)

SALib.**interactions**(**problem**, **Y**, **print_to_console=False**)

Computes the second order effects (interactions) between all combinations of pairs of input factors

**Parameters**

- **problem** (*dict*) – The problem definition
- **Y** (*numpy.array*) – The NumPy array containing the model outputs
- **print_to_console** (*bool, default=False*) – Print results directly to console

**Returns**

- **ie_names** (*list*) – The names of the interaction pairs
- **IE** (*list*) – The sensitivity indices for the pairwise interactions

SALib.**to_df**(**self**)

Conversion method to Pandas DataFrame. To be attached to ResultDict.

**Returns**

- **main_effect, inter_effect** – A tuple of DataFrames for main effects and interaction effects. The second element (for interactions) will be None if not available.

**Return type** tuple
SALib Documentation, Release 1.3.8.post0.dev3+g32e33c4

SALib.analyze.morris module

SALib.analyze.morris.analyze(problem, X, Y, num_resamples=1000, conf_level=0.95, 
print_to_console=False, num_levels=4, seed=None)

Perform Morris Analysis on model outputs.

Returns a dictionary with keys ‘mu’, ‘mu_star’, ‘sigma’, and ‘mu_star_conf’, where each entry is a list of 
parameters containing the indices in the same order as the parameter file.

Parameters

• problem (dict) – The problem definition
• X (numpy.matrix) – The NumPy matrix containing the model inputs of dtype=float
• Y (numpy.array) – The NumPy array containing the model outputs of dtype=float
• num_resamples (int) – The number of resamples used to compute the confidence inter-
valls (default 1000)
• conf_level (float) – The confidence interval level (default 0.95)
• print_to_console (bool) – Print results directly to console (default False)
• num_levels (int) – The number of grid levels, must be identical to the value passed to 
SALib.sample.morris (default 4)

Returns

Si – A dictionary of sensitivity indices containing the following entries.

• mu - the mean elementary effect
• mu_star - the absolute of the mean elementary effect
• sigma - the standard deviation of the elementary effect
• mu_star_conf - the bootstrapped confidence interval
• names - the names of the parameters

Return type dict

References

Examples

```python
>>> X = morris.sample(problem, 1000, num_levels=4)
>>> Y = Ishigami.evaluate(X)
>>> Si = morris.analyze(problem, X, Y, conf_level=0.95,
                       print_to_console=True, num_levels=4)
```

SALib.analyze.morris.cli_action(args)

SALib.analyze.morris.cli_parse(parser)

SALib.analyze.morris.compute_elementary_effects(model_inputs, model_outputs, trajectory_size, delta)

Parameters

• model_inputs (matrix of inputs to the model under analysis.) – 
x-by-r where x is the number of variables and r is the number of rows (a function of x 
and num_trajectories)
• **model_outputs** – an r-length vector of model outputs
• **trajectory_size** – a scalar indicating the number of rows in a trajectory
• **delta** (*float*) – scaling factor computed from num_levels

**Returns**

- **ee** – Elementary Effects for each parameter

**Return type** np.array

SALib.analyze.morris.compute_grouped_metric(ungrouped_metric, group_matrix)

Computes the mean value for the groups of parameter values in the argument ungrouped_metric

SALib.analyze.morris.compute_grouped_sigma(ungrouped_sigma, group_matrix)

Returns sigma for the groups of parameter values in the argument ungrouped_metric where the group consists of no more than one parameter

SALib.analyze.morris.compute_mu_star_confidence(ee, num_trajectories, num_resamples, conf_level)

Uses bootstrapping where the elementary effects are resampled with replacement to produce a histogram of resampled mu_star metrics. This resample is used to produce a confidence interval.

SALib.analyze.morris.get_decreased_values(op_vec, up, lo)

SALib.analyze.morris.get_increased_values(op_vec, up, lo)

SALib.analyze.rbd_fast module

SALib.analyze.rbd_fast.analyze(problem, X, Y, M=10, print_to_console=False, seed=None)

Performs the Random Balanced Design - Fourier Amplitude Sensitivity Test (RBD-FAST) on model outputs.

Returns a dictionary with keys ‘S1’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file.

**Parameters**

- **problem** (*dict*) – The problem definition
- **X** (*numpy.array*) – A NumPy array containing the model inputs
- **Y** (*numpy.array*) – A NumPy array containing the model outputs
- **M** (*int*) – The interference parameter, i.e., the number of harmonics to sum in the Fourier series decomposition (default 10)
- **print_to_console** (*bool*) – Print results directly to console (default False)

**References**

**Examples**

```python
>>> X = latin.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = rbd_fast.analyze(problem, X, Y, print_to_console=False)
```

SALib.analyze.rbd_fast.cli_action(args)

SALib.analyze.rbd_fast.cli_parse(parser)

SALib.analyze.rbd_fast.compute_first_order(permuted_outputs, M)
SALib.analyze.rbd_fast.permute_outputs \((X, Y)\)

Permute the output according to one of the inputs as in \([2]\)

**References**

SALib.analyze.rbd_fast.unskew_S1 \((S_1, M, N)\)


**SALib.analyze.sobol module**

SALib.analyze.sobol.Si_list_to_dict \((S_list, D, calc_second_order)\)

SALib.analyze.sobol.Si_to_pandas_dict \((S_dict)\)

Convert Si information into Pandas DataFrame compatible dict.

**Parameters**

\(S_dict\) (ResultDict) – Sobol sensitivity indices

**See also:**

Si_list_to_dict ()

**Returns**

tuple – Total and first order are dicts. Second order sensitivities contain a tuple of parameter name combinations for use as the DataFrame index and second order sensitivities. If no second order indices found, then returns tuple of (None, None)

**Return type**

do of total, first, and second order sensitivities.

**Examples**

```python
>>> X = saltelli.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = sobol.analyze(problem, Y, print_to_console=True)
>>> t_Si, first_Si, (idx, second_Si) = sobol.Si_to_pandas_dict(Si, problem)
```

SALib.analyze.sobol.analyze \((problem, Y, calc_second_order=True, num_resamples=100, conf_level=0.95, print_to_console=False, parallel=False, n_processors=None, seed=None)\)

Perform Sobol Analysis on model outputs.

Returns a dictionary with keys ‘S1’, ‘S1_conf’, ‘ST’, and ‘ST_conf’, where each entry is a list of size D (the number of parameters) containing the indices in the same order as the parameter file. If calc_second_order is True, the dictionary also contains keys ‘S2’ and ‘S2_conf’.

**Parameters**

- **problem** (dict) – The problem definition
- **Y** (numpy.array) – A NumPy array containing the model outputs
- **calc_second_order** (bool) – Calculate second-order sensitivities (default True)
- **num_resamples** (int) – The number of resamples (default 100)
- **conf_level** (float) – The confidence interval level (default 0.95)
- **print_to_console** (bool) – Print results directly to console (default False)
References

Examples

```python
>>> X = saltelli.sample(problem, 1000)
>>> Y = Ishigami.evaluate(X)
>>> Si = sobol.analyze(problem, Y, print_to_console=True)
```

SALib.analyze.sobol.cli_action(args)
SALib.analyze.sobol.cli_parse(parser)
SALib.analyze.sobol.create_Si_dict(D, calc_second_order)
SALib.analyze.sobol.create_task_list(D, calc_second_order, n_processors)
SALib.analyze.sobol.first_order(A, AB, B)
SALib.analyze.sobol.print_indices(S, problem, calc_second_order)
SALib.analyze.sobol.second_order(A, ABj, ABk, BAj, B)
SALib.analyze.sobol.separate_output_values(Y, D, N, calc_second_order)
SALib.analyze.sobol.sobol_parallel(Z, A, AB, BA, B, r, tasks)
SALib.analyze.sobol.to_df(self)
Conversion method to Pandas DataFrame. To be attached to ResultDict.

Returns List

Return type of Pandas DataFrames in order of Total, First, Second

SALib.analyze.sobol.total_order(A, AB, B)

Module contents

SALib.plotting package

Submodules

SALib.plotting.bar module

SALib.plotting.bar.plot(Si_df, ax=None)
Create bar chart of results

Parameters Si_df (*) –

Returns * ax

Return type matplotlib axes object

Examples

```python
>>> from SALib.plotting.bar import plot as barplot
>>> from SALib.test_functions import Ishigami
>>> 
>>> X = saltelli.sample(problem, 1000)
```
>>> Y = Ishigami.evaluate(X)
>>> Si = sobol.analyze(problem, Y, print_to_console=False)
>>> Si_df = Si.to_df()
>>> barplot(Si_df)

SALib.plotting.morris module

Created on 29 Jun 2015
@author: @willu47

This module provides the basic infrastructure for plotting charts for the Method of Morris results

The procedures should build upon and return an axes instance:

```python
import matplotlib.pyplot as plt
Si = morris.analyze(problem, param_values, Y, conf_level=0.95,
                    print_to_console=False, num_levels=10)
p = morris.horizontal_bar_plot(Si)
# set plot style etc.
fig, ax = plt.subplots(1, 1)
my_plotter(ax, data1, data2, {'marker':'x'})
p.show()
```

SALib.plotting.morris.covariance_plot(ax, Si, param_dict, unit="")
Plots mu* against sigma or the 95% confidence interval

SALib.plotting.morris.horizontal_bar_plot(ax, Si, param_dict, sortby='mu_star', unit="")
Updates a matplotlib axes instance with a horizontal bar plot
of mu_star, with error bars representing mu_star_conf

SALib.plotting.morris.sample_histograms(fig, input_sample, problem, param_dict)
Plots a set of subplots of histograms of the input sample

Module contents

SALib.sample package

Subpackages

SALib.sample.morris package

Submodules

SALib.sample.morris.brute module

```python
class SALib.sample.morris.brute.BruteForce
    Bases: SALib.sample.morris.strategy.Strategy
    Implements the brute force optimisation strategy
```
brute_force_most_distant (input_sample, num_samples, num_params, k_choices, num_groups=None)
Use brute force method to find most distant trajectories

Parameters
- input_sample (numpy.ndarray)
- num_samples (int) – The number of samples to generate
- num_params (int) – The number of parameters
- k_choices (int) – The number of optimal trajectories
- num_groups (int, default=None) – The number of groups

Returns
Return type list

find_maximum (scores, N, k_choices)
Finds the k_choices maximum scores from scores

Parameters
- scores (numpy.ndarray)
- N (int)
- k_choices (int)

Returns
Return type list

find_most_distant (input_sample, num_samples, num_params, k_choices, num_groups=None)
Finds the ‘k_choices’ most distant choices from the ‘num_samples’ trajectories contained in ‘input_sample’

Parameters
- input_sample (numpy.ndarray)
- num_samples (int) – The number of samples to generate
- num_params (int) – The number of parameters
- k_choices (int) – The number of optimal trajectories
- num_groups (int, default=None) – The number of groups

Returns
Return type numpy.ndarray

static grouper (n, iterable)

static mappable (combos, pairwise, distance_matrix)
Obtains scores from the distance_matrix for each pairwise combination held in the combos array

Parameters
- combos (numpy.ndarray)
- pairwise (numpy.ndarray)
- distance_matrix (numpy.ndarray)

static nth (iterable, n, default=None)
Returns the nth item or a default value
Parameters

- **iterable** (iterable)
- **n** (int)
- **default** (default=None) – The default value to return

SALib.sample.morris.gurobi module

Finds optimal trajectories using a global optimisation method

Example

Run using

```bash
>>> optimal_trajectories.py -n=10 -p=esme_param.txt -o=test_op.txt -s=12892 --num-levels=4 --grid-jump=2 --k-choices=4
```

SALib.sample.morris.gurobi.**timestamp** *(num_params, p_levels, k_choices, N)*

Returns a uniform timestamp with parameter values for file identification

SALib.sample.morris.local module

**class** SALib.sample.morris.local.**LocalOptimisation**

**Bases:** SALib.sample.morris.strategy.**Strategy**

Implements the local optimisation algorithm using the Strategy interface

**add_indices** *(indices, distance_matrix)*

Adds extra indices for the combinatorial problem.

**Parameters**

- **indices** (tuple)
- **distance_matrix** (numpy.ndarray (M,M))

Example

```python
>>> add_indices((1,2), numpy.array((5,5)))
[(1, 2, 3), (1, 2, 4), (1, 2, 5)]
```

**find_local_maximum** *(input_sample, N, num_params, k_choices, num_groups=None)*

Find the most different trajectories in the input sample using a local approach

An alternative by Ruano et al. (2012) for the brute force approach as originally proposed by Campolongo et al. (2007). The method should improve the speed with which an optimal set of trajectories is found tremendously for larger sample sizes.

**Parameters**

- **input_sample** (np.ndarray)
- **N** (int) – The number of trajectories
- **num_params** (int) – The number of factors
• **k_choices** *(int)* – The number of optimal trajectories to return

• **num_groups** *(int, default=None)* – The number of groups

Returns

Return type *list*

**get_max_sum_ind**(indices_list, distances, i, m)

Get the indices that belong to the maximum distance in *distances*

Parameters

• **indices_list** *(list)* – list of tuples

• **distances** *(numpy.ndarray)* – size M

• **i** *(int)* –

• **m** *(int)* –

Returns

Return type *list*

**sum_distances**(indices, distance_matrix)

Calculate combinatorial distance between a select group of trajectories, indicated by indices

Parameters

• **indices** *(tuple)* –

• **distance_matrix** *(numpy.ndarray (M,M))* –

Returns

Return type *numpy.ndarray*

Notes

This function can perhaps be quickened by calculating the sum of the distances. The calculated distances, as they are right now, are only used in a relative way. Purely summing distances would lead to the same result, at a perhaps quicker rate.

**SALib.sample.morris.strategy module**

Defines a family of algorithms for generating samples

The sample a for use with *SALib.analyze.morris.analyze*, encapsulate each one, and makes them interchangeable.

**Example**

```python
>>> localoptimisation = LocalOptimisation()
>>> context = SampleMorris(localoptimisation)
>>> context.sample(input_sample, num_samples, num_params, k_choices, groups)
```

**class** *SALib.sample.morris.strategy.SampleMorris*(strategy)

Bases: *object*

Computes the optimum *k_choices* of trajectories from the input_sample.
Parameters **strategy** (*Strategy*) –

**sample** (*input_sample, num_samples, num_params, k_choices, num_groups*)

Computes the optimum *k_choices* of trajectories from the *input_sample*.

Parameters

- **input_sample** (*numpy.ndarray*) –
- **num_samples** (*int*) – The number of samples to generate
- **num_params** (*int*) – The number of parameters
- **k_choices** (*int*) – The number of optimal trajectories
- **num_groups** (*int*) – The number of groups

Returns An array of optimal trajectories

Return type *numpy.ndarray*

class SALib.sample.morris.strategy.Strategy

Bases: *object*

Declare an interface common to all supported algorithms. *SampleMorris* uses this interface to call the algorithm defined by a ConcreteStrategy.

*static check_input_sample* (*input_sample, num_params, num_samples*)

Checks input sample is:

- the correct size
- values between 0 and 1

Parameters

- **input_sample** (*numpy.ndarray*) –
- **num_params** (*int*) –
- **num_samples** (*int*) –

*compile_output* (*input_sample, num_samples, num_params, maximum_combo, num_groups=None*)

Picks the trajectories from the input

Parameters

- **input_sample** (*numpy.ndarray*) –
- **num_samples** (*int*) –
- **num_params** (*int*) –
- **maximum_combo** (*list*) –
- **num_groups** (*int*) –

*static compute_distance* (*m, l*)

Compute distance between two trajectories

Returns

Return type *numpy.ndarray*
**compute_distance_matrix**(*input_sample*, *num_samples*, *num_params*, *num_groups=None*, *local_optimization=False*)

Computes the distance between each and every trajectory.

Each entry in the matrix represents the sum of the geometric distances between all the pairs of points of the two trajectories.

If the *groups* argument is filled, then the distances are still calculated for each trajectory.

**Parameters**

- **input_sample** (*numpy.ndarray*) – The input sample of trajectories for which to compute the distance matrix.
- **num_samples** (*int*) – The number of trajectories.
- **num_params** (*int*) – The number of factors.
- **num_groups** (*int, default=None*) – The number of groups.
- **local_optimization** (*bool, default=False*) – If True, fills the lower triangle of the distance matrix.

**Returns**

**distance_matrix**

**Return type**

*numpy.ndarray*

**static run_checks**(*number_samples*, *k_choices*)

Runs checks on *k_choices*.

**sample**(*input_sample*, *num_samples*, *num_params*, *k_choices*, *num_groups=None*)

Computes the optimum *k_choices* of trajectories from the *input_sample*.

**Parameters**

- **input_sample** (*numpy.ndarray*) –
- **num_samples** (*int*) – The number of samples to generate.
- **num_params** (*int*) – The number of parameters.
- **k_choices** (*int*) – The number of optimal trajectories.
- **num_groups** (*int, default=None*) – The number of groups.

**Returns**

**Return type**

*numpy.ndarray*

**Module contents**

Generate a sample using the Method of Morris.

Three variants of Morris’ sampling for elementary effects is supported:

- Vanilla Morris
- **Optimised trajectories when optimal_trajectories=True** (using Campolongo’s enhancements from 2007 and optionally Ruano’s enhancement from 2012; *local_optimization=True*)
- **Groups with optimised trajectories when optimal_trajectories=True** and the problem definition specifies groups (note that *local_optimization* must be *False*)
At present, optimised trajectories is implemented using either a brute-force approach, which can be very slow, especially if you require more than four trajectories, or a local method based which is much faster. Both methods now implement working with groups of factors.

Note that the number of factors makes little difference, but the ratio between number of optimal trajectories and the sample size results in an exponentially increasing number of scores that must be computed to find the optimal combination of trajectories. We suggest going no higher than 4 from a pool of 100 samples with the brute force approach. With local_optimization = True (which is default), it is possible to go higher than the previously suggested 4 from 100.

SALib.sample.morris.sample(problem, N, num_levels=4, optimal_trajectories=None, local_optimization=True)

Generate model inputs using the Method of Morris

Returns a NumPy matrix containing the model inputs required for Method of Morris. The resulting matrix has \((G + 1) \times T\) rows and \(D\) columns, where \(D\) is the number of parameters, \(G\) is the number of groups (if no groups are selected, the number of parameters). \(T\) is the number of trajectories \(N\), or optimal_trajectories if selected. These model inputs are intended to be used with SALib.analyze.morris.analyze().

Parameters

- **problem (dict)** – The problem definition
- **N (int)** – The number of trajectories to generate
- **num_levels (int, default=4)** – The number of grid levels
- **optimal_trajectories (int)** – The number of optimal trajectories to sample (between 2 and \(N\))
- **local_optimization (bool, default=True)** – Flag whether to use local optimization according to Ruano et al. (2012) Speeds up the process tremendously for bigger \(N\) and num_levels. If set to False brute force method is used, unless gurobipy is available

Returns **sample** – Returns a numpy.ndarray containing the model inputs required for Method of Morris. The resulting matrix has \((G/D + 1) \times N/T\) rows and \(D\) columns, where \(D\) is the number of parameters.

Return type **numpy.ndarray**

Submodules

SALib.sample.common_args module

SALib.sample.common_args.create(cli_parser=None)

Create CLI parser object.

Parameters **cli_parser (function [optional])** – Function to add method specific arguments to parser

Returns

Return type **argparse object**

SALib.sample.common_args.run_cli(cli_parser, run_sample, known_args=None)

Run sampling with CLI arguments.

Parameters

- **cli_parser (function)** – Function to add method specific arguments to parser
- **run_sample (function)** – Method specific function that runs the sampling
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- **known_args** *(list [optional]) – Additional arguments to parse*

  Returns

  Return type: argparse object

SALib.sample.common_args.setup *(parser)*

Add common sampling options to CLI parser.

  Parameters: **parser** *(argparse object)* –

  Returns

  Return type: Updated argparse object

SALib.sample.directions module

SALib.sample.fast_sampler module

- **SALib.sample.fast_sampler.cli_action** *(args)*

  Run sampling method

  Parameters: **args** *(argparse namespace)* –

  Returns

  Return type: Updated argparse object

- **SALib.sample.fast_sampler.sample** *(problem, N, M=4, seed=None)*

  Generate model inputs for the Fourier Amplitude Sensitivity Test (FAST).

  Returns a NumPy matrix containing the model inputs required by the Fourier Amplitude sensitivity test. The resulting matrix contains N * D rows and D columns, where D is the number of parameters. The samples generated are intended to be used by *SALib.analyze.fast.analyze()*.

  Parameters:

  - **problem** *(dict)* – The problem definition
  - **N** *(int)* – The number of samples to generate
  - **M** *(int)* – The interference parameter, i.e., the number of harmonics to sum in the Fourier series decomposition (default 4)

SALib.sample.ff module

- The sampling implementation of fractional factorial method

  - This implementation is based on the formulation put forward in [Saltelli et al. 2008]

  - **SALib.sample.ff.cli_action** *(args)*

    Run sampling method

    Parameters: **args** *(argparse namespace)* –

    Returns

    **SALib.sample.ff.extend_bounds** *(problem)*

    Extends the problem bounds to the nearest power of two
Parameters **problem** *(dict)* – The problem definition

SALib.sample.ff.**find_smallest**(num_vars)

Find the smallest exponent of two that is greater than the number of variables

Parameters **num_vars** *(int)* – Number of variables

Returns **x** – Smallest exponent of two greater than num_vars

Return type **int**

SALib.sample.ff.**generate_contrast**(problem)

Generates the raw sample from the problem file

Parameters **problem** *(dict)* – The problem definition

SALib.sample.ff.**sample**(problem, seed=None)

Generates model inputs using a fractional factorial sample

Returns a NumPy matrix containing the model inputs required for a fractional factorial analysis. The resulting matrix has D columns, where D is smallest power of 2 that is greater than the number of parameters. These model inputs are intended to be used with SALib.analyze.ff.analyze().

The problem file is padded with a number of dummy variables called dummy_0 required for this procedure. These dummy variables can be used as a check for errors in the analyze procedure.

This algorithm is an implementation of that contained in [Saltelli et al. 2008]

Parameters **problem** *(dict)* – The problem definition

Returns **sample**

Return type **numpy.array**

**SALib.sample.finite_diff module**

SALib.sample.finite_diff.**cli_action**(args)

Run sampling method

Parameters **args**(argparse namespace)

SALib.sample.finite_diff.**cli_parse**(parser)

Add method specific options to CLI parser.

Parameters **parser**(argparse object)

Returns

Return type Updated argparse object

SALib.sample.finite_diff.**sample**(problem, N, delta=0.01, seed=None)

**SALib.sample.latin module**

SALib.sample.latin.**cli_action**(args)

Run sampling method

Parameters **args**(argparse namespace)

SALib.sample.latin.**sample**(problem, N, seed=None)

Generate model inputs using Latin hypercube sampling (LHS).
Returns a NumPy matrix containing the model inputs generated by Latin hypercube sampling. The resulting matrix contains N rows and D columns, where D is the number of parameters.

**Parameters**
- `problem (dict)` – The problem definition
- `N (int)` – The number of samples to generate

**SALib.sample.saltelli module**

SALib.sample.saltelli.cli_action(args)
Run sampling method

**Parameters**
- `args (argparse namespace)`

SALib.sample.saltelli.cli_parse(parser)
Add method specific options to CLI parser.

**Parameters**
- `parser (argparse object)`

**Returns**
- `Return type` Updated argparse object

SALib.sample.saltelli.sample(problem, N, calc_second_order=True, seed=None)
Generates model inputs using Saltelli’s extension of the Sobol sequence.

Returns a NumPy matrix containing the model inputs using Saltelli’s sampling scheme. Saltelli’s scheme extends the Sobol sequence in a way to reduce the error rates in the resulting sensitivity index calculations. If `calc_second_order` is False, the resulting matrix has N * (D + 2) rows, where D is the number of parameters. If `calc_second_order` is True, the resulting matrix has N * (2D + 2) rows. These model inputs are intended to be used with `SALib.analyze.sobol.analyze()`.

**Parameters**
- `problem (dict)` – The problem definition
- `N (int)` – The number of samples to generate
- `calc_second_order (bool)` – Calculate second-order sensitivities (default True)

**SALib.sample.sobol_sequence module**

SALib.sample.sobol_sequence.index_of_least_significant_zero_bit(value)

SALib.sample.sobol_sequence.sample(N, D)
Generate (N x D) numpy array of Sobol sequence samples

**Module contents**

**SALib.scripts package**

**Submodules**

**SALib.scripts.salib module**

Command-line utility for SALib
SALib.scripts.salib.main()

SALib.scripts.salib.parse_subargs(module, parser, method, opts)
   Attach argument parser for action specific options.

   Parameters
   • module (module) – name of module to extract action from
   • parser (argparser) – argparser object to attach additional arguments to
   • method (str) – name of method (morris, sobol, etc). Must match one of the available submodules
   • opts (list) – A list of argument options to parse

   Returns subargs
   Return type argparse namespace object

Module contents

SALib.test_functions package

Submodules

SALib.test_functions.Ishigami module

SALib.test_functions.Ishigami.evaluate(values)

SALib.test_functions.Sobol_G module

SALib.test_functions.Sobol_G.evaluate(values, a=None)
SALib.test_functions.Sobol_G.partial_first_order_variance(a=None)
SALib.test_functions.Sobol_G.sensitivity_index(a)
SALib.test_functions.Sobol_G.total_sensitivity_index(a)
SALib.test_functions.Sobol_G.total_variance(a=None)

Module contents

SALib.util package

Submodules

SALib.util.results module

class SALib.util.results.ResultDict(*args, **kwargs)
   Bases: dict

   Dictionary holding analysis results.
   Conversion methods (e.g. to Pandas DataFrames) to be attached as necessary by each implementing method
plot()
    Create bar chart of results

to_df()
    Convert dict structure into Pandas DataFrame.

Module contents

A set of utility functions

SALib.util.scale_samples(params, bounds)
    Rescale samples in 0-to-1 range to arbitrary bounds

Parameters

• params (numpy.ndarray) – numpy array of dimensions num_params-by-N, where N is the number of samples
• bounds (list) – list of lists of dimensions num_params-by-2

SALib.util.read_param_file(filename, delimiter=None)
    Unpacks a parameter file into a dictionary

Reads a parameter file of format:

Param1,0,1,Group1,dist1
Param2,0,1,Group2,dist2
Param3,0,1,Group3,dist3

(Group and Dist columns are optional)

Returns a dictionary containing:

• names - the names of the parameters
• bounds - a list of lists of lower and upper bounds
• num_vars - a scalar indicating the number of variables (the length of names)
• groups - a list of group names (strings) for each variable
• dists - a list of distributions for the problem, None if not specified or all uniform

Parameters

• filename (str) – The path to the parameter file
• delimiter (str, default=None) – The delimiter used in the file to distinguish between columns

class SALib.util.ResultDict(*args, **kwargs)
    Bases: dict

Dictionary holding analysis results.

Conversion methods (e.g. to Pandas DataFrames) to be attached as necessary by each implementing method

plot()
    Create bar chart of results

to_df()
    Convert dict structure into Pandas DataFrame.
SALib.util.avail_approaches(pkg)

Create list of available modules.

**Parameters**
- `pkg` *(module)* – module to inspect

**Returns**
- `method` – A list of available submodules

**Return type**
- `list`

### Module contents

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