Cryptography Documentation

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Individual Contributors

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cryptography includes both high level recipes and low level interfaces to common cryptographic algorithms such as symmetric ciphers, message digests, and key derivation functions. For example, to encrypt something with cryptography’s high level symmetric encryption recipe:

```python
>>> from cryptography.fernet import Fernet
>>> # Put this somewhere safe!
>>> key = Fernet.generate_key()
>>> f = Fernet(key)
>>> token = f.encrypt(b"A really secret message. Not for prying eyes.")
>>> token
'...
>>> f.decrypt(token)
'A really secret message. Not for prying eyes.'
```

If you are interested in learning more about the field of cryptography, we recommend Crypto 101, by Laurens Van Houtven and The Cryptopals Crypto Challenges.
You can install cryptography with pip:

```bash
$ pip install cryptography
```

See *Installation* for more information.
cryptography is broadly divided into two levels. One with safe cryptographic recipes that require little to no configuration choices. These are safe and easy to use and don’t require developers to make many decisions.

The other level is low-level cryptographic primitives. These are often dangerous and can be used incorrectly. They require making decisions and having an in-depth knowledge of the cryptographic concepts at work. Because of the potential danger in working at this level, this is referred to as the “hazardous materials” or “hazmat” layer. These live in the cryptography.hazmat package, and their documentation will always contain an admonition at the top.

We recommend using the recipes layer whenever possible, and falling back to the hazmat layer only when necessary.

2.1 Fernet (symmetric encryption)

Fernet guarantees that a message encrypted using it cannot be manipulated or read without the key. Fernet is an implementation of symmetric (also known as “secret key”) authenticated cryptography. Fernet also has support for implementing key rotation via MultiFernet.

class cryptography.fernet.Fernet (key)

This class provides both encryption and decryption facilities.

```python
>>> from cryptography.fernet import Fernet
>>> key = Fernet.generate_key()
>>> f = Fernet(key)
>>> token = f.encrypt(b"my deep dark secret")
>>> token
b'...

>>> f.decrypt(token)

b'my deep dark secret'
```

Parameters key (bytes) – A URL-safe base64-encoded 32-byte key. This must be kept secret. Anyone with this key is able to create and read messages.
classmethod generate_key()
Generates a fresh fernet key. Keep this some place safe! If you lose it you’ll no longer be able to decrypt messages; if anyone else gains access to it, they’ll be able to decrypt all of your messages, and they’ll also be able forge arbitrary messages that will be authenticated and decrypted.

encrypt(data)
Encrypts data passed. The result of this encryption is known as a “Fernet token” and has strong privacy and authenticity guarantees.

Parameters
data (bytes) – The message you would like to encrypt.

Returns bytes A secure message that cannot be read or altered without the key. It is URL-safe base64-encoded. This is referred to as a “Fernet token”.

Raises TypeError – This exception is raised if data is not bytes.

Note: The encrypted message contains the current time when it was generated in plaintext, the time a message was created will therefore be visible to a possible attacker.

decrypt(token, ttl=None)
Decrypts a Fernet token. If successfully decrypted you will receive the original plaintext as the result, otherwise an exception will be raised. It is safe to use this data immediately as Fernet verifies that the data has not been tampered with prior to returning it.

Parameters

- token (bytes) – The Fernet token. This is the result of calling encrypt().

- ttl (int) – Optionally, the number of seconds old a message may be for it to be valid. If the message is older than ttl seconds (from the time it was originally created) an exception will be raised. If ttl is not provided (or is None), the age of the message is not considered.

Returns bytes The original plaintext.

Raises

- cryptography.fernet.InvalidToken – If the token is in any way invalid, this exception is raised. A token may be invalid for a number of reasons: it is older than the ttl, it is malformed, or it does not have a valid signature.

- TypeError – This exception is raised if token is not bytes.

extract_timestamp(token)
New in version 2.3.

Returns the timestamp for the token. The caller can then decide if the token is about to expire and, for example, issue a new token.

Parameters token (bytes) – The Fernet token. This is the result of calling encrypt().

Returns int The UNIX timestamp of the token.

Raises

- cryptography.fernet.InvalidToken – If the token’s signature is invalid this exception is raised.

- TypeError – This exception is raised if token is not bytes.

class cryptography.fernet.MultiFernet(fernets)
New in version 0.7.
This class implements key rotation for Fernet. It takes a list of Fernet instances and implements the same API with the exception of one additional method: `MultiFernet.rotate()`:

```python
>>> from cryptography.fernet import Fernet, MultiFernet
>>> key1 = Fernet(Fernet.generate_key())
>>> key2 = Fernet(Fernet.generate_key())
>>> f = MultiFernet([key1, key2])
>>> token = f.encrypt(b"Secret message!")
>>> token
b'...

>>> f.decrypt(token)
b'Secret message!'
```

MultiFernet performs all encryption options using the first key in the list provided. MultiFernet attempts to decrypt tokens with each key in turn. A `cryptography.fernet.InvalidToken` exception is raised if the correct key is not found in the list provided.

Key rotation makes it easy to replace old keys. You can add your new key at the front of the list to start encrypting new messages, and remove old keys as they are no longer needed.

Token rotation as offered by `MultiFernet.rotate()` is a best practice and manner of cryptographic hygiene designed to limit damage in the event of an undetected event and to increase the difficulty of attacks. For example, if an employee who had access to your company’s fernet keys leaves, you’ll want to generate new fernet key, rotate all of the tokens currently deployed using that new key, and then retire the old fernet key(s) to which the employee had access.

```python
rotate(msg)
```

New in version 2.2.

Rotates a token by re-encrypting it under the `MultiFernet` instance’s primary key. This preserves the timestamp that was originally saved with the token. If a token has successfully been rotated then the rotated token will be returned. If rotation fails this will raise an exception.

```python
>>> from cryptography.fernet import Fernet, MultiFernet
>>> key1 = Fernet(Fernet.generate_key())
>>> key2 = Fernet(Fernet.generate_key())
>>> f = MultiFernet([key1, key2])
>>> token = f.encrypt(b"Secret message!")
>>> token
b'...

>>> f.decrypt(token)
b'Secret message!'
```

```python
>>> key3 = Fernet(Fernet.generate_key())
>>> f = MultiFernet([key3, key1, key2])
>>> rotated = f.rotate(token)
>>> f2.decrypt(rotated)
b'Secret message!'
```

**Parameters** `msg` (*bytes*) – The token to re-encrypt.

**Returns** *bytes* A secure message that cannot be read or altered without the key. This is URL-safe base64-encoded. This is referred to as a “Fernet token”.

**Raises**

* `cryptography.fernet.InvalidToken` – If a token is in any way invalid this exception is raised.

* `TypeError` – This exception is raised if the `msg` is not `bytes`.  

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2.1. Fernet (symmetric encryption)
class cryptography.fernet.InvalidToken
    See Fernet.decrypt() for more information.

2.1.1 Using passwords with Fernet

It is possible to use passwords with Fernet. To do this, you need to run the password through a key derivation function such as PBKDF2HMAC, bcrypt or Scrypt.

```python
>>> import base64
>>> import os
>>> from cryptography.fernet import Fernet
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.pbkdf2 import PBKDF2HMAC

>>> password = b"password"
>>> salt = os.urandom(16)
>>> kdf = PBKDF2HMAC(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=salt,
...     iterations=100000,
...     backend=default_backend()
...)

>>> key = base64.urlsafe_b64encode(kdf.derive(password))
>>> f = Fernet(key)
>>> token = f.encrypt(b"Secret message!")
>>> token
b'...
>>> f.decrypt(token)
 b'Secret message!'```

In this scheme, the salt has to be stored in a retrievable location in order to derive the same key from the password in the future.

The iteration count used should be adjusted to be as high as your server can tolerate. A good default is at least 100,000 iterations which is what Django recommended in 2014.

2.1.2 Implementation

Fernet is built on top of a number of standard cryptographic primitives. Specifically it uses:

- **AES** in **CBC** mode with a 128-bit key for encryption; using **PKCS7** padding.
- **HMAC** using **SHA256** for authentication.
- Initialization vectors are generated using **os.urandom()**.

For complete details consult the specification.

2.1.3 Limitations

Fernet is ideal for encrypting data that easily fits in memory. As a design feature it does not expose unauthenticated bytes. Unfortunately, this makes it generally unsuitable for very large files at this time.
2.2 X.509

X.509 is an ITU-T standard for a public key infrastructure. X.509v3 is defined in RFC 5280 (which obsoletes RFC 2459 and RFC 3280). X.509 certificates are commonly used in protocols like TLS.

2.2.1 Tutorial

X.509 certificates are used to authenticate clients and servers. The most common use case is for web servers using HTTPS.

Creating a Certificate Signing Request (CSR)

When obtaining a certificate from a certificate authority (CA), the usual flow is:

1. You generate a private/public key pair.
2. You create a request for a certificate, which is signed by your key (to prove that you own that key).
3. You give your CSR to a CA (but not the private key).
4. The CA validates that you own the resource (e.g. domain) you want a certificate for.
5. The CA gives you a certificate, signed by them, which identifies your public key, and the resource you are authenticated for.
6. You configure your server to use that certificate, combined with your private key, to server traffic.

If you want to obtain a certificate from a typical commercial CA, here’s how. First, you’ll need to generate a private key, we’ll generate an RSA key (these are the most common types of keys on the web right now):

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import serialization
>>> from cryptography.hazmat.primitives.asymmetric import rsa

>>> # Generate our key
>>> key = rsa.generate_private_key(  
...     public_exponent=65537,  
...     key_size=2048,  
...     backend=default_backend()  
... )

>>> # Write our key to disk for safe keeping
>>> with open("path/to/store/key.pem", "wb") as f:
...     f.write(key.private_bytes(  
...         encoding=serialization.Encoding.PEM,  
...         format=serialization.PrivateFormat.TraditionalOpenSSL,  
...         encryption_algorithm=serialization.BestAvailableEncryption(b"passphrase"),  
...     ))
```

If you’ve already generated a key you can load it with `load_pem_private_key()`.

Next we need to generate a certificate signing request. A typical CSR contains a few details:

- Information about our public key (including a signature of the entire body).
- Information about who we are.
- Information about what domains this certificate is for.
>>> from cryptography import x509
>>> from cryptography.x509.oid import NameOID
>>> from cryptography.hazmat.primitives import hashes

>>> # Generate a CSR
>>> csr = x509.CertificateSigningRequestBuilder().subject_name(x509.Name([...
...     # Provide various details about who we are.
...     x509.NameAttribute(NameOID.COUNTRY_NAME, u"US"),
...     x509.NameAttribute(NameOID.STATE_OR_PROVINCE_NAME, u"California"),
...     x509.NameAttribute(NameOID.LOCALITY_NAME, u"San Francisco"),
...     x509.NameAttribute(NameOID.ORGANIZATION_NAME, u"My Company"),
...     x509.NameAttribute(NameOID.COMMON_NAME, u"mysite.com"),
... ])).add_extension(
...     x509.SubjectAlternativeName([...
...         # Describe what sites we want this certificate for.
...         x509.DNSName(u"mysite.com"),
...         x509.DNSName(u"www.mysite.com"),
...         x509.DNSName(u"subdomain.mysite.com"),
...     ]),
...     critical=False,
... ).sign(key, hashes.SHA256(), default_backend())

>>> # Write our CSR out to disk.
>>> with open("path/to/csr.pem", "wb") as f:
...     f.write(csr.public_bytes(serialization.Encoding.PEM))

Now we can give our CSR to a CA, who will give a certificate to us in return.

Creating a self-signed certificate

While most of the time you want a certificate that has been signed by someone else (i.e. a certificate authority), so that trust is established, sometimes you want to create a self-signed certificate. Self-signed certificates are not issued by a certificate authority, but instead they are signed by the private key corresponding to the public key they embed.

This means that other people don’t trust these certificates, but it also means they can be issued very easily. In general the only use case for a self-signed certificate is local testing, where you don’t need anyone else to trust your certificate.

Like generating a CSR, we start with creating a new private key:

```python
>>> # Generate our key
>>> key = rsa.generate_private_key(
...     public_exponent=65537,
...     key_size=2048,
...     backend=default_backend()
... )

>>> # Write our key to disk for safe keeping
>>> with open("path/to/store/key.pem", "wb") as f:
...     f.write(key.private_bytes(
...         encoding=serialization.Encoding.PEM,
...         format=serialization.PrivateFormat.TraditionalOpenSSL,
...         encryption_algorithm=serialization.BestAvailableEncryption(b"passphrase"),
...     ))
```

Then we generate the certificate itself:

```python
>>> # Various details about who we are. For a self-signed certificate the
>>> # subject and issuer are always the same.
>>> subject = issuer = x509.Name([...
...     # (continues on next page)
```
And now we have a private key and certificate that can be used for local testing.

## Determining Certificate or Certificate Signing Request Key Type

Certificates and certificate signing requests can be issued with multiple key types. You can determine what the key type is by using `isinstance` checks:

```python
>>> public_key = cert.public_key()
>>> if isinstance(public_key, rsa.RSAPublicKey):
... # Do something RSA specific
>>> elif isinstance(public_key, ec.EllipticCurvePublicKey):
... # Do something EC specific
>>> else:
... # Remember to handle this case
```

### 2.2.2 Certificate Transparency

Certificate Transparency is a set of protocols specified in [RFC 6962](https://tools.ietf.org/html/rfc6962) which allow X.509 certificates to be sent to append-only logs and have small cryptographic proofs that a certificate has been publicly logged. This allows for external auditing of the certificates that a certificate authority has issued.

```python
class cryptography.x509.certificate_transparency.SignedCertificateTimestamp
New in version 2.0.
```

SignedCertificateTimestamps (SCTs) are small cryptographically signed assertions that the specified certificate has been submitted to a Certificate Transparency Log, and that it will be part of the public log within some time period, this is called the “maximum merge delay” (MMD) and each log specifies its own.
version

Type Version

The SCT version as an enumeration. Currently only one version has been specified.

log_id

Type bytes

An opaque identifier, indicating which log this SCT is from. This is the SHA256 hash of the log’s public key.

timestamp

Type datetime.datetime

A naïve datetime representing the time in UTC at which the log asserts the certificate had been submitted to it.

entry_type

Type LogEntryType

The type of submission to the log that this SCT is for. Log submissions can either be certificates themselves or “pre-certificates” which indicate a binding-intent to issue a certificate for the same data, with SCTs embedded in it.

class cryptography.x509.certificate_transparency.Version

New in version 2.0.

An enumeration for SignedCertificateTimestamp versions.

v1

For version 1 SignedCertificateTimestamps.

class cryptography.x509.certificate_transparency.LogEntryType

New in version 2.0.

An enumeration for SignedCertificateTimestamp log entry types.

X509_CERTIFICATE

For SCTs corresponding to X.509 certificates.

PRE_CERTIFICATE

For SCTs corresponding to pre-certificates.

2.2.3 OCSP

OCSP (Online Certificate Status Protocol) is a method of checking the revocation status of certificates. It is specified in RFC 6960, as well as other obsoleted RFCs.

Loading Requests

cryptography.x509.ocsp.load_der_ocsp_request(data)

New in version 2.4.

Deserialize an OCSP request from DER encoded data.

Parameters data (bytes) – The DER encoded OCSP request data.

Returns An instance of OCSPRequest.
Creating Requests

class cryptography.x509.ocsp.OCSPRequestBuilder

New in version 2.4.

This class is used to create OCSPRequest objects.

add_certificate(cert, issuer, algorithm)

Adds a request using a certificate, issuer certificate, and hash algorithm. This can only be called once.

Parameters

- cert – The Certificate whose validity is being checked.
- issuer – The issuer Certificate of the certificate that is being checked.
- algorithm – A HashAlgorithm instance. For OCSP only SHA1, SHA224, SHA256, SHA384, and SHA512 are allowed.

add_extension(extension, critical)

Adds an extension to the request.

Parameters

- extension – An extension conforming to the ExtensionType interface.
- critical – Set to True if the extension must be understood and handled.

build()

Returns A new OCSPRequest.

Loading Responses

cryptography.x509.ocsp.load_der_ocsp_response(data)

New in version 2.4.

Deserialize an OCSP response from DER encoded data.

Parameters data(bytes) – The DER encoded OCSP response data.
Returns An instance of `OCSPResponse`.

```python
>>> from cryptography.x509 import ocsp
>>> ocsp_resp = ocsp.load_der_ocsp_response(der_ocsp_resp_unauth)
>>> print(ocsp_resp.response_status)
OCSPResponseStatus.UNAUTHORIZED
```

### Creating Responses

**class** `cryptography.x509.ocsp.OCSPResponseBuilder`

New in version 2.4.

This class is used to create `OCSPResponse` objects. You cannot set `produced_at` on OCSP responses at this time. Instead the field is set to current UTC time when calling `sign`. For unsuccessful statuses call the class method `build_unsuccessful()`.

**add_response**

```
add_response(cert, issuer, algorithm, cert_status, this_update, next_update, revocation_time, revocation_reason)
```

This method adds status information about the certificate that was requested to the response.

**Parameters**

- `cert` – The `Certificate` whose validity is being checked.
- `issuer` – The issuer `Certificate` of the certificate that is being checked.
- `algorithm` – A `HashAlgorithm` instance. For OCSP only `SHA1`, `SHA224`, `SHA256`, `SHA384`, and `SHA512` are allowed.
- `cert_status` – An item from the `OCSPCertStatus` enumeration.
- `this_update` – A naïve `datetime.datetime` object representing the most recent time in UTC at which the status being indicated is known by the responder to be correct.
- `next_update` – A naïve `datetime.datetime` object or `None`. The time in UTC at or before which newer information will be available about the status of the certificate.
- `revocation_time` – A naïve `datetime.datetime` object or `None` if the `cert` is not revoked. The time in UTC at which the certificate was revoked.
- `revocation_reason` – An item from the `ReasonFlags` enumeration or `None` if the `cert` is not revoked.

**certificates**

```
certificates(certs)
```

Add additional certificates that should be used to verify the signature on the response. This is typically used when the responder utilizes an OCSP delegate.

**Parameters**

- `certs` – A list of `Certificate` objects.

**responder_id**

```
responder_id(encoding, responder_cert)
```

Set the responderID on the OCSP response. This is the data a client will use to determine what certificate signed the response.

**Parameters**

- `responder_cert` – The `Certificate` object for the certificate whose private key will sign the OCSP response. If the certificate and key do not match an error will be raised when calling `sign`.
- `encoding` – Either `HASH` or `NAME`.

**add_extension**

```
add_extension(extension, critical)
```

Adds an extension to the response.
Parameters

- **extension** – An extension conforming to the `ExtensionType` interface.
- **critical** – Set to `True` if the extension must be understood and handled.

**sign** *(private_key, algorithm)*

Creates the OCSP response that can then be serialized and sent to clients. This method will create a `SUCCESSFUL` response.

Parameters

- **private_key** – The `RSAPrivateKey` or `EllipticCurvePrivateKey` that will be used to sign the certificate.
- **algorithm** – The `HashAlgorithm` that will be used to generate the signature.

Returns A new `OCSPResponse`.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes, serialization
>>> cert = load_pem_x509_certificate(pem_cert, default_backend())
>>> issuer = load_pem_x509_certificate(pem_issuer, default_backend())
>>> responder_cert = load_pem_x509_certificate(pem_responder_cert, default_backend())
>>> responder_key = serialization.load_pem_private_key(pem_responder_key, None, default_backend())
>>> builder = ocsp.OCSPResponseBuilder()
>>> # SHA1 is in this example because RFC 5019 mandates its use.
>>> builder = builder.add_response(
...     cert=cert, issuer=issuer, algorithm=hashes.SHA1(),
...     cert_status=ocsp.OCSPCertStatus.GOOD,
...     this_update=datetime.datetime.now(),
...     next_update=datetime.datetime.now(),
...     revocation_time=None, revocation_reason=None
... ).responder_id(
...     ocsp.OCSPResponderEncoding.HASH, responder_cert
... )
>>> response = builder.sign(responder_key, hashes.SHA256())
>>> response.certificate_status
<OCSPCertStatus.GOOD: 0>
```

classmethod **build_unsuccessful** *(response_status)*

Creates an unsigned OCSP response which can then be serialized and sent to clients. `build_unsuccessful` may only be called with a `OCSPResponseStatus` that is not `SUCCESSFUL`. Since this is a class method note that no other methods can or should be called as unsuccessful statuses do not encode additional data.

Returns A new `OCSPResponse`.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes, serialization
>>> response = ocsp.OCSPResponseBuilder.build_unsuccessful(
...     ocsp.OCSPResponseStatus.UNAUTHORIZED
... )
>>> response.response_status
<OCSPResponseStatus.UNAUTHORIZED: 6>
```
Interfaces

class cryptography.x509.ocsp.OCSPRequest
New in version 2.4.

An OCSPRequest is an object containing information about a certificate whose status is being checked.

issuer_key_hash
Type bytes
The hash of the certificate issuer’s key. The hash algorithm used is defined by the hash_algorithm property.

issuer_name_hash
Type bytes
The hash of the certificate issuer’s name. The hash algorithm used is defined by the hash_algorithm property.

hash_algorithm
Type HashAlgorithm
The algorithm used to generate the issuer_key_hash and issuer_name_hash.

serial_number
Type int
The serial number of the certificate to check.

extensions
Type Extensions
The extensions encoded in the request.

public_bytes(encoding)
Parameters encoding – The encoding to use. Only DER is supported.
Return bytes The serialized OCSP request.

class cryptography.x509.ocsp.OCSPResponse
New in version 2.4.

An OCSPResponse is the data provided by an OCSP responder in response to an OCSPRequest.

response_status
Type OCSPResponseStatus
The status of the response.

signature_algorithm_oid
Type ObjectIdentifier
Returns the object identifier of the signature algorithm used to sign the response. This will be one of the OIDs from SignatureAlgorithmOID.

Raises ValueError – If response_status is not SUCCESSFUL.

signature_hash_algorithm
New in version 2.5.
Type HashAlgorithm
Returns the HashAlgorithm which was used in signing this response.

**signature**

* Type bytes
  - The signature bytes.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**tbs_response_bytes**

* Type bytes
  - The DER encoded bytes payload that is hashed and then signed. This data may be used to validate the signature on the OCSP response.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**certificates**

* Type list
  - A list of zero or more Certificate objects used to help build a chain to verify the OCSP response. This situation occurs when the OCSP responder uses a delegate certificate.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**responder_key_hash**

* Type bytes or None
  - The responder’s key hash or None if the response has a responder_name.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**responder_name**

* Type Name or None
  - The responder’s Name or None if the response has a responder_key_hash.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**produced_at**

* Type datetime.datetime
  - A naïve datetime representing the time when the response was produced.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**certificate_status**

* Type OCSPCertStatus
  - The status of the certificate being checked.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**revocation_time**

* Type datetime.datetime or None
  - A naïve datetime representing the time when the certificate was revoked or None if the certificate has not been revoked.
  - Raises ValueError – If response_status is not SUCCESSFUL.

**revocation_reason**
Type `ReasonFlags` or None

The reason the certificate was revoked or None if not specified or not revoked.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`this_update`

Type `datetime.datetime`

A naïve datetime representing the most recent time at which the status being indicated is known by the responder to have been correct.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`next_update`

Type `datetime.datetime`

A naïve datetime representing the time when newer information will be available.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`issuer_key_hash`

Type `bytes`

The hash of the certificate issuer’s key. The hash algorithm used is defined by the `hash_algorithm` property.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`issuer_name_hash`

Type `bytes`

The hash of the certificate issuer’s name. The hash algorithm used is defined by the `hash_algorithm` property.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`hash_algorithm`

Type `HashAlgorithm`

The algorithm used to generate the `issuer_key_hash` and `issuer_name_hash`.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`serial_number`

Type `int`

The serial number of the certificate that was checked.

Raises `ValueError` – If `response_status` is not `SUCCESSFUL`.

`extensions`

Type `Extensions`

The extensions encoded in the response.

`public_bytes` *(encoding)*

Parameters `encoding` – The encoding to use. Only `DER` is supported.

Return `bytes` The serialized OCSP response.
class cryptography.x509.ocsp.OCSPResponseStatus
New in version 2.4.
An enumeration of response statuses.

SUCCESSFUL
Represents a successful OCSP response.

MALFORMED_REQUEST
May be returned by an OCSP responder that is unable to parse a given request.

INTERNAL_ERROR
May be returned by an OCSP responder that is currently experiencing operational problems.

TRY_LATER
May be returned by an OCSP responder that is overloaded.

SIG_REQUIRED
May be returned by an OCSP responder that requires signed OCSP requests.

UNAUTHORIZED
May be returned by an OCSP responder when queried for a certificate for which the responder is unaware
or an issuer for which the responder is not authoritative.

class cryptography.x509.ocsp.OCSPCertStatus
New in version 2.4.
An enumeration of certificate statuses in an OCSP response.

GOOD
The value for a certificate that is not revoked.

REVOKED
The certificate being checked is revoked.

UNKNOWN
The certificate being checked is not known to the OCSP responder.

class cryptography.x509.ocsp.OCSPResponderEncoding
New in version 2.4.
An enumeration of responderID encodings that can be passed to responder_id().

HASH
Encode the hash of the public key whose corresponding private key signed the response.

NAME
Encode the X.509 Name of the certificate whose private key signed the response.

2.2.4 X.509 Reference

Loading Certificates

cryptography.x509.load_pem_x509_certificate(data, backend)
New in version 0.7.
Deserialze a certificate from PEM encoded data. PEM certificates are base64 decoded and have delimiters that
look like -----BEGIN CERTIFICATE-----.

Parameters
- data (bytes) – The PEM encoded certificate data.
• **backend** – A backend supporting the `X509Backend` interface.

**Returns**  An instance of `Certificate`.

```python
>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> cert = x509.load_pem_x509_certificate(pem_data, default_backend())
>>> cert.serial_number
2
```

**cryptography.x509.load_der_x509_certificate** (*data, backend*)

New in version 0.7.

Deserialize a certificate from DER encoded data. DER is a binary format and is commonly found in files with the `.cer` extension (although file extensions are not a guarantee of encoding type).

**Parameters**

- **data** *(bytes)* – The DER encoded certificate data.
- **backend** – A backend supporting the `X509Backend` interface.

**Returns**  An instance of `Certificate`.

**Loading Certificate Revocation Lists**

**cryptography.x509.load_pem_x509_crl** (*data, backend*)

New in version 1.1.

Deserialize a certificate revocation list (CRL) from PEM encoded data. PEM requests are base64 decoded and have delimiters that look like `-----BEGIN X509 CRL-----`.

**Parameters**

- **data** *(bytes)* – The PEM encoded request data.
- **backend** – A backend supporting the `X509Backend` interface.

**Returns**  An instance of `CertificateRevocationList`.

```python
>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes

>>> crl = x509.load_pem_x509_crl(pem_crl_data, default_backend())
>>> isinstance(crl.signature_hash_algorithm, hashes.SHA256)
True
```

**cryptography.x509.load_der_x509_crl** (*data, backend*)

New in version 1.1.

Deserialize a certificate revocation list (CRL) from DER encoded data. DER is a binary format.

**Parameters**

- **data** *(bytes)* – The DER encoded request data.
- **backend** – A backend supporting the `X509Backend` interface.

**Returns**  An instance of `CertificateRevocationList`.
Loading Certificate Signing Requests

cryptography.x509.load_pem_x509_csr(data, backend)

New in version 0.9.

Deserialize a certificate signing request (CSR) from PEM encoded data. PEM requests are base64 decoded and have delimiters that look like -----BEGIN CERTIFICATE REQUEST-----. This format is also known as PKCS#10.

Parameters

• **data (bytes)** – The PEM encoded request data.

• **backend** – A backend supporting the X509Backend interface.

Returns An instance of CertificateSigningRequest.

```python
>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes

>>> csr = x509.load_pem_x509_csr(pem_req_data, default_backend())
>>> isinstance(csr.signature_hash_algorithm, hashes.SHA1)
True
```

cryptography.x509.load_der_x509_csr(data, backend)

New in version 0.9.

Deserialize a certificate signing request (CSR) from DER encoded data. DER is a binary format and is not commonly used with CSRs.

Parameters

• **data (bytes)** – The DER encoded request data.

• **backend** – A backend supporting the X509Backend interface.

Returns An instance of CertificateSigningRequest.

X.509 Certificate Object

class cryptography.x509.Certificate

New in version 0.7.

version

Type Version

The certificate version as an enumeration. Version 3 certificates are the latest version and also the only type you should see in practice.

Raises cryptography.x509.InvalidVersion – If the version in the certificate is not a known X.509 version.

```python
>>> cert.version
<Version.v3: 2>
```

fingerprint(algorithm)

Parameters **algorithm** – The HashAlgorithm that will be used to generate the fingerprint.

Return bytes The fingerprint using the supplied hash algorithm, as bytes.
```python
>>> from cryptography.hazmat.primitives import hashes
>>> cert.fingerprint(hashes.SHA256())
b\x86\xd2\x18\x7G\xcfc\xe7\x8d\xb4\xe5S\xda\x18\xbe\xa04?

serial_number

    Type int
    The serial as a Python integer.

>>> cert.serial_number
2

public_key()

    The public key associated with the certificate.

    Returns RSAPublicKey or DSAPublicKey or EllipticCurvePublicKey

>>> from cryptography.hazmat.primitives.asymmetric import rsa
>>> public_key = cert.public_key()
>>> isinstance(public_key, rsa.RSAPublicKey)
True

not_valid_before

    Type datetime.datetime
    A naïve datetime representing the beginning of the validity period for the certificate in UTC. This value is inclusive.

>>> cert.not_valid_before
datetime.datetime(2010, 1, 1, 8, 30)

not_valid_after

    Type datetime.datetime
    A naïve datetime representing the end of the validity period for the certificate in UTC. This value is inclusive.

>>> cert.not_valid_after
datetime.datetime(2030, 12, 31, 8, 30)

issuer

    New in version 0.8.

    Type Name
    The Name of the issuer.

subject

    New in version 0.8.

    Type Name
    The Name of the subject.

signature_hash_algorithm

    Type HashAlgorithm
    Returns the HashAlgorithm which was used in signing this certificate.
```python
>>> from cryptography.hazmat.primitives import hashes
>>> isinstance(cert.signature_hash_algorithm, hashes.SHA256)
True
```

**signature_algorithm_oid**

New in version 1.6.

**Type** ObjectIdentifier

Returns the ObjectIdentifier of the signature algorithm used to sign the certificate. This will be one of the OIDs from SignatureAlgorithmOID.

```python
>>> cert.signature_algorithm_oid
<ObjectIdentifier(oid=1.2.840.113549.1.1.11, name=sha256WithRSAEncryption)>
```

**extensions**

**Type** Extensions

The extensions encoded in the certificate.

**Raises**

- cryptography.x509.DuplicateExtension – If more than one extension of the same type is found within the certificate.
- cryptography.x509.UnsupportedGeneralNameType – If an extension contains a general name that is not supported.
- UnicodeError – If an extension contains IDNA encoding that is invalid or not compliant with IDNA 2008.

```python
>>> for ext in cert.extensions:
...     print(ext)
<Extension(oid=<ObjectIdentifier(oid=2.5.29.35, name=authorityKeyIdentifier)>,
  critical=False, value=<AuthorityKeyIdentifier(key_identifier=b'\xe4\x}\xd1\x95\x86\x08,\x05\xae\xb6e\xa7\xd9\xa8f',
     authority_cert_issuer=None, authority_cert_serial_number=None)>)>
<Extension(oid=<ObjectIdentifier(oid=2.5.29.14, name=subjectKeyIdentifier)>,
  critical=False, value=<SubjectKeyIdentifier(digest=b'X\x01\x84\$\x1b\xbc+R\x94J=\xa5\x10r\x14Q\xdf:\xc9')>)>
<Extension(oid=<ObjectIdentifier(oid=2.5.29.15, name=keyUsage)>,
  critical=True, value=<KeyUsage(digital_signature=False, content_commitment=False, key_encipherment=False, data_encipherment=False, key_agreement=False, key_cert_sign=True, crl_sign=True, encipher_only=None, decipher_only=None)>)>
<Extension(oid=<ObjectIdentifier(oid=2.5.29.32, name=certificatePolicies)>,
  critical=False, value=<CertificatePolicies([<PolicyInformation(policy_identifier=<ObjectIdentifier(oid=2.16.840.1.101.3.2.1.48.1, name=Unknown_OID)>, policy_qualifiers=None)>)])>
<Extension(oid=<ObjectIdentifier(oid=2.5.29.19, name=basicConstraints)>,
  critical=True, value=<BasicConstraints(ca=False, path_length=None)>)>
```

**signature**

New in version 1.2.

**Type** bytes

The bytes of the certificate’s signature.
**tbs_certificate_bytes**
New in version 1.2.

**Type** bytes

The DER encoded bytes payload (as defined by [RFC 5280](https://tools.ietf.org/html/rfc5280)) that is hashed and then signed by the private key of the certificate’s issuer. This data may be used to validate a signature, but use extreme caution as certificate validation is a complex problem that involves much more than just signature checks.

To validate the signature on a certificate you can do the following. Note: This only verifies that the certificate was signed with the private key associated with the public key provided and does not perform any of the other checks needed for secure certificate validation. Additionally, this example will only work for RSA public keys with PKCS1v15 signatures, and so it can’t be used for general purpose signature verification.

```python
>>> from cryptography.hazmat.primitives.serialization import load_pem_public_key
>>> from cryptography.hazmat.primitives.asymmetric import padding
>>> issuer_public_key = load_pem_public_key(pem_issuer_public_key, default_backend())
>>> cert_to_check = x509.load_pem_x509_certificate(pem_data_to_check, default_backend())
>>> issuer_public_key.verify(...    cert_to_check.signature,
...    cert_to_check.tbs_certificate_bytes,
...    # Depends on the algorithm used to create the certificate
...    padding.PKCS1v15(),
...    cert_to_check.signature_hash_algorithm,
...)
```

An :class:`cryptography.exceptions.InvalidSignature` exception will be raised if the signature fails to verify.

**public_bytes(encoding)**
New in version 1.0.

**Parameters** encoding – The Encoding that will be used to serialize the certificate.

**Return** bytes The data that can be written to a file or sent over the network to be verified by clients.

**X.509 CRL (Certificate Revocation List) Object**

**class** cryptography.x509.CertificateRevocationList
New in version 1.0.

A CertificateRevocationList is an object representing a list of revoked certificates. The object is iterable and will yield the RevokedCertificate objects stored in this CRL.

```python
>>> len(crl)
1
>>> revoked_certificate = crl[0]
>>> type(revoked_certificate)
<class 'cryptography.hazmat.backends.openssl.x509._RevokedCertificate'>
>>> for r in crl:
...    print(r.serial_number)
0
```
**fingerprint(algorithm)**

**Parameters** algorithm – The HashAlgorithm that will be used to generate the fingerprint.

**Return bytes** The fingerprint using the supplied hash algorithm, as bytes.

```python
>>> from cryptography.hazmat.primitives import hashes
>>> crl.fingerprint(hashes.SHA256())
b'e\xcf.\xc4:\x83?1\xd7\xb3\x87\xb3\xe8\xb93!
˓
→\x87\x07\x9d\xb4\xe4W\xf4\xlf'
```

**get_revoked_certificate_by_serial_number(serial_number)**

New in version 2.3.

**Parameters** serial_number – The serial as a Python integer.

**Returns** RevokedCertificate if the serial_number is present in the CRL or None if it is not.

**signature_hash_algorithm**

**Type** HashAlgorithm

**Returns** the HashAlgorithm which was used in signing this CRL.

```python
>>> from cryptography.hazmat.primitives import hashes
>>> isinstance(crl.signature_hash_algorithm, hashes.SHA256)
True
```

**signature_algorithm_oid**

New in version 1.6.

**Type** ObjectIdentifier

**Returns** the ObjectIdentifier of the signature algorithm used to sign the CRL. This will be one of the OIDs from SignatureAlgorithmOID.

```python
>>> crl.signature_algorithm_oid
<ObjectIdentifier(oid=1.2.840.113549.1.1.11, name=sha256WithRSAEncryption)>
```

**issuer**

**Type** Name

The Name of the issuer.

```python
>>> crl.issuer
{Name(C=US,CN=cryptography.io)}
```

**next_update**

**Type** datetime.datetime

A naïve datetime representing when the next update to this CRL is expected.

```python
>>> crl.next_update
datetime.datetime(2016, 1, 1, 0, 0)
```

**last_update**

**Type** datetime.datetime

A naïve datetime representing when this CRL was last updated.
extensions
  Type Extensions
  The extensions encoded in the CRL.

signature
  New in version 1.2.
  Type bytes
  The bytes of the CRL's signature.

tbs_certlist_bytes
  New in version 1.2.
  Type bytes
  The DER encoded bytes payload (as defined by RFC 5280) that is hashed and then signed by the private key of the CRL's issuer. This data may be used to validate a signature, but use extreme caution as CRL validation is a complex problem that involves much more than just signature checks.

public_bytes(encoding)
  New in version 1.2.
  Parameters encoding – The Encoding that will be used to serialize the certificate revocation list.
  Return bytes The data that can be written to a file or sent over the network and used as part of a certificate verification process.

is_signature_valid(public_key)
  New in version 2.1.

  Warning: Checking the validity of the signature on the CRL is insufficient to know if the CRL should be trusted. More details are available in RFC 5280.

Returns True if the CRL signature is correct for given public key, False otherwise.

X.509 Certificate Builder

class cryptography.x509.CertificateBuilder
  New in version 1.0.

  >>> from cryptography import x509
  >>> from cryptography.hazmat.backends import default_backend
  >>> from cryptography.hazmat.primitives import hashes
  >>> from cryptography.hazmat.primitives.asymmetric import rsa
  >>> from cryptography.x509.oid import NameOID
  >>> import datetime
  >>> one_day = datetime.timedelta(1, 0, 0)
  >>> private_key = rsa.generate_private_key(...  public_exponent=65537,
  ...  key_size=2048,
  ...  backend=default_backend())

(continues on next page)
```python
public_key = private_key.public_key()

builder = x509.CertificateBuilder()
builder = builder.subject_name(x509.Name([
    x509.NameAttribute(NameOID.COMMON_NAME, u'cryptography.io'),
    ...
]))
builder = builder.issuer_name(x509.Name([
    x509.NameAttribute(NameOID.COMMON_NAME, u'cryptography.io'),
    ...
]))
builder = builder.not_valid_before(datetime.datetime.today() - one_day)
builder = builder.not_valid_after(datetime.datetime.today() + (one_day * 30))
builder = builder.serial_number(x509.random_serial_number())
builder = builder.public_key(public_key)
builder = builder.add_extension(
    x509.SubjectAlternativeName([x509.DNSName(u'cryptography.io')]),
    critical=False
)
builder = builder.add_extension(
    x509.BasicConstraints(ca=False, path_length=None), critical=True,
)

certificate = builder.sign(
    private_key=private_key, algorithm=hashes.SHA256(),
    backend=default_backend()
)
isinstance(certificate, x509.Certificate)
True
```

**issuer_name** *(name)*

Sets the issuer’s distinguished name.

**Parameters**

- **name** – The *Name* that describes the issuer (CA).

**subject_name** *(name)*

Sets the subject’s distinguished name.

**Parameters**

- **name** – The *Name* that describes the subject.

**public_key** *(public_key)*

Sets the subject’s public key.

**Parameters**

- **public_key** – The subject’s public key. This can be one of *RSA*\Public*Key*, *DSAPublicKey* or *EllipticCurvePublic*Key

**serial_number** *(serial_number)*

Sets the certificate’s serial number (an integer). The CA’s policy determines how it attributes serial numbers to certificates. This number must uniquely identify the certificate given the issuer. CABForum Guidelines require entropy in the serial number to provide protection against hash collision attacks. For more information on secure random number generation, see Random number generation.

**Parameters**

- **serial_number** – Integer number that will be used by the CA to identify this certificate (most notably during certificate revocation checking). Users should consider using *random_serial_number()* when possible.

**not_valid_before** *(time)*

Sets the certificate’s activation time. This is the time from which clients can start trusting the certificate. It may be different from the time at which the certificate was created.
Parameters `time` - The `datetime.datetime` object (in UTC) that marks the activation time for the certificate. The certificate may not be trusted clients if it is used before this time.

`not_valid_after` *(time)*
Sets the certificate’s expiration time. This is the time from which clients should no longer trust the certificate. The CA’s policy will determine how long the certificate should remain in use.

Parameters `time` - The `datetime.datetime` object (in UTC) that marks the expiration time for the certificate. The certificate may not be trusted clients if it is used after this time.

`add_extension` *(extension, critical)*
Adds an X.509 extension to the certificate.

Parameters
- `extension` – An extension conforming to the `ExtensionType` interface.
- `critical` – Set to `True` if the extension must be understood and handled by whoever reads the certificate.

`sign` *(private_key, algorithm, backend)*
Sign the certificate using the CA’s private key.

Parameters
- `private_key` – The `RSAPrivateKey`, `DSAPrivateKey` or `EllipticCurvePrivateKey` that will be used to sign the certificate.
- `algorithm` – The `HashAlgorithm` that will be used to generate the signature.
- `backend` – Backend that will be used to build the certificate. Must support the `X509Backend` interface.

Returns `Certificate`

**X.509 CSR (Certificate Signing Request) Object**

class `cryptography.x509.CertificateSigningRequest`

New in version 0.9.

`public_key`()
The public key associated with the request.

Returns `RSAPublicKey` or `DSAPublicKey` or `EllipticCurvePublicKey`

```python
>>> from cryptography.hazmat.primitives.asymmetric import rsa
>>> public_key = csr.public_key()
>>> isinstance(public_key, rsa.RSAPublicKey)
True
```

`subject`

Type `Name`
The `Name` of the subject.

`signature_hash_algorithm`

Type `HashAlgorithm`
Returns the `HashAlgorithm` which was used in signing this request.
```python
>>> from cryptography.hazmat.primitives import hashes
>>> isinstance(csr.signature_hash_algorithm, hashes.SHA1)
True
```

**signature_algorithm_oid**

New in version 1.6.

**Type** ObjectIdentifier

Returns the ObjectIdentifier of the signature algorithm used to sign the request. This will be one of the OIDs from SignatureAlgorithmOID.

```python
>>> csr.signature_algorithm_oid
<ObjectIdentifier(oid=1.2.840.113549.1.1.5, name=sha1WithRSAEncryption)>  
```

**extensions**

**Type** Extensions

The extensions encoded in the certificate signing request.

**Raises**

- cryptography.x509.DuplicateExtension – If more than one extension of the same type is found within the certificate signing request.
- cryptography.x509.UnsupportedGeneralNameType – If an extension contains a general name that is not supported.
- UnicodeError – If an extension contains IDNA encoding that is invalid or not compliant with IDNA 2008.

**public_bytes** *(encoding)*

New in version 1.0.

**Parameters** encoding – The Encoding that will be used to serialize the certificate request.

**Return** bytes The data that can be written to a file or sent over the network to be signed by the certificate authority.

**signature**

New in version 1.2.

**Type** bytes

The bytes of the certificate signing request’s signature.

**tbs_certrequest_bytes**

New in version 1.2.

**Type** bytes

The DER encoded bytes payload (as defined by RFC 2986) that is hashed and then signed by the private key (corresponding to the public key embedded in the CSR). This data may be used to validate the CSR signature.

**is_signature_valid**

New in version 1.3.

Returns True if the CSR signature is correct, False otherwise.
**X.509 Certificate Revocation List Builder**

```python
certificate_revocation_list_builder = builder.issuer_name(x509.Name([... x509.NameAttribute(NameOID.COMMON_NAME, u'cryptography.io CA'), ... ]))
certificate_revocation_list_builder = builder.last_update(datetime.datetime.today())
certificate_revocation_list_builder = builder.next_update(datetime.datetime.today() + one_day)
revoked_certificate_builder = x509.RevokedCertificateBuilder().serial_number(333)
revoked_certificate_builder = revoked_certificate_builder.revocation_date(datetime.datetime.today()).build(default_backend())
builder = builder.add_revoked_certificate(revoked_certificate_builder)
```  

```python
certificate_revocation_list_builder = builder.sign(
    private_key=private_key, algorithm=hashes.SHA256(),
    backend=default_backend())
```  

```python
certificate_revocation_list_builder = builder.sign(
    private_key=private_key, algorithm=hashes.SHA256(),
    backend=default_backend())
```  

```python
len(certificate_revocation_list_builder)
```  

 Issuer Name

Sets the issuer’s distinguished name.

**Parameters**

- **name** – The Name that describes the issuer (CA).

Last Update

Sets this CRL’s activation time. This is the time from which clients can start trusting this CRL. It may be different from the time at which this CRL was created. This is also known as the thisUpdate time.

**Parameters**

- **time** – The datetime.datetime object (in UTC) that marks the activation time for this CRL. The CRL may not be trusted if it is used before this time.

Next Update

Sets this CRL’s next update time. This is the time by which a new CRL will be issued. The CA is allowed to issue a new CRL before this date, however clients are not required to check for it.

**Parameters**

- **time** – The datetime.datetime object (in UTC) that marks the next update time for this CRL.

Add Extension

Adds an X.509 extension to this CRL.

**Parameters**

- **extension** – An extension with the ExtensionType interface.
• **critical** – Set to `True` if the extension must be understood and handled by whoever reads the CRL.

```python
add_revoked_certificate(revoked_certificate)
```

Adds a revoked certificate to this CRL.

**Parameters**

• `revoked_certificate` – An instance of `RevokedCertificate`. These can be obtained from an existing CRL or created with `RevokedCertificateBuilder`.

```python
sign(private_key, algorithm, backend)
```

Sign this CRL using the CA’s private key.

**Parameters**

• `private_key` – The `RSAPrivateKey`, `DSAPrivateKey` or `EllipticCurvePrivateKey` that will be used to sign the certificate.

• `algorithm` – The `HashAlgorithm` that will be used to generate the signature.

• `backend` – Backend that will be used to build the CRL. Must support the `X509Backend` interface.

Returns `CertificateRevocationList`

### X.509 Revoked Certificate Object

```python
class cryptography.x509.RevokedCertificate
```

New in version 1.0.

**serial_number**

Type `int`

An integer representing the serial number of the revoked certificate.

```python
>>> revoked_certificate.serial_number
0
```

**revocation_date**

Type `datetime.datetime`

A naïve datetime representing the date this certificates was revoked.

```python
>>> revoked_certificate.revocation_date
datetime.datetime(2015, 1, 1, 0, 0)
```

**extensions**

Type `Extensions`

The extensions encoded in the revoked certificate.

```python
>>> for ext in revoked_certificate.extensions:
...     print(ext)
<Extension(oid=<ObjectIdentifier(oid=2.5.29.24, name=invalidityDate)>,
    critical=False, value=<InvalidityDate(invalidity_date=2015-01-01 00:00:00)>
    )>
<Extension(oid=<ObjectIdentifier(oid=2.5.29.21, name=cRLReason)>,
    critical=False, value=<CRLReason(reason=ReasonFlags.key_compromise)>)>
```
X.509 Revoked Certificate Builder

class cryptography.x509.RevokedCertificateBuilder

This class is used to create RevokedCertificate objects that can be used with the CertificateRevocationListBuilder.

New in version 1.2.

```python
>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> builder = x509.RevokedCertificateBuilder()
>>> builder = builder.revocation_date(datetime.datetime.today())
>>> builder = builder.serial_number(3333)
>>> revoked_certificate = builder.build(default_backend())
>>> isinstance(revoked_certificate, x509.RevokedCertificate)
True
```

serial_number(serial_number)

Sets the revoked certificate’s serial number.

Parameters serial_number – Integer number that is used to identify the revoked certificate.

revocation_date(time)

Sets the certificate’s revocation date.

Parameters time – The datetime.datetime object (in UTC) that marks the revocation time for the certificate.

add_extension(extension, critical)

Adds an X.509 extension to this revoked certificate.

Parameters

- extension – An instance of one of the CRL entry extensions.
- critical – Set to True if the extension must be understood and handled.

build(backend)

Create a revoked certificate object using the provided backend.

Parameters backend – Backend that will be used to build the revoked certificate. Must support the X509Backend interface.

Returns RevokedCertificate

X.509 CSR (Certificate Signing Request) Builder Object

class cryptography.x509.CertificateSigningRequestBuilder

New in version 1.0.

```python
>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import rsa
>>> from cryptography.x509.oid import NameOID
>>> private_key = rsa.generate_private_key(...
...     public_exponent=65537,
...     key_size=2048,
...     backend=default_backend()
```
... }
>>> builder = x509.CertificateSigningRequestBuilder()
>>> builder = builder.subject_name(x509.Name([
...     x509.NameAttribute(NameOID.COMMON_NAME, u'cryptography.io'),
... ]))
>>> builder = builder.add_extension(
...     x509.BasicConstraints(ca=False, path_length=None), critical=True,
... )
>>> request = builder.sign(
...     private_key, hashes.SHA256(), default_backend()
... )
>>> isinstance(request, x509.CertificateSigningRequest)
True

subject_name(name)

Parameters
name – The Name of the certificate subject.

Returns
A new CertificateSigningRequestBuilder.

add_extension(extension, critical)

Parameters

- extension – An extension conforming to the ExtensionType interface.
- critical – Set to True if the extension must be understood and handled by whoever reads the certificate.

Returns
A new CertificateSigningRequestBuilder.

sign(private_key, algorithm, backend)

Parameters

- backend – Backend that will be used to sign the request. Must support the X509Backend interface.
- private_key – The RSAPrivateKey, DSAPrivateKey or EllipticCurvePrivateKey that will be used to sign the request. When the request is signed by a certificate authority, the private key’s associated public key will be stored in the resulting certificate.
- algorithm – The HashAlgorithm that will be used to generate the request signature.

Returns
A new CertificateSigningRequest.

class cryptography.x509.Name

New in version 0.8.

An X509 Name is an ordered list of attributes. The object is iterable to get every attribute or you can use Name.get_attributes_for_oid() to obtain the specific type you want. Names are sometimes represented as a slash or comma delimited string (e.g. /CN=mydomain.com/O=My Org/C=US or CN=mydomain.com, O=My Org,C=US).

Technically, a Name is a list of sets of attributes, called Relative Distinguished Names or RDNs, although multi-valued RDNs are rarely encountered. The iteration order of values within a multi-valued RDN is preserved. If you need to handle multi-valued RDNs, the rdns property gives access to an ordered list of RelativeDistinguishedName objects.
A Name can be initialized with an iterable of NameAttribute (the common case where each RDN has a single attribute) or an iterable of RelativeDistinguishedName objects (in the rare case of multi-valued RDNs).

```python
>>> len(cert.subject)
3
>>> for attribute in cert.subject:
...     print(attribute)
<NameAttribute(oid=<ObjectIdentifier(oid=2.5.4.6, name=countryName)>, value='US')>
<NameAttribute(oid=<ObjectIdentifier(oid=2.5.4.10, name=organizationName)>, value='Test Certificates 2011')>
<NameAttribute(oid=<ObjectIdentifier(oid=2.5.4.3, name=commonName)>, value='Good CA')>
```

dn
New in version 1.6.

**Type** list of RelativeDistinguishedName

**get_attributes_for_oid**(oid)

**Parameters** oid – An ObjectIdentifier instance.

**Returns** A list of NameAttribute instances that match the OID provided. If nothing matches an empty list will be returned.

```python
>>> cert.subject.get_attributes_for_oid(NameOID.COMMON_NAME)
[<NameAttribute(oid=<ObjectIdentifier(oid=2.5.4.3, name=commonName)>, value='Good CA')>]
```

cert
New in version 1.6.

**Parameters** backend – A backend supporting the X509Backend interface.

**Return bytes** The DER encoded name.

rfc4514_string()
New in version 2.5.

**Return str** Format the given name as a RFC 4514 Distinguished Name string, for example CN=mydomain.com, O=My Org, C=US.

class cryptography.x509.Version
New in version 0.7.

An enumeration for X.509 versions.

**v1**
For version 1 X.509 certificates.

**v3**
For version 3 X.509 certificates.

class cryptography.x509.NameAttribute
New in version 0.8.

An X.509 name consists of a list of RelativeDistinguishedName instances, which consist of a set of NameAttribute instances.

**oid**
Type ObjectIdentifier
The attribute OID.

value

Type text

The value of the attribute.

rfc4514_string()

New in version 2.5.

Return str Format the given attribute as a RFC 4514 Distinguished Name string.

class cryptography.x509.RelativeDistinguishedName(attributes)

New in version 1.6.

A relative distinguished name is a non-empty set of name attributes. The object is iterable to get every attribute, preserving the original order. Passing duplicate attributes to the constructor raises ValueError.

get_attributes_for_oid(oid)

Parameters oid – An ObjectIdentifier instance.

Returns A list of NameAttribute instances that match the OID provided. The list should contain zero or one values.

rfc4514_string()

New in version 2.5.

Return str Format the given RDN set as a RFC 4514 Distinguished Name string.

class cryptography.x509.ObjectIdentifier

New in version 0.8.

Object identifiers (frequently seen abbreviated as OID) identify the type of a value (see: NameAttribute).

dotted_string

Type str

The dotted string value of the OID (e.g. "2.5.4.3")

General Name Classes

class cryptography.x509.GeneralName

New in version 0.9.

This is the generic interface that all the following classes are registered against.

class cryptography.x509.RFC822Name(value)

New in version 0.9.

Changed in version 2.1.

Warning: Starting with version 2.1 U-label input is deprecated. If passing an internationalized domain name (IDN) you should first IDNA encode the value and then pass the result as a string. Accessing value will return the A-label encoded form even if you pass a U-label. This breaks backwards compatibility, but only for internationalized domain names.

This corresponds to an email address. For example, user@example.com.
Parameters value – The email address. If the address contains an internationalized domain name then it must be encoded to an A-label string before being passed.

value

Type text

class cryptography.x509.DNSName(value)

New in version 0.9.

Changed in version 2.1.

Warning: Starting with version 2.1 U-label input is deprecated. If passing an internationalized domain name (IDN) you should first IDNA encode the value and then pass the result as a string. Accessing value will return the A-label encoded form even if you pass a U-label. This breaks backwards compatibility, but only for internationalized domain names.

This corresponds to a domain name. For example, cryptography.io.

Parameters value – The domain name. If it is an internationalized domain name then it must be encoded to an A-label string before being passed.

type text

value

Type text

class cryptography.x509.DirectoryName(value)

New in version 0.9.

This corresponds to a directory name.

value

Type Name

class cryptography.x509.UniformResourceIdentifier(value)

New in version 0.9.

Changed in version 2.1.

Warning: Starting with version 2.1 U-label input is deprecated. If passing an internationalized domain name (IDN) you should first IDNA encode the value and then pass the result as a string. Accessing value will return the A-label encoded form even if you pass a U-label. This breaks backwards compatibility, but only for internationalized domain names.

This corresponds to a uniform resource identifier. For example, https://cryptography.io.

Parameters value – The URI. If it contains an internationalized domain name then it must be encoded to an A-label string before being passed.

value

Type text

class cryptography.x509.IPAddress(value)

New in version 0.9.

This corresponds to an IP address.
value

Type IPv4Address, IPv6Address, IPv4Network, or IPv4Network.

class cryptography.x509.RegisteredID(value)
New in version 0.9.
This corresponds to a registered ID.

value

Type ObjectIdentifier

class cryptography.x509.OtherName(type_id, value)
New in version 1.0.
This corresponds to an otherName. An otherName has a type identifier and a value represented in binary DER format.
type_id

Type ObjectIdentifier

value

Type bytes

X.509 Extensions

class cryptography.x509.Extensions
New in version 0.9.
An X.509 Extensions instance is an ordered list of extensions. The object is iterable to get every extension.

get_extension_for_oid(oid)

Parameters oid – An ObjectIdentifier instance.

Returns An instance of the extension class.

Raises cryptography.x509.ExtensionNotFound – If the certificate does not have the extension requested.

```python
>>> from cryptography.x509.oid import ExtensionOID
>>> cert.extensions.get_extension_for_oid(ExtensionOID.BASIC_CONSTRAINTS)
<Extension(oid=<ObjectIdentifier(oid=2.5.29.19, name=basicConstraints)>,
critical=True, value=<BasicConstraints(ca=True, path_length=None)>)>
```

get_extension_for_class(extclass)

New in version 1.1.

Parameters extclass – An extension class.

Returns An instance of the extension class.

Raises cryptography.x509.ExtensionNotFound – If the certificate does not have the extension requested.

```python
>>> from cryptography import x509
>>> cert.extensions.get_extension_for_class(x509.BasicConstraints)
<Extension(oid=<ObjectIdentifier(oid=2.5.29.19, name=basicConstraints)>,
critical=True, value=<BasicConstraints(ca=True, path_length=None)>)>
```
class cryptography.x509.Extension

    New in version 0.9.

    oid

      Type ObjectIdentifier

      One of the ExtensionOID OIDs.

    critical

      Type bool

      Determines whether a given extension is critical or not. RFC 5280 requires that “A certificate-using system MUST reject the certificate if it encounters a critical extension it does not recognize or a critical extension that contains information that it cannot process”.

    value

      Returns an instance of the extension type corresponding to the OID.

class cryptography.x509.ExtensionType

    New in version 1.0.

    This is the interface against which all the following extension types are registered.

class cryptography.x509.KeyUsage(digital_signature, content_commitment, key_encipherment, data_encipherment, key_agreement, key_cert_sign, crl_sign, encipher_only, decipher_only)

    New in version 0.9.

    The key usage extension defines the purpose of the key contained in the certificate. The usage restriction might be employed when a key that could be used for more than one operation is to be restricted.

    oid

      New in version 1.0.

      Type ObjectIdentifier

      Returns KEY_USAGE.

    digital_signature

      Type bool

      This purpose is set to true when the subject public key is used for verifying digital signatures, other than signatures on certificates (key_cert_sign) and CRLs (crl_sign).

    content_commitment

      Type bool

      This purpose is set to true when the subject public key is used for verifying digital signatures, other than signatures on certificates (key_cert_sign) and CRLs (crl_sign). It is used to provide a non-repudiation service that protects against the signing entity falsely denying some action. In the case of later conflict, a reliable third party may determine the authenticity of the signed data. This was called non_reputation in older revisions of the X.509 specification.

    key_encipherment

      Type bool

      This purpose is set to true when the subject public key is used for enciphering private or secret keys.

    data_encipherment

      Type bool
This purpose is set to true when the subject public key is used for directly enciphering raw user data without the use of an intermediate symmetric cipher.

**key_agreement**

Type bool

This purpose is set to true when the subject public key is used for key agreement. For example, when a Diffie-Hellman key is to be used for key management, then this purpose is set to true.

**key_cert_sign**

Type bool

This purpose is set to true when the subject public key is used for verifying signatures on public key certificates. If this purpose is set to true then `ca` must be true in the `BasicConstraints` extension.

**crl_sign**

Type bool

This purpose is set to true when the subject public key is used for verifying signatures on certificate revocation lists.

**encipher_only**

Type bool

When this purposes is set to true and the `key_agreement` purpose is also set, the subject public key may be used only for enciphering data while performing key agreement.

Raises `ValueError` – This is raised if accessed when `key_agreement` is false.

**decipher_only**

Type bool

When this purposes is set to true and the `key_agreement` purpose is also set, the subject public key may be used only for deciphering data while performing key agreement.

Raises `ValueError` – This is raised if accessed when `key_agreement` is false.

```python
class cryptography.x509.BasicConstraints(ca, path_length)
```

New in version 0.9.

Basic constraints is an X.509 extension type that defines whether a given certificate is allowed to sign additional certificates and what path length restrictions may exist.

**oid**

New in version 1.0.

Type `ObjectIdentifier`

Returns `BASIC_CONSTRAINTS`.

**ca**

Type bool

Whether the certificate can sign certificates.

**path_length**

Type int or `None`

The maximum path length for certificates subordinate to this certificate. This attribute only has meaning if `ca` is true. If `ca` is true then a path length of `None` means there’s no restriction on the number of subordinate CAs in the certificate chain. If it is zero or greater then it defines the maximum length for a
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subordinate CA's certificate chain. For example, a path_length of 1 means the certificate can sign a subordinate CA, but the subordinate CA is not allowed to create subordinates with ca set to true.

class cryptography.x509.ExtendedKeyUsage(usage)
New in version 0.9.

This extension indicates one or more purposes for which the certified public key may be used, in addition to or in place of the basic purposes indicated in the key usage extension. The object is iterable to obtain the list of ExtendedKeyUsageOID OIDs present.

Parameters usage(list) – A list of ExtendedKeyUsageOID OIDs.

oid
New in version 1.0.

Type ObjectIdentifier

Returns EXTENDED_KEY_USAGE.

class cryptography.x509.OCSPNoCheck
New in version 1.0.

This presence of this extension indicates that an OCSP client can trust a responder for the lifetime of the responder’s certificate. CAs issuing such a certificate should realize that a compromise of the responder’s key is as serious as the compromise of a CA key used to sign CRLs, at least for the validity period of this certificate. CA’s may choose to issue this type of certificate with a very short lifetime and renew it frequently. This extension is only relevant when the certificate is an authorized OCSP responder.

oid
New in version 1.0.

Type ObjectIdentifier

Returns OCSP_NO_CHECK.

class cryptography.x509.TLSFeature(features)
New in version 2.1.

The TLS Feature extension is defined in RFC 7633 and is used in certificates for OCSP Must-Staple. The object is iterable to get every element.

Parameters features(list) – A list of features to enable from the TLSFeatureType enum.

At this time only status_request or status_request_v2 are allowed.

oid

Type ObjectIdentifier

Returns TLS_FEATURE.

class cryptography.x509.TLSFeatureType
New in version 2.1.

An enumeration of TLS Feature types.

status_request
This feature type is defined in RFC 6066 and, when embedded in an X.509 certificate, signals to the client that it should require a stapled OCSP response in the TLS handshake. Commonly known as OCSP Must-Staple in certificates.

status_request_v2
This feature type is defined in RFC 6961. This value is not commonly used and if you want to enable OCSP Must-Staple you should use status_request.
class cryptography.x509.NameConstraints(permitted_subtrees, excluded_subtrees)
New in version 1.0.

The name constraints extension, which only has meaning in a CA certificate, defines a name space within which all subject names in certificates issued beneath the CA certificate must (or must not) be in. For specific details on the way this extension should be processed see RFC 5280.

oid
New in version 1.0.

Type ObjectIdentifier
Returns NAME_CONSTRAINTS.

permitted_subtrees

Type list of GeneralName objects or None

The set of permitted name patterns. If a name matches this and an element in excluded_subtrees it is invalid. At least one of permitted_subtrees and excluded_subtrees will be non-None.

excluded_subtrees

Type list of GeneralName objects or None

Any name matching a restriction in the excluded_subtrees field is invalid regardless of information appearing in the permitted_subtrees. At least one of permitted_subtrees and excluded_subtrees will be non-None.

class cryptography.x509.AuthorityKeyIdentifier(key_identifier, authority_cert_issuer, authority_cert_serial_number)
New in version 0.9.

The authority key identifier extension provides a means of identifying the public key corresponding to the private key used to sign a certificate. This extension is typically used to assist in determining the appropriate certificate chain. For more information about generation and use of this extension see RFC 5280 section 4.2.1.1.

oid
New in version 1.0.

Type ObjectIdentifier
Returns AUTHORITY_KEY_IDENTIFIER.

key_identifier

Type bytes

A value derived from the public key used to verify the certificate’s signature.

authority_cert_issuer

Type A list of GeneralName instances or None

The Name of the issuer’s issuer.

authority_cert_serial_number

Type int or None

The serial number of the issuer’s issuer.

classmethod from_issuer_public_key(public_key)
New in version 1.0.
Note: This method should be used if the issuer certificate does not contain a SubjectKeyIdentifier. Otherwise, use from_issuer_subject_key_identifier().

Creates a new AuthorityKeyIdentifier instance using the public key provided to generate the appropriate digest. This should be the issuer’s public key. The resulting object will contain key_identifier, but authority_cert_issuer and authority_cert_serial_number will be None. The generated key_identifier is the SHA1 hash of the subjectPublicKey ASN.1 bit string. This is the first recommendation in RFC 5280 section 4.2.1.2.

Parameters public_key – One of RSAPublicKey, DSAPublicKey, or EllipticCurvePublicKey.

```python
generate = x509.AuthorityKeyIdentifier.from_issuer_public_key(issuer_cert.public_key())
```

classmethod from_issuer_subject_key_identifier(ski)

New in version 1.3.

Note: This method should be used if the issuer certificate contains a SubjectKeyIdentifier. Otherwise, use from_issuer_public_key().

Creates a new AuthorityKeyIdentifier instance using the SubjectKeyIdentifier from the issuer certificate. The resulting object will contain key_identifier, but authority_cert_issuer and authority_cert_serial_number will be None.

Parameters ski – The SubjectKeyIdentifier from the issuer certificate.

```python
generate = x509.AuthorityKeyIdentifier.from_issuer_subject_key_identifier(ski)
```

class cryptography.x509.SubjectKeyIdentifier(digest)

New in version 0.9.

The subject key identifier extension provides a means of identifying certificates that contain a particular public key.

oid

New in version 1.0.

Type ObjectIdentifier

Returns SUBJECT_KEY_IDENTIFIER.
Type bytes

The binary value of the identifier.

classmethod from_public_key(public_key)

New in version 1.0.

Creates a new SubjectKeyIdentifier instance using the public key provided to generate the appropriate digest. This should be the public key that is in the certificate. The generated digest is the SHA1 hash of the subjectPublicKey ASN.1 bit string. This is the first recommendation in RFC 5280 section 4.2.1.2.

Parameters public_key – One of RSAVerboseKey, DSAPublicKey, or EllipticCurvePublicKey.

>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> csr = x509.load_pem_x509_csr(pem_req_data, default_backend())
>>> x509.SubjectKeyIdentifier.from_public_key(csr.public_key())
<SubjectKeyIdentifier(digest=b'\xd3\xee\x06\x11\x93\x03\x88\xa6\xa7\xf7')>

class cryptography.x509.SubjectAlternativeName(general_names)

New in version 0.9.

Subject alternative name is an X.509 extension that provides a list of general name instances that provide a set of identities for which the certificate is valid. The object is iterable to get every element.

Parameters general_names (list) – A list of GeneralName instances.

oid

New in version 1.0.

Type ObjectIdentifier

Returns SUBJECT_ALTERNATIVE_NAME.

general_names_for_type(type)

Parameters type – A GeneralName instance. This is one of the general name classes.

Returns A list of values extracted from the matched general names. The type of the returned values depends on the GeneralName.

>>> from cryptography import x509
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> cert = x509.load_pem_x509_certificate(cryptography_cert_pem, default_backend())
>>> # Get the subjectAltName extension from the certificate
>>> ext = cert.extensions.get_extension_for_oid(ExtensionOID.SUBJECT_ALTERNATIVE_NAME)
>>> # Get the DNSName entries from the SAN extension
>>> ext.value.get_values_for_type(x509.DNSName)
['www.cryptography.io', 'cryptography.io']

class cryptography.x509.IssuerAlternativeName(general_names)

New in version 1.0.

Issuer alternative name is an X.509 extension that provides a list of general name instances that provide a set of identities for the certificate issuer. The object is iterable to get every element.

Parameters general_names (list) – A list of GeneralName instances.
oid
New in version 1.0.
  Type ObjectIdentifier
Returns ISSUER_ALTERNATIVE_NAME.

get_values_for_type(type)
  Parameters type – A GeneralName instance. This is one of the general name classes.
  Returns A list of values extracted from the matched general names.

class cryptography.x509.PrecertificateSignedCertificateTimestamps(scts)
New in version 2.0.
This extension contains SignedCertificateTimestamp instances which were issued for the pre-certificate corresponding to this certificate. These can be used to verify that the certificate is included in a public Certificate Transparency log.

It is an iterable containing one or more SignedCertificateTimestamp objects.
  Parameters scts(list) – A list of SignedCertificateTimestamp objects.

oid
  Type ObjectIdentifier
Returns PRECERT_SIGNED_CERTIFICATE_TIMESTAMPS.

class cryptography.x509.PrecertPoison
New in version 2.4.
This extension indicates that the certificate should not be treated as a certificate for the purposes of validation, but is instead for submission to a certificate transparency log in order to obtain SCTs which will be embedded in a PrecertificateSignedCertificateTimestamps extension on the final certificate.

oid
  Type ObjectIdentifier
Returns PRECERT_POISON.

class cryptography.x509.DeltaCRLIndicator(crl_number)
New in version 2.1.
The delta CRL indicator is a CRL extension that identifies a CRL as being a delta CRL. Delta CRLs contain updates to revocation information previously distributed, rather than all the information that would appear in a complete CRL.

Parameters crl_number(int) – The CRL number of the complete CRL that the delta CRL is updating.

oid
  Type ObjectIdentifier
Returns DELTA_CRL_INDICATOR.

crl_number
  Type int

class cryptography.x509.AuthorityInformationAccess(descriptions)
New in version 0.9.
The authority information access extension indicates how to access information and services for the issuer of the certificate in which the extension appears. Information and services may include online validation services (such as OCSP) and issuer data. It is an iterable, containing one or more `AccessDescription` instances.

**Parameters**

- **descriptions** *(list)* – A list of `AccessDescription` objects.

**oid**

- New in version 1.0.
- **Type** `ObjectIdentifier`
- **Returns** `AUTHORITY_INFORMATION_ACCESS`.

```python
cryptography.x509.AccessDescription(access_method, access_location)
```

- New in version 0.9.

**access_method**

- **Type** `ObjectIdentifier`
- The access method defines what the `access_location` means. It must be either `OCSP` or `CA_ISSUERS`. If it is `OCSP` the access location will be where to obtain OCSP information for the certificate. If it is `CA_ISSUERS` the access location will provide additional information about the issuing certificate.

**access_location**

- **Type** `GeneralName`
- Where to access the information defined by the access method.

```python
cryptography.x509.FreshestCRL(distribution_points)
```

- New in version 2.1.
- The freshest CRL extension (also known as Delta CRL Distribution Point) identifies how delta CRL information is obtained. It is an iterable, containing one or more `DistributionPoint` instances.

**Parameters**

- **distribution_points** *(list)* – A list of `DistributionPoint` instances.

**oid**

- **Type** `ObjectIdentifier`
- **Returns** `FRESHEST_CRL`.

```python
cryptography.x509.CRLDistributionPoints(distribution_points)
```

- New in version 0.9.
- The CRL distribution points extension identifies how CRL information is obtained. It is an iterable, containing one or more `DistributionPoint` instances.

**Parameters**

- **distribution_points** *(list)* – A list of `DistributionPoint` instances.

**oid**

- New in version 1.0.
- **Type** `ObjectIdentifier`
- **Returns** `CRL_DISTRIBUTION_POINTS`.

```python
cryptography.x509.DistributionPoint(full_name, relative_name, reasons, crl_issuer)
```

- New in version 0.9.

**full_name**

- **Type** list of `GeneralName` instances or None
This field describes methods to retrieve the CRL. At most one of \texttt{full_name} or \texttt{relative_name} will be non-None.

**relative_name**

Type `RelativeDistinguishedName` or None

This field describes methods to retrieve the CRL relative to the CRL issuer. At most one of \texttt{full_name} or \texttt{relative_name} will be non-None.

Changed in version 1.6: Changed from \texttt{Name} to \texttt{RelativeDistinguishedName}.

**crl_issuer**

Type list of \texttt{GeneralName} instances or None

Information about the issuer of the CRL.

**reasons**

Type frozenset of \texttt{ReasonFlags} or None

The reasons a given distribution point may be used for when performing revocation checks.

```python
class cryptography.x509.ReasonFlags
```

New in version 0.9.

An enumeration for CRL reasons.

- **unspecified**
  
  It is unspecified why the certificate was revoked. This reason cannot be used as a reason flag in a `DistributionPoint`.

- **key_compromise**
  
  This reason indicates that the private key was compromised.

- **ca_compromise**
  
  This reason indicates that the CA issuing the certificate was compromised.

- **affiliation_changed**
  
  This reason indicates that the subject’s name or other information has changed.

- **superseded**
  
  This reason indicates that a certificate has been superseded.

- **cessation_of_operation**
  
  This reason indicates that the certificate is no longer required.

- **certificate_hold**
  
  This reason indicates that the certificate is on hold.

- **privilege_withdrawn**
  
  This reason indicates that the privilege granted by this certificate have been withdrawn.

- **aa_compromise**
  
  When an attribute authority has been compromised.

- **remove_from_crl**
  
  This reason indicates that the certificate was on hold and should be removed from the CRL. This reason cannot be used as a reason flag in a `DistributionPoint`.

```python
class cryptography.x509.InhibitAnyPolicy
```

New in version 1.0.
The inhibit anyPolicy extension indicates that the special OID ANY_POLICY, is not considered an explicit match for other CertificatePolicies except when it appears in an intermediate self-issued CA certificate. The value indicates the number of additional non-self-issued certificates that may appear in the path before ANY_POLICY is no longer permitted. For example, a value of one indicates that ANY_POLICY may be processed in certificates issued by the subject of this certificate, but not in additional certificates in the path.

oid

New in version 1.0.

Type ObjectIdentifier

Returns INHIBIT_ANY_POLICY.

skip_certs

Type int

class cryptography.x509.PolicyConstraints

New in version 1.3.

The policy constraints extension is used to inhibit policy mapping or require that each certificate in a chain contain an acceptable policy identifier. For more information about the use of this extension see RFC 5280.

oid

Type ObjectIdentifier

Returns POLICY_CONSTRAINTS.

require_explicit_policy

Type int or None

If this field is not None, the value indicates the number of additional certificates that may appear in the chain before an explicit policy is required for the entire path. When an explicit policy is required, it is necessary for all certificates in the chain to contain an acceptable policy identifier in the certificate policies extension. An acceptable policy identifier is the identifier of a policy required by the user of the certification path or the identifier of a policy that has been declared equivalent through policy mapping.

inhibit_policy_mapping

Type int or None

If this field is not None, the value indicates the number of additional certificates that may appear in the chain before policy mapping is no longer permitted. For example, a value of one indicates that policy mapping may be processed in certificates issued by the subject of this certificate, but not in additional certificates in the chain.

class cryptography.x509.CRLNumber(crl_number)

New in version 1.2.

The CRL number is a CRL extension that conveys a monotonically increasing sequence number for a given CRL scope and CRL issuer. This extension allows users to easily determine when a particular CRL supersedes another CRL. RFC 5280 requires that this extension be present in conforming CRLs.

oid

Type ObjectIdentifier

Returns CRL_NUMBER.

crl_number

Type int
class cryptography.x509.IssuingDistributionPoint(full_name, relative_name,
   only_contains_user_certs,
   only_contains_ca_certs,
   only_some_reasons, indirect_crl,
   only_contains_attribute_certs)

New in version 2.5.

Issuing distribution point is a CRL extension that identifies the CRL distribution point and scope for a particular CRL. It indicates whether the CRL covers revocation for end entity certificates only, CA certificates only, attribute certificates only, or a limited set of reason codes. For specific details on the way this extension should be processed see RFC 5280.

oid

   Type ObjectIdentifier
   Returns ISSUING_DISTRIBUTION_POINT.

only_contains_user_certs

   Type bool
   Set to True if the CRL this extension is embedded within only contains information about user certificates.

only_contains_ca_certs

   Type bool
   Set to True if the CRL this extension is embedded within only contains information about CA certificates.

indirect_crl

   Type bool
   Set to True if the CRL this extension is embedded within includes certificates issued by one or more authorities other than the CRL issuer.

only_contains_attribute_certs

   Type bool
   Set to True if the CRL this extension is embedded within only contains information about attribute certificates.

only_some_reasons

   Type frozenset of ReasonFlags or None
   The reasons for which the issuing distribution point is valid. None indicates that it is valid for all reasons.

full_name

   Type list of GeneralName instances or None
   This field describes methods to retrieve the CRL. At most one of full_name or relative_name will be non-None.

relative_name

   Type RelativeDistinguishedName or None
   This field describes methods to retrieve the CRL relative to the CRL issuer. At most one of full_name or relative_name will be non-None.

class cryptography.x509.UnrecognizedExtension

New in version 1.2.
A generic extension class used to hold the raw value of extensions that `cryptography` does not know how to parse.

**oid**

Type `ObjectIdentifier`

Returns the OID associated with this extension.

**value**

Type `bytes`

Returns the DER encoded bytes payload of the extension.

```python
class cryptography.x509.CertificatePolicies(policies)
```

New in version 0.9.

The certificate policies extension is an iterable, containing one or more `PolicyInformation` instances.

**Parameters**

- **policies** (`list`): A list of `PolicyInformation` instances.

**oid**

New in version 1.0.

Type `ObjectIdentifier`

Returns `CERTIFICATE_POLICIES`.

## Certificate Policies Classes

These classes may be present within a `CertificatePolicies` instance.

```python
class cryptography.x509.PolicyInformation(policy_identifier, policy_qualifiers)
```

New in version 0.9.

Contains a policy identifier and an optional list of qualifiers.

**policy_identifier**

Type `ObjectIdentifier`

**policy_qualifiers**

Type `list`

A list consisting of `text` and/or `UserNotice` objects. If the value is text it is a pointer to the practice statement published by the certificate authority. If it is a user notice it is meant for display to the relying party when the certificate is used.

```python
class cryptography.x509.UserNotice(notice_reference, explicit_text)
```

New in version 0.9.

User notices are intended for display to a relying party when a certificate is used. In practice, few if any UIs expose this data and it is a rarely encoded component.

**notice_reference**

Type `NoticeReference` or `None`

The notice reference field names an organization and identifies, by number, a particular statement prepared by that organization.

**explicit_text**

This field includes an arbitrary textual statement directly in the certificate.
Notice reference can name an organization and provide information about notices related to the certificate. For example, it might identify the organization name and notice number 1. Application software could have a notice file containing the current set of notices for the named organization; the application would then extract the notice text from the file and display it. In practice this is rarely seen.

New in version 0.9.

organization
  Type text

notice_numbers
  Type list
  A list of integers.

CRL Entry Extensions

These extensions are only valid within a RevokedCertificate object.

class cryptography.x509.CertificateIssuer (general_names)
  New in version 1.2.
  The certificate issuer is an extension that is only valid inside RevokedCertificate objects. If the indirectCRL property of the parent CRL's IssuingDistributionPoint extension is set, then this extension identifies the certificate issuer associated with the revoked certificate. The object is iterable to get every element.

  Parameters general_names (list) – A list of GeneralName instances.

oid
  Type ObjectIdentifier
  Returns CERTIFICATE_ISSUER.

get_values_for_type (type)
  Parameters type – A GeneralName instance. This is one of the general name classes.
  Returns A list of values extracted from the matched general names. The type of the returned values depends on the GeneralName.

class cryptography.x509.CRLReason (reason)
  New in version 1.2.
  CRL reason (also known as reasonCode) is an extension that is only valid inside RevokedCertificate objects. It identifies a reason for the certificate revocation.

  Parameters reason – An element from ReasonFlags.

oid
  Type ObjectIdentifier
  Returns CRL_REASON.

reason
  Type An element from ReasonFlags
class cryptography.x509.InvalidityDate(invalidity_date)
New in version 1.2.

Invalidity date is an extension that is only valid inside RevokedCertificate objects. It provides the date on which it is known or suspected that the private key was compromised or that the certificate otherwise became invalid. This date may be earlier than the revocation date in the CRL entry, which is the date at which the CA processed the revocation.

Parameters invalidity_date – The datetime.datetime when it is known or suspected that the private key was compromised.

oid
  Type ObjectIdentifier
  Returns INVALIDITY_DATE.

invalidity_date
  Type datetime.datetime

OCSP Extensions

class cryptography.x509.OCSPNonce(nonce)
New in version 2.4.

OCSP nonce is an extension that is only valid inside OCSPRequest and OCSPResponse objects. The nonce cryptographically binds a request and a response to prevent replay attacks. In practice nonces are rarely used in OCSP due to the desire to precompute OCSP responses at large scale.

oid
  Type ObjectIdentifier
  Returns NONCE.

nonce
  Type bytes

Object Identifiers

X.509 elements are frequently identified by ObjectIdentifier instances. The following common OIDs are available as constants.

class cryptography.x509.oid.NameOID
These OIDs are typically seen in X.509 names.
New in version 1.0.

COMMON_NAME
  Corresponds to the dotted string "2.5.4.3". Historically the domain name would be encoded here for server certificates. RFC 2818 deprecates this practice and names of that type should now be located in a SubjectAlternativeName extension.

COUNTRY_NAME
  Corresponds to the dotted string "2.5.4.6".

LOCALITY_NAME
  Corresponds to the dotted string "2.5.4.7".
STATE_OR_PROVINCE_NAME
Corresponds to the dotted string "2.5.4.8".

STREET_ADDRESS
New in version 1.6.
Corresponds to the dotted string "2.5.4.9".

ORGANIZATION_NAME
Corresponds to the dotted string "2.5.4.10".

ORGANIZATIONAL_UNIT_NAME
Corresponds to the dotted string "2.5.4.11".

SERIAL_NUMBER
Corresponds to the dotted string "2.5.4.5". This is distinct from the serial number of the certificate itself (which can be obtained with `serial_number()`).

SURNAME
Corresponds to the dotted string "2.5.4.4".

GIVEN_NAME
Corresponds to the dotted string "2.5.4.42".

TITLE
Corresponds to the dotted string "2.5.4.12".

GENERATION_QUALIFIER
Corresponds to the dotted string "2.5.4.44".

X500_UNIQUE_IDENTIFIER
New in version 1.6.
Corresponds to the dotted string "2.5.4.45".

DN_QUALIFIER
Corresponds to the dotted string "2.5.4.46". This specifies disambiguating information to add to the relative distinguished name of an entry. See RFC 2256.

PSEUDONYM
Corresponds to the dotted string "2.5.4.65".

USER_ID
New in version 1.6.
Corresponds to the dotted string "0.9.2342.19200300.100.1.1".

DOMAIN_COMPONENT
Corresponds to the dotted string "0.9.2342.19200300.100.1.25". A string holding one component of a domain name. See RFC 4519.

EMAIL_ADDRESS
Corresponds to the dotted string "1.2.840.113549.1.9.1".

JURISDICTION_COUNTRY_NAME
Corresponds to the dotted string "1.3.6.1.4.1.311.60.2.1.3".

JURISDICTION_LOCALITY_NAME
Corresponds to the dotted string "1.3.6.1.4.1.311.60.2.1.1".

JURISDICTION_STATE_OR_PROVINCE_NAME
Corresponds to the dotted string "1.3.6.1.4.1.311.60.2.1.2".
BUSINESS CATEGORY
Corresponds to the dotted string "2.5.4.15".

POSTAL_ADDRESS
New in version 1.6.
Corresponds to the dotted string "2.5.4.16".

POSTAL_CODE
New in version 1.6.
Corresponds to the dotted string "2.5.4.17".

class cryptography.x509.oid.SignatureAlgorithmOID
New in version 1.0.

RSA_WITH_MD5
Corresponds to the dotted string "1.2.840.113549.1.1.4". This is an MD5 digest signed by an RSA key.

RSA_WITH_SHA1
Corresponds to the dotted string "1.2.840.113549.1.1.5". This is a SHA1 digest signed by an RSA key.

RSA_WITH_SHA224
Corresponds to the dotted string "1.2.840.113549.1.1.14". This is a SHA224 digest signed by an RSA key.

RSA_WITH_SHA256
Corresponds to the dotted string "1.2.840.113549.1.1.11". This is a SHA256 digest signed by an RSA key.

RSA_WITH_SHA384
Corresponds to the dotted string "1.2.840.113549.1.1.12". This is a SHA384 digest signed by an RSA key.

RSA_WITH_SHA512
Corresponds to the dotted string "1.2.840.113549.1.1.13". This is a SHA512 digest signed by an RSA key.

RSASSA_PSS
New in version 2.3.
Corresponds to the dotted string "1.2.840.113549.1.1.10". This is signed by an RSA key using the Probabilistic Signature Scheme (PSS) padding from RFC 4055. The hash function and padding are defined by signature algorithm parameters.

ECDSA_WITH_SHA1
Corresponds to the dotted string "1.2.840.10045.4.1". This is a SHA1 digest signed by an ECDSA key.

ECDSA_WITH_SHA224
Corresponds to the dotted string "1.2.840.10045.4.3.1". This is a SHA224 digest signed by an ECDSA key.

ECDSA_WITH_SHA256
Corresponds to the dotted string "1.2.840.10045.4.3.2". This is a SHA256 digest signed by an ECDSA key.

ECDSA_WITH_SHA384
Corresponds to the dotted string "1.2.840.10045.4.3.3". This is a SHA384 digest signed by an ECDSA key.
ECDSA_WITH_SHA512
Corresponds to the dotted string "1.2.840.10045.4.3.4". This is a SHA512 digest signed by an ECDSA key.

DSA_WITH_SHA1
Corresponds to the dotted string "1.2.840.10040.4.3". This is a SHA1 digest signed by a DSA key.

DSA_WITH_SHA224
Corresponds to the dotted string "2.16.840.1.101.3.4.3.1". This is a SHA224 digest signed by a DSA key.

DSA_WITH_SHA256
Corresponds to the dotted string "2.16.840.1.101.3.4.3.2". This is a SHA256 digest signed by a DSA key.

class cryptography.x509.oid.ExtendedKeyUsageOID
New in version 1.0.

SERVER_AUTH
Corresponds to the dotted string "1.3.6.1.5.5.7.3.1". This is used to denote that a certificate may be used for TLS web server authentication.

CLIENT_AUTH
Corresponds to the dotted string "1.3.6.1.5.5.7.3.2". This is used to denote that a certificate may be used for TLS web client authentication.

CODE_SIGNING
Corresponds to the dotted string "1.3.6.1.5.5.7.3.3". This is used to denote that a certificate may be used for code signing.

EMAIL_PROTECTION
Corresponds to the dotted string "1.3.6.1.5.5.7.3.4". This is used to denote that a certificate may be used for email protection.

TIME_STAMPING
Corresponds to the dotted string "1.3.6.1.5.5.7.3.8". This is used to denote that a certificate may be used for time stamping.

OCSP_SIGNING
Corresponds to the dotted string "1.3.6.1.5.5.7.3.9". This is used to denote that a certificate may be used for signing OCSP responses.

ANY_EXTENDED_KEY_USAGE
New in version 2.0.
Corresponds to the dotted string "2.5.29.37.0". This is used to denote that a certificate may be used for any purposes.

class cryptography.x509.oid.AuthorityInformationAccessOID
New in version 1.0.

OCSP
Corresponds to the dotted string "1.3.6.1.5.5.7.48.1". Used as the identifier for OCSP data in AccessDescription objects.

CA_ISSUERS
Corresponds to the dotted string "1.3.6.1.5.5.7.48.2". Used as the identifier for CA issuer data in AccessDescription objects.

class cryptography.x509.oid.CertificatePoliciesOID
New in version 1.0.
CPS_QUALIFIER
Corresponds to the dotted string "1.3.6.1.5.5.7.2.1".

CPS_USER_NOTICE
Corresponds to the dotted string "1.3.6.1.5.5.7.2.2".

ANY_POLICY
Corresponds to the dotted string "2.5.29.32.0".

class cryptography.x509.oid.ExtensionOID
New in version 1.0.

BASIC_CONSTRAINTS
Corresponds to the dotted string "2.5.29.19". The identifier for the BasicConstraints extension type.

KEY_USAGE
Corresponds to the dotted string "2.5.29.15". The identifier for the KeyUsage extension type.

SUBJECT_ALTERNATIVE_NAME
Corresponds to the dotted string "2.5.29.17". The identifier for the SubjectAlternativeName extension type.

ISSUER_ALTERNATIVE_NAME
Corresponds to the dotted string "2.5.29.18". The identifier for the IssuerAlternativeName extension type.

SUBJECT_KEY_IDENTIFIER
Corresponds to the dotted string "2.5.29.14". The identifier for the SubjectKeyIdentifier extension type.

NAME_CONSTRAINTS
Corresponds to the dotted string "2.5.29.30". The identifier for the NameConstraints extension type.

CRL_DISTRIBUTION_POINTS
Corresponds to the dotted string "2.5.29.31". The identifier for the CRLDistributionPoints extension type.

CERTIFICATE_POLICIES
Corresponds to the dotted string "2.5.29.32". The identifier for the CertificatePolicies extension type.

AUTHORITY_KEY_IDENTIFIER
Corresponds to the dotted string "2.5.29.35". The identifier for the AuthorityKeyIdentifier extension type.

EXTENDED_KEY_USAGE
Corresponds to the dotted string "2.5.29.37". The identifier for the ExtendedKeyUsage extension type.

AUTHORITY_INFORMATION_ACCESS
Corresponds to the dotted string "1.3.6.1.5.5.7.1.1". The identifier for the AuthorityInformationAccess extension type.

INHIBIT_ANY_POLICY
Corresponds to the dotted string "2.5.29.54". The identifier for the InhibitAnyPolicy extension type.

OCSP_NO_CHECK
Corresponds to the dotted string "1.3.6.1.5.5.7.48.1.5". The identifier for the OCSPNoCheck extension type.

2.2. X.509
**TLS_FEATURE**
Corresponds to the dotted string "1.3.6.1.5.5.7.1.24". The identifier for the `TLSFeature` extension type.

**CRL_NUMBER**
Corresponds to the dotted string "2.5.29.20". The identifier for the `CRLNumber` extension type. This extension only has meaning for certificate revocation lists.

**DELTA_CRL_INDICATOR**
New in version 2.1.
Corresponds to the dotted string "2.5.29.27". The identifier for the `DeltaCRLIndicator` extension type. This extension only has meaning for certificate revocation lists.

**PRECERT_SIGNED_CERTIFICATE_TIMESTAMPS**
New in version 1.9.
Corresponds to the dotted string "1.3.6.1.4.1.11129.2.4.2".

**PRECERT_POISON**
New in version 2.4.
Corresponds to the dotted string "1.3.6.1.4.1.11129.2.4.3".

**POLICY_CONSTRAINTS**
Corresponds to the dotted string "2.5.29.36". The identifier for the `PolicyConstraints` extension type.

**FRESHEST_CRL**
Corresponds to the dotted string "2.5.29.46". The identifier for the `FreshestCRL` extension type.

**ISSUING_DISTRIBUTION_POINT**
New in version 2.4.
Corresponds to the dotted string "2.5.29.28".

```python
class cryptography.x509.oid.CRLEntryExtensionOID
New in version 1.2.

**CERTIFICATE_ISSUER**
Corresponds to the dotted string "2.5.29.29".

**CRL_REASON**
Corresponds to the dotted string "2.5.29.21".

**INVALIDITY_DATE**
Corresponds to the dotted string "2.5.29.24".
```

```python
class cryptography.x509.oid.OCSPExtensionOID
New in version 2.4.

**NONCE**
Corresponds to the dotted string "1.3.6.1.5.5.7.48.1.2".
```

**Helper Functions**

```python
cryptography.x509.random_serial_number()
New in version 1.6.
Generates a random serial number suitable for use when constructing certificates.
```
Exceptions

class cryptography.x509.InvalidVersion
This is raised when an X.509 certificate has an invalid version number.

parsed_version
Type int
Returns the raw version that was parsed from the certificate.

class cryptography.x509.DuplicateExtension
This is raised when more than one X.509 extension of the same type is found within a certificate.

oid
Type ObjectIdentifier
Returns the OID.

class cryptography.x509.ExtensionNotFound
This is raised when calling Extensions.get_extension_for_oid() with an extension OID that is not present in the certificate.

oid
Type ObjectIdentifier
Returns the OID.

class cryptography.x509.UnsupportedGeneralNameType
This is raised when a certificate contains an unsupported general name type in an extension.

type
Type int
The integer value of the unsupported type. The complete list of types can be found in RFC 5280 section 4.2.1.6.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

2.3 Primitives

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

2.3.1 Authenticated encryption

Authenticated encryption with associated data (AEAD) are encryption schemes which provide both confidentiality and integrity for their ciphertext. They also support providing integrity for associated data which is not encrypted.
class cryptography.hazmat.primitives.ciphers.aead.ChaCha20Poly1305(key)
    New in version 2.0.

The ChaCha20Poly1305 construction is defined in RFC 7539 section 2.8. It is a stream cipher combined with a MAC that offers strong integrity guarantees.

Parameters key (bytes-like) – A 32-byte key. This must be kept secret.

Raises cryptography.exceptions.UnsupportedAlgorithm – If the version of OpenSSL does not support ChaCha20Poly1305.

```python
>>> import os
>>> from cryptography.hazmat.primitives.ciphers.aead import ChaCha20Poly1305
>>> data = b"a secret message"
>>> aad = b"authenticated but unencrypted data"
>>> key = ChaCha20Poly1305.generate_key()
>>> nonce = os.urandom(12)
>>> ct = chacha.encrypt(nonce, data, aad)
>>> chacha.decrypt(nonce, ct, aad)
b'a secret message'
```

classmethod generate_key()

Securely generates a random ChaCha20Poly1305 key.

    Returns bytes A 32 byte key.

encrypt (nonce, data, associated_data)

Warning: Reuse of a nonce with a given key compromises the security of any message with that nonce and key pair.

Encrypts the data provided and authenticates the associated_data. The output of this can be passed directly to the decrypt method.

Parameters

- nonce (bytes-like) – A 12 byte value. NEVER REUSE A NONCE with a key.
- data (bytes) – The data to encrypt.
- associated_data (bytes) – Additional data that should be authenticated with the key, but does not need to be encrypted. Can be None.

    Returns bytes The ciphertext bytes with the 16 byte tag appended.

    Raises OverflowError – If data or associated_data is larger than $2^{32}$ bytes.

decrypt (nonce, data, associated_data)

Decrypts the data and authenticates the associated_data. If you called encrypt with associated_data you must pass the same associated_data in decrypt or the integrity check will fail.

Parameters

- nonce (bytes-like) – A 12 byte value. NEVER REUSE A NONCE with a key.
- data (bytes) – The data to decrypt (with tag appended).
- associated_data (bytes) – Additional data to authenticate. Can be None if none was passed during encryption.
Returns bytes  The original plaintext.

Raises cryptography.exceptions.InvalidTag – If the authentication tag doesn’t validate this exception will be raised. This will occur when the ciphertext has been changed, but will also occur when the key, nonce, or associated data are wrong.

class cryptography.hazmat.primitives.ciphers.aead.AESGCM(key)
New in version 2.0.

The AES-GCM construction is composed of the AES block cipher utilizing Galois Counter Mode (GCM).

Parameters key (bytes-like) – A 128, 192, or 256-bit key. This must be kept secret.

>>> import os
>>> from cryptography.hazmat.primitives.ciphers.aead import AESGCM
>>> data = b"a secret message"
>>> aad = b"authenticated but unencrypted data"
>>> key = AESGCM.generate_key(bit_length=128)
>>> aesgcm = AESGCM(key)
>>> nonce = os.urandom(12)
>>> ct = aesgcm.encrypt(nonce, data, aad)
>>> aesgcm.decrypt(nonce, ct, aad)
b'a secret message'

classmethod generate_key (bit_length)
Securely generates a random AES-GCM key.

Parameters bit_length – The bit length of the key to generate. Must be 128, 192, or 256.

Returns bytes The generated key.

encrypt (nonce, data, associated_data)

Warning: Reuse of a nonce with a given key compromises the security of any message with that nonce and key pair.

Encrypts and authenticates the data provided as well as authenticating the associated_data. The output of this can be passed directly to the decrypt method.

Parameters

• nonce (bytes-like) – NIST recommends a 96-bit IV length for best performance but it can be up to $2^{64} - 1$ bits. NEVER REUSE A NONCE with a key.

• data (bytes) – The data to encrypt.

• associated_data (bytes) – Additional data that should be authenticated with the key, but is not encrypted. Can be None.

Returns bytes The ciphertext bytes with the 16 byte tag appended.

Raises OverflowError – If data or associated_data is larger than $2^{32}$ bytes.

decrypt (nonce, data, associated_data)

Decrypts the data and authenticates the associated_data. If you called encrypt with associated_data you must pass the same associated_data in decrypt or the integrity check will fail.

Parameters
• nonce (bytes-like) – NIST recommends a 96-bit IV length for best performance but it can be up to $2^{32} - 1$ bits. NEVER REUSE A NONCE with a key.

• data (bytes) – The data to decrypt (with tag appended).

• associated_data (bytes) – Additional data to authenticate. Can be None if none was passed during encryption.

Returns bytes The original plaintext.

Raises cryptography.exceptions.InvalidTag – If the authentication tag doesn’t validate this exception will be raised. This will occur when the ciphertext has been changed, but will also occur when the key, nonce, or associated data are wrong.

class cryptography.hazmat.primitives.ciphers.aead.AESCCM(key, tag_length=16)

New in version 2.0.

The AES-CCM construction is composed of the AES block cipher utilizing Counter with CBC-MAC (CCM) (specified in RFC 3610).

Parameters

• key (bytes-like) – A 128, 192, or 256-bit key. This must be kept secret.

• tag_length (int) – The length of the authentication tag. This defaults to 16 bytes and it is strongly recommended that you do not make it shorter unless absolutely necessary. Valid tag lengths are 4, 6, 8, 10, 12, 14, and 16.

Raises cryptography.exceptions.UnsupportedAlgorithm – If the version of OpenSSL does not support AES-CCM.

```python
>>> import os
>>> from cryptography.hazmat.primitives.ciphers.aead import AESCCM
>>> data = b"a secret message"
>>> aad = b"authenticated but unencrypted data"
>>> key = AESCCM.generate_key(bit_length=128)
>>> aesccm = AESCCM(key)
>>> nonce = os.urandom(13)
>>> ct = aesccm.encrypt(nonce, data, aad)
>>> aesccm.decrypt(nonce, ct, aad)
'b'a secret message'
```

clasmethod generate_key (bit_length)

Securely generates a random AES-CCM key.

Parameters bit_length – The bit length of the key to generate. Must be 128, 192, or 256.

Returns bytes The generated key.

encrypt (nonce, data, associated_data)

Warning: Reuse of a nonce with a given key compromises the security of any message with that nonce and key pair.

Encrypts and authenticates the data provided as well as authenticating the associated_data. The output of this can be passed directly to the decrypt method.

Parameters
• nonce (bytes-like) – A value of between 7 and 13 bytes. The maximum length is determined by the length of the ciphertext you are encrypting and must satisfy the condition: \( \text{len(data)} < 2^{8 \times (15 - \text{len(nonce)})} \) NEVER REUSE A NONCE with a key.

• data (bytes) – The data to encrypt.

• associated_data (bytes) – Additional data that should be authenticated with the key, but is not encrypted. Can be None.

Returs bytes The ciphertext bytes with the tag appended.

Raises OverflowError – If data or associated_data is larger than \(2^{32}\) bytes.

decrypt (nonce, data, associated_data)

Decrypts the data and authenticates the associated_data. If you called encrypt with associated_data you must pass the same associated_data in decrypt or the integrity check will fail.

Parameters

• nonce (bytes-like) – A value of between 7 and 13 bytes. This is the same value used when you originally called encrypt. NEVER REUSE A NONCE with a key.

• data (bytes) – The data to decrypt (with tag appended).

• associated_data (bytes) – Additional data to authenticate. Can be None if none was passed during encryption.

Returns bytes The original plaintext.

Raises cryptography.exceptions.InvalidTag – If the authentication tag doesn’t validate this exception will be raised. This will occur when the ciphertext has been changed, but will also occur when the key, nonce, or associated data are wrong.

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2.3.2 Asymmetric algorithms

Asymmetric cryptography is a branch of cryptography where a secret key can be divided into two parts, a public key and a private key. The public key can be given to anyone, trusted or not, while the private key must be kept secret (just like the key in symmetric cryptography).

Asymmetric cryptography has two primary use cases: authentication and confidentiality. Using asymmetric cryptography, messages can be signed with a private key, and then anyone with the public key is able to verify that the message was created by someone possessing the corresponding private key. This can be combined with a proof of identity system to know what entity (person or group) actually owns that private key, providing authentication.

Encryption with asymmetric cryptography works in a slightly different way from symmetric encryption. Someone with the public key is able to encrypt a message, providing confidentiality, and then only the person in possession of the private key is able to decrypt it.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.
Ed25519 signing

Ed25519 is an elliptic curve signing algorithm using EdDSA and Curve25519. If you do not have legacy interoperability concerns then you should strongly consider using this signature algorithm.

Signing & Verification

```python
>>> from cryptography.hazmat.primitives.asymmetric.ed25519 import Ed25519PrivateKey
>>> private_key = Ed25519PrivateKey.generate()
>>> signature = private_key.sign(b"my authenticated message")
>>> public_key = private_key.public_key()
>>> # Raises InvalidSignature if verification fails
>>> public_key.verify(signature, b"my authenticated message")
```

Key interfaces

class cryptography.hazmat.primitives.asymmetric.ed25519.Ed25519PrivateKey

New in version 2.6.

classmethod generate()

Generate an Ed25519 private key.

Returns Ed25519PrivateKey

classmethod from_private_bytes(data)

Parameters data (bytes-like) – 32 byte private key.

Returns Ed25519PrivateKey

```python
>>> from cryptography.hazmat.primitives import serialization
>>> from cryptography.hazmat.primitives.asymmetric import ed25519

>>> private_key = ed25519.Ed25519PrivateKey.generate()
>>> private_bytes = private_key.private_bytes(
...     encoding=serialization.Encoding.Raw,
...     format=serialization.PrivateFormat.Raw,
...     encryption_algorithm=serialization.NoEncryption()
...

>>> loaded_private_key = ed25519.Ed25519PrivateKey.from_private_bytes(private_bytes)
```

public_key()

Returns Ed25519PublicKey

sign(data)

Parameters data (bytes) – The data to sign.

Returns bytes The 64 byte signature.

private_bytes(encoding, format, encryption_algorithm)

Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (PKCS8 or Raw) are chosen to define the exact serialization.

Parameters

- encoding – A value from the Encoding enum.
• **format** – A value from the `PrivateFormat` enum. If the encoding is `Raw` then format must be `Raw`, otherwise it must be `PKCS8`.

• **encryption_algorithm** – An instance of an object conforming to the `KeySerializationEncryption` interface.

  Return bytes  Serialized key.

```python
class cryptography.hazmat.primitives.asymmetric.ed25519.Ed25519PublicKey
New in version 2.6.

classmethod from_public_bytes(data)

Parameters  data (bytes) – 32 byte public key.

Returns  Ed25519PublicKey
```

```python
>>> from cryptography.hazmat.primitives import serialization
>>> from cryptography.hazmat.primitives.asymmetric import ed25519

>>> private_key = ed25519.Ed25519PrivateKey.generate()

>>> public_key = private_key.public_key()

>>> public_bytes = public_key.public_bytes(...
...    encoding=serialization.Encoding.Raw,
...    format=serialization.PublicFormat.Raw
...)

>>> loaded_public_key = ed25519.Ed25519PublicKey.from_public_bytes(public_˓
→bytes)
```

**public_bytes (encoding, format)**

Allows serialization of the key to bytes. Encoding (PEM, DER, OpenSSH, or Raw) and format (SubjectPublicKeyInfo, OpenSSH, or Raw) are chosen to define the exact serialization.

Parameters

• **encoding** – A value from the `Encoding` enum.

• **format** – A value from the `PublicFormat` enum. If the encoding is `Raw` then format must be `Raw`. If encoding is `OpenSSH` then format must be `OpenSSH`. In all other cases format must be `SubjectPublicKeyInfo`.

Returns bytes  The public key bytes.

**verify**(signature, data)

Parameters

• **signature (bytes)** – The signature to verify.

• **data (bytes)** – The data to verify.

Raises `cryptography.exceptions.InvalidSignature` – Raised when the signature cannot be verified.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

**X25519 key exchange**

X25519 is an elliptic curve Diffie-Hellman key exchange using Curve25519. It allows two parties to jointly agree on a shared secret using an insecure channel.

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Exchange Algorithm

For most applications the `shared_key` should be passed to a key derivation function. This allows mixing of additional information into the key, derivation of multiple keys, and destroys any structure that may be present.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric.x25519 import X25519PrivateKey
>>> from cryptography.hazmat.primitives.kdf.hkdf import HKDF

>>> # Generate a private key for use in the exchange.
>>> private_key = X25519PrivateKey.generate()

>>> # In a real handshake the peer_public_key will be received from the
>>> # other party. For this example we'll generate another private key and
>>> # get a public key from that. Note that in a DH handshake both peers
>>> # must agree on a common set of parameters.
>>> peer_public_key = X25519PrivateKey.generate().public_key()

>>> shared_key = private_key.exchange(peer_public_key)

>>> # Perform key derivation.
>>> derived_key = HKDF(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=None,
...     info=b'handshake data',
...     backend=default_backend()
... ).derive(shared_key)

>>> # For the next handshake we MUST generate another private key.
>>> private_key_2 = X25519PrivateKey.generate()

>>> peer_public_key_2 = X25519PrivateKey.generate().public_key()

>>> shared_key_2 = private_key_2.exchange(peer_public_key_2)

>>> derived_key_2 = HKDF(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=None,
...     info=b'handshake data',
...     backend=default_backend()
... ).derive(shared_key_2)
```

Key interfaces

```python
class cryptography.hazmat.primitives.asymmetric.x25519.X25519PrivateKey

New in version 2.0.

   classmethod generate()

   Generate an X25519 private key.

   Returns X25519PrivateKey

   classmethod from_private_bytes(data)

   New in version 2.5.

   A class method for loading an X25519 key encoded as Raw.

   Parameters data (bytes) – 32 byte private key.

   Returns X25519PrivateKey
```
```python
>>> from cryptography.hazmat.primitives import serialization
>>> from cryptography.hazmat.primitives.asymmetric import x25519

private_key = x25519.X25519PrivateKey.generate()

private_bytes = private_key.private_bytes(...
    encoding=serialization.Encoding.Raw,
    format=serialization.PrivateFormat.Raw,
    encryption_algorithm=serialization.NoEncryption()
    )

loaded_private_key = x25519.X25519PrivateKey.from_private_bytes(private_bytes)

public_key

Returns X25519PublicKey

echange(peer_public_key)

Parameters peer_public_key (X25519PublicKey) – The public key for the peer.

Returns bytes A shared key.

private_bytes (encoding, format, encryption_algorithm)

New in version 2.5.

Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (PKCS8 or Raw) are chosen to define the exact serialization.

Parameters

• encoding – A value from the Encoding enum.

• format – A value from the PrivateFormat enum. If the encoding is Raw then format must be Raw, otherwise it must be PKCS8.

• encryption_algorithm – An instance of an object conforming to the KeySerializationEncryption interface.

Returns bytes Serialized key.

class cryptography.hazmat.primitives.asymmetric.x25519.X25519PublicKey

New in version 2.0.

classmethod from_public_bytes(data)

Parameters data (bytes) – 32 byte public key.

Returns X25519PublicKey

public_bytes (encoding, format)

New in version 2.5.

Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (SubjectPublicKeyInfo or Raw) are chosen to define the exact serialization.

Parameters

• encoding – A value from the Encoding enum.
• **format** – A value from the `PublicFormat` enum. If the `encoding` is `Raw` then `format` must be `Raw`, otherwise it must be `SubjectPublicKeyInfo`.

Returns bytes The public key bytes.

This is a “Hazardous Materials” module. You should **ONLY** use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

**Ed448 signing**

Ed448 is an elliptic curve signing algorithm using EdDSA.

**Signing & Verification**

```python
>>> from cryptography.hazmat.primitives.asymmetric.ed448 import Ed448PrivateKey
>>> private_key = Ed448PrivateKey.generate()
>>> signature = private_key.sign(b"my authenticated message")
>>> public_key = private_key.public_key()
>>> # Raises InvalidSignature if verification fails
>>> public_key.verify(signature, b"my authenticated message")
```

**Key interfaces**

```python
class cryptography.hazmat.primitives.asymmetric.ed448.Ed448PrivateKey
New in version 2.6.

classmethod generate()
Generate an Ed448 private key.

Returns `Ed448PrivateKey`

classmethod from_private_bytes(data)
Parameters data (bytes-like) – 57 byte private key.

Returns `Ed448PrivateKey`

public_key()
Returns `Ed448PublicKey`

sign(data)
Parameters data (bytes) – The data to sign.

Returns bytes The 114 byte signature.

private_bytes(encoding, format, encryption_algorithm)
Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (PKCS8 or Raw) are chosen to define the exact serialization.

Parameters

• encoding – A value from the `Encoding` enum.

• format – A value from the `PrivateFormat` enum. If the `encoding` is `Raw` then `format` must be `Raw`, otherwise it must be `PKCS8`.```
• encryption_algorithm – An instance of an object conforming to the
KeySerializationEncryption interface.

Return bytes Serialized key.

class cryptography.hazmat.primitives.asymmetric.ed448.Ed448PublicKey
New in version 2.6.

classmethod from_public_bytes(data)
Parameters data (bytes) – 57 byte public key.
Returns Ed448PublicKey

public_bytes(encoding, format)
Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (SubjectPublicKeyInfo or Raw) are chosen to define the exact serialization.

Parameters
• encoding – A value from the Encoding enum.
• format – A value from the PublicFormat enum. If the encoding is Raw then format must be Raw, otherwise it must be SubjectPublicKeyInfo.

Returns bytes The public key bytes.

verify(signature, data)
Parameters
• signature (bytes) – The signature to verify.
• data (bytes) – The data to verify.

Raises cryptography.exceptions.InvalidSignature – Raised when the signature cannot be verified.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

X448 key exchange

X448 is an elliptic curve Diffie-Hellman key exchange using Curve448. It allows two parties to jointly agree on a shared secret using an insecure channel.

Exchange Algorithm

For most applications the shared_key should be passed to a key derivation function. This allows mixing of additional information into the key, derivation of multiple keys, and destroys any structure that may be present.

```python
classfrom cryptography.hazmat.backends import default_backend
classfrom cryptography.hazmat.primitives import hashes
classfrom cryptography.hazmat.primitives.asymmetric.x448 import X448PrivateKey
classfrom cryptography.hazmat.primitives.kdf.hkdf import HKDF
>>> # Generate a private key for use in the exchange.
>>> private_key = X448PrivateKey.generate()
>>> # In a real handshake the peer_public_key will be received from the
```
(continues on next page)
other party. For this example we’ll generate another private key and
get a public key from that. Note that in a DH handshake both peers
must agree on a common set of parameters.
peer_public_key = X448PrivateKey.generate().public_key()
shared_key = private_key.exchange(peer_public_key)
# Perform key derivation.
derived_key = HKDF(
    algorithm=hashes.SHA256(),
    length=32,
    salt=None,
    info=b'handshake data',
    backend=default_backend() 
).derive(shared_key)

# For the next handshake we MUST generate another private key.
private_key_2 = X448PrivateKey.generate()
peer_public_key_2 = X448PrivateKey.generate().public_key()
shared_key_2 = private_key_2.exchange(peer_public_key_2)
derived_key_2 = HKDF(
    algorithm=hashes.SHA256(),
    length=32,
    salt=None,
    info=b'handshake data',
    backend=default_backend() 
).derive(shared_key_2)

Key interfaces

```python
class cryptography.hazmat.primitives.asymmetric.x448.X448PrivateKey

New in version 2.5.

classmethod generate()
    Generate an X448 private key.

Returns X448PrivateKey

classmethod from_private_bytes(data)
    Parameters data (bytes-like) – 56 byte private key.

Returns X448PrivateKey
```

```python
>>> from cryptography.hazmat.primitives import serialization
>>> from cryptography.hazmat.primitives.asymmetric import x448

>>> private_key = x448.X448PrivateKey.generate()
>>> private_bytes = private_key.private_bytes(
    encoding=serialization.Encoding.Raw,
    format=serialization.PrivateFormat.Raw,
    encryption_algorithm=serialization.NoEncryption()
)
>>> loaded_private_key = x448.X448PrivateKey.from_private_bytes(private_bytes)

public_key()

Returns X448PublicKey

exchange(peer_public_key)
    Parameters peer_public_key (X448PublicKey) – The public key for the peer.
Returns bytes  A shared key.

`private_bytes`(encoding, format, encryption_algorithm)

Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (PKCS8 or Raw) are chosen to define the exact serialization.

Parameters

- **encoding** – A value from the `Encoding` enum.
- **format** – A value from the `PrivateFormat` enum. If the `encoding` is Raw then `format` must be Raw, otherwise it must be PKCS8.
- **encryption_algorithm** – An instance of an object conforming to the `KeySerializationEncryption` interface.

Returns bytes  Serialized key.

class cryptography.hazmat.primitives.asymmetric.x448.X448PublicKey

New in version 2.5.

`classmethod from_public_bytes`(data)

Parameters data (bytes) – 56 byte public key.

Returns  `X448PublicKey`

```python
>>> from cryptography.hazmat.primitives import serialization
>>> from cryptography.hazmat.primitives.asymmetric import x448

>>> private_key = x448.X448PrivateKey.generate()
>>> public_key = private_key.public_key()

>>> public_bytes = public_key.public_bytes(... encoding=serialization.Encoding.Raw,
... format=serialization.PublicFormat.Raw)

>>> loaded_public_key = x448.X448PublicKey.from_public_bytes(public_bytes)
```

`public_bytes`(encoding, format)

Allows serialization of the key to bytes. Encoding (PEM, DER, or Raw) and format (SubjectPublicKeyInfo or Raw) are chosen to define the exact serialization.

Parameters

- **encoding** – A value from the `Encoding` enum.
- **format** – A value from the `PublicFormat` enum. If the `encoding` is Raw then `format` must be Raw, otherwise it must be SubjectPublicKeyInfo.

Returns bytes  The public key bytes.

This is a “Hazardous Materials” module. You should **ONLY** use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

Elliptic curve cryptography

cryptography.hazmat.primitives.asymmetric.ec.`generate_private_key`(curve, back-end)

New in version 0.5.

Generate a new private key on `curve` for use with `backend`.

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Parameters

- **curve** – An instance of `EllipticCurve`.
- **backend** – An instance of `EllipticCurveBackend`.

Returns A new instance of `EllipticCurvePrivateKey`.

```python
import cryptography.hazmat.primitives.asymmetric.ec

cryptography.hazmat.primitives.asymmetric.ec.derive_private_key(private_value, curve, backend)
```

New in version 1.6.

Derive a private key from `private_value` on `curve` for use with `backend`.

Parameters

- **private_value** (*int*) – The secret scalar value.
- **curve** – An instance of `EllipticCurve`.
- **backend** – An instance of `EllipticCurveBackend`.

Returns A new instance of `EllipticCurvePrivateKey`.

Elliptic Curve Signature Algorithms

```python
class cryptography.hazmat.primitives.asymmetric.ec.ECDSA(algorithm)
```

New in version 0.5.

The ECDSA signature algorithm first standardized in NIST publication FIPS 186-3, and later in FIPS 186-4.

Parameters **algorithm** – An instance of `HashAlgorithm`.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import ec

>>> private_key = ec.generate_private_key(ec.SECP384R1(), default_backend())

>>> data = b"this is some data I'd like to sign"

>>> signature = private_key.sign(data, ec.ECDSA(hashes.SHA256()))
```

The signature is a bytes object, whose contents is DER encoded as described in RFC 3279. This can be decoded using `decode_dss_signature()`.

If your data is too large to be passed in a single call, you can hash it separately and pass that value using `Prehashed`.

```python
>>> from cryptography.hazmat.primitives.asymmetric import utils

>>> chosen_hash = hashes.SHA256()

>>> hasher = hashes.Hash(chosen_hash, default_backend())

>>> hasher.update(b"data & ")

>>> hasher.update(b"more data")

>>> digest = hasher.finalize()

>>> sig = private_key.sign(digest)
```
ec.ECDSA(utils.Prehashed(chosen_hash))

Verification requires the public key, the signature itself, the signed data, and knowledge of the hashing algorithm that was used when producing the signature:

```python
>>> public_key = private_key.public_key()
>>> public_key.verify(signature, data, ec.ECDSA(hashes.SHA256()))
```

If the signature is not valid, an `InvalidSignature` exception will be raised.

If your data is too large to be passed in a single call, you can hash it separately and pass that value using `Prehashed`.

```python
>>> chosen_hash = hashes.SHA256()
>>> hasher = hashes.Hash(chosen_hash, default_backend())
>>> hasher.update(b"data & ")
>>> hasher.update(b"more data")
>>> digest = hasher.finalize()
>>> public_key.verify(...
... sig,
... digest,
... ec.ECDSA(utils.Prehashed(chosen_hash))
... )
```

**Note:** Although in this case the public key was derived from the private one, in a typical setting you will not possess the private key. The *Key loading* section explains how to load the public key from other sources.

```python
class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurvePrivateNumbers
  (private_value, pub-
    lic_numbers)
```

New in version 0.5.

The collection of integers that make up an EC private key.

**public_numbers**

Type `EllipticCurvePublicNumbers`

The `EllipticCurvePublicNumbers` which makes up the EC public key associated with this EC private key.

**private_value**

Type `int`

The private value.

**private_key (backend)**

Convert a collection of numbers into a private key suitable for doing actual cryptographic operations.

Parameters **backend** – An instance of `EllipticCurveBackend`.

Returns A new instance of `EllipticCurvePrivateKey`.

```python
class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurvePublicNumbers
  (x, y, curve)
```

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Warning: The point represented by this object is not validated in any way until `EllipticCurvePublicNumbers.public_key()` is called and may not represent a valid point on the curve. You should not attempt to perform any computations using the values from this class until you have either validated it yourself or called `public_key()` successfully.

New in version 0.5.

The collection of integers that make up an EC public key.

```
curve
  Type EllipticCurve
  The elliptic curve for this key.
```

```
x
  Type int
  The affine x component of the public point used for verifying.
```

```
y
  Type int
  The affine y component of the public point used for verifying.
```

```
public_key(backend)
  Convert a collection of numbers into a public key suitable for doing actual cryptographic operations.
  Parameters backend – An instance of `EllipticCurveBackend`.
  Raises ValueError – Raised if the point is invalid for the curve.
  Returns A new instance of `EllipticCurvePublicKey`.
```

```
encode_point()
```

Warning: This method is deprecated as of version 2.5. Callers should migrate to using `public_bytes()`.

New in version 1.1.

Encodes an elliptic curve point to a byte string as described in SEC 1 v2.0 section 2.3.3. This method only supports uncompressed points.

```
Return bytes The encoded point.
```

```
classmethod from_encoded_point(curve, data)
  New in version 1.1.
  Note: This has been deprecated in favor of `from_encoded_point()`
```

Decodes a byte string as described in SEC 1 v2.0 section 2.3.3 and returns an `EllipticCurvePublicNumbers`. This method only supports uncompressed points.

```
Parameters
  • curve – An `EllipticCurve` instance.
  • data (bytes) – The serialized point byte string.
```
Returns  An EllipticCurvePublicNumbers instance.

Raises

- ValueError – Raised on invalid point type or data length.
- TypeError – Raised when curve is not an EllipticCurve.

Elliptic Curve Key Exchange algorithm

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import ec
>>> from cryptography.hazmat.primitives.kdf.hkdf import HKDF

>>> # Generate a private key for use in the exchange.
>>> server_private_key = ec.generate_private_key(
...   ec.SECP384R1(), default_backend()
...
>>> # In a real handshake the peer is a remote client. For this
>>> # example we'll generate another local private key too.
>>> peer_private_key = ec.generate_private_key(
...   ec.SECP384R1(), default_backend()
...
>>> shared_key = server_private_key.exchange(
...   ec.ECDH(), peer_private_key.public_key())

>>> derived_key = HKDF(
...   algorithm=hashes.SHA256(),
...   length=32,
...   salt=None,
...   info=b'handshake data',
...   backend=default_backend()
... ).derive(shared_key)

>>> # And now we can demonstrate that the handshake performed in the
>>> # opposite direction gives the same final value
>>> same_shared_key = peer_private_key.exchange(
...   ec.ECDH(), server_private_key.public_key())

>>> same_derived_key = HKDF(
...   algorithm=hashes.SHA256(),
...   length=32,
...   salt=None,
...   info=b'handshake data',
```

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Elliptic Curves

Elliptic curves provide equivalent security at much smaller key sizes than other asymmetric cryptography systems such as RSA or DSA. For many operations elliptic curves are also significantly faster; elliptic curve diffie-hellman is faster than diffie-hellman.
Note: Curves with a size of less than 224 bits should not be used. You should strongly consider using curves of at least 224 bits.

Generally the NIST prime field (“P”) curves are significantly faster than the other types suggested by NIST at both signing and verifying with ECDSA.

Prime fields also minimize the number of security concerns for elliptic-curve cryptography. However, there is some concern that both the prime field and binary field (“B”) NIST curves may have been weakened during their generation.

Currently cryptography only supports NIST curves, none of which are considered “safe” by the SafeCurves project run by Daniel J. Bernstein and Tanja Lange.

All named curves are instances of EllipticCurve.

class cryptography.hazmat.primitives.asymmetric.ec.SECP256R1
    New in version 0.5.
    SECG curve secp256r1. Also called NIST P-256.

class cryptography.hazmat.primitives.asymmetric.ec.SECP384R1
    New in version 0.5.
    SECG curve secp384r1. Also called NIST P-384.

class cryptography.hazmat.primitives.asymmetric.ec.SECP521R1
    New in version 0.5.
    SECG curve secp521r1. Also called NIST P-521.

class cryptography.hazmat.primitives.asymmetric.ec.SECP224R1
    New in version 0.5.
    SECG curve secp224r1. Also called NIST P-224.

class cryptography.hazmat.primitives.asymmetric.ec.SECP192R1
    New in version 0.5.
    SECG curve secp192r1. Also called NIST P-192.

class cryptography.hazmat.primitives.asymmetric.ec.SECT571K1
    New in version 0.9.
    SECG curve sect571k1.

class cryptography.hazmat.primitives.asymmetric.ec.BrainpoolP256R1
    New in version 2.2.
    Brainpool curve specified in RFC 5639. These curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.BrainpoolP384R1
    New in version 2.2.
    Brainpool curve specified in RFC 5639. These curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.BrainpoolP512R1
    New in version 2.2.
    Brainpool curve specified in RFC 5639. These curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT571K1
    New in version 0.5.
    SECG curve sect571k1. Also called NIST K-571. These binary curves are discouraged for new systems.
class cryptography.hazmat.primitives.asymmetric.ec.SECT409K1
    New in version 0.5.
    SECG curve sect409k1. Also called NIST K-409. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT283K1
    New in version 0.5.
    SECG curve sect283k1. Also called NIST K-283. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT233K1
    New in version 0.5.
    SECG curve sect233k1. Also called NIST K-233. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT163K1
    New in version 0.5.
    SECG curve sect163k1. Also called NIST K-163. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT571R1
    New in version 0.5.
    SECG curve sect571r1. Also called NIST B-571. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT409R1
    New in version 0.5.
    SECG curve sect409r1. Also called NIST B-409. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT283R1
    New in version 0.5.
    SECG curve sect283r1. Also called NIST B-283. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT233R1
    New in version 0.5.
    SECG curve sect233r1. Also called NIST B-233. These binary curves are discouraged for new systems.

class cryptography.hazmat.primitives.asymmetric.ec.SECT163R2
    New in version 0.5.
    SECG curve sect163r2. Also called NIST B-163. These binary curves are discouraged for new systems.

Key Interfaces

class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurve
    New in version 0.5.
    A named elliptic curve.

    name
        Type  str
        The name of the curve. Usually the name used for the ASN.1 OID such as secp256k1.

    key_size
        Type  int
        Size (in bits) of a secret scalar for the curve (as generated by generate_private_key()).
class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurveSignatureAlgorithm

New in version 0.5.

Changed in version 1.6: Prehashed can now be used as an algorithm.

A signature algorithm for use with elliptic curve keys.

algorithm

Type HashAlgorithm or Prehashed

The digest algorithm to be used with the signature scheme.

class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurvePrivateKey

New in version 0.5.

An elliptic curve private key for use with an algorithm such as ECDSA or EdDSA. An elliptic curve private key that is not an opaque key also implements EllipticCurvePrivateKeyWithSerialization to provide serialization methods.

exchange (algorithm, peer_public_key)

New in version 1.1.

Performs a key exchange operation using the provided algorithm with the peer’s public key.

For most applications the shared_key should be passed to a key derivation function. This allows mixing of additional information into the key, derivation of multiple keys, and destroys any structure that may be present.

Parameters

• algorithm – The key exchange algorithm, currently only ECDH is supported.
• peer_public_key (EllipticCurvePublicKey) – The public key for the peer.

Returns bytes A shared key.

class (algorithm, peer_public_key)

New in version 1.1.

Performs a key exchange operation using the provided algorithm with the peer’s public key.

For most applications the shared_key should be passed to a key derivation function. This allows mixing of additional information into the key, derivation of multiple keys, and destroys any structure that may be present.

Parameters

• algorithm – The key exchange algorithm, currently only ECDH is supported.
• peer_public_key (EllipticCurvePublicKey) – The public key for the peer.

Returns bytes A shared key.

public_key ()

Returns EllipticCurvePublicKey

The EllipticCurvePublicKey object for this private key.

sign (data, signature_algorithm)

New in version 1.5.

Sign one block of data which can be verified later by others using the public key.

Parameters

• data (bytes) – The message string to sign.
• signature_algorithm – An instance of EllipticCurveSignatureAlgorithm, such as ECDSA.

Return bytes Signature.

key_size

New in version 1.9.

Type int

Size (in bits) of a secret scalar for the curve (as generated by generate_private_key()).

class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurvePrivateKeyWithSerialization

New in version 0.8.
This interface contains additional methods relating to serialization. Any object with this interface also has all the methods from EllipticCurvePrivateKey.

private_numbers() Create a EllipticCurvePrivateNumbers object.

Returns An EllipticCurvePrivateNumbers instance.

private_bytes(encoding, format, encryption_algorithm) Allows serialization of the key to bytes. Encoding (PEM or DER), format (TraditionalOpenSSL or PKCS8) and encryption algorithm (such as BestAvailableEncryption or NoEncryption) are chosen to define the exact serialization.

Parameters

- **encoding** – A value from the Encoding enum.
- **format** – A value from the PrivateFormat enum.
- **encryption_algorithm** – An instance of an object conforming to the KeySerializationEncryption interface.

Return bytes Serialized key.

class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurvePublicKey New in version 0.5.

An elliptic curve public key.

curve

Type EllipticCurve

The elliptic curve for this key.

public_numbers() Create a EllipticCurvePublicNumbers object.

Returns An EllipticCurvePublicNumbers instance.

public_bytes(encoding, format) Allows serialization of the key data to bytes. When encoding the public key the encodings (PEM, DER) and format (SubjectPublicKeyInfo) are chosen to define the exact serialization. When encoding the point the encoding X962 should be used with the formats (UncompressedPoint or CompressedPoint).

Parameters

- **encoding** – A value from the Encoding enum.
- **format** – A value from the PublicFormat enum.

Return bytes Serialized data.

verify(signature, data, signature_algorithm) New in version 1.5.

Verify one block of data was signed by the private key associated with this public key.

Parameters

- **signature** (bytes) – The signature to verify.
- **data** (bytes) – The message string that was signed.
- **signature_algorithm** – An instance of EllipticCurveSignatureAlgorithm.
Raises `cryptography.exceptions.InvalidSignature` – If the signature does not validate.

**key_size**

New in version 1.9.

**Type** `int`

Size (in bits) of a secret scalar for the curve (as generated by `generate_private_key()`).

**classmethod from_encoded_point** *(curve, data)*

New in version 2.5.

Decodes a byte string as described in SEC 1 v2.0 section 2.3.3 and returns an `EllipticCurvePublicKey`. This class method supports compressed points.

**Parameters**

- **curve** – An `EllipticCurve` instance.
- **data** *(bytes)* – The serialized point byte string.

**Returns** An `EllipticCurvePublicKey` instance.

**Raises**

- **ValueError** – Raised when an invalid point is supplied.
- **TypeError** – Raised when curve is not an `EllipticCurve`.

**class** `cryptography.hazmat.primitives.asymmetric.ec.EllipticCurvePublicKeyWithSerialization`

New in version 0.6.

Alias for `EllipticCurvePublicKey`.

**Serialization**

This sample demonstrates how to generate a private key and serialize it.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import ec
>>> from cryptography.hazmat.primitives import serialization

>>> private_key = ec.generate_private_key(ec.SECP384R1(), default_backend())

>>> serialized_private = private_key.private_bytes(... encoding=serialization.Encoding.PEM,
... format=serialization.PrivateFormat.PKCS8,
... encryption_algorithm=serialization.BestAvailableEncryption(b'testpassword'))
...

>>> serialized_private.splitlines()[0]
b'-----BEGIN ENCRYPTED PRIVATE KEY-----'
```

You can also serialize the key without a password, by relying on `NoEncryption`.

The public key is serialized as follows:

```python
>>> public_key = private_key.public_key()

>>> serialized_public = public_key.public_bytes(... encoding=serialization.Encoding.PEM,
...
```

(continues on next page)
This is the part that you would normally share with the rest of the world.

**Key loading**

This extends the sample in the previous section, assuming that the variables `serialized_private` and `serialized_public` contain the respective keys in PEM format.

```python
>>> loaded_public_key = serialization.load_pem_public_key(
...    serialized_public,
...    backend=default_backend()
...)

>>> loaded_private_key = serialization.load_pem_private_key(
...    serialized_private,
...    password=b'testpassword',
...    backend=default_backend()
...)
```

### Elliptic Curve Object Identifiers

```python
class cryptography.hazmat.primitives.asymmetric.ec.EllipticCurveOID

New in version 2.4.

<table>
<thead>
<tr>
<th>Elliptic Curve OID</th>
<th>Dotted String</th>
</tr>
</thead>
<tbody>
<tr>
<td>SECP192R1</td>
<td>1.2.840.10045.3.1.1</td>
</tr>
<tr>
<td>SECP224R1</td>
<td>1.3.132.0.33</td>
</tr>
<tr>
<td>SECP256K1</td>
<td>1.3.132.0.10</td>
</tr>
<tr>
<td>SECP256R1</td>
<td>1.2.840.10045.3.1.7</td>
</tr>
<tr>
<td>SECP384R1</td>
<td>1.3.132.0.34</td>
</tr>
<tr>
<td>SECP521R1</td>
<td>1.3.132.0.35</td>
</tr>
<tr>
<td>BRAINPOOLP256R1</td>
<td>1.3.36.3.3.2.8.1.1.7</td>
</tr>
<tr>
<td>BRAINPOOLP384R1</td>
<td>1.3.36.3.3.2.8.1.1.11</td>
</tr>
</tbody>
</table>
```
**BRAINPOOLP512R1**
New in version 2.5.
Corresponds to the dotted string "1.3.36.3.3.2.8.1.1.13".

**SECT163K1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.1".

**SECT163R2**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.15".

**SECT233K1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.26".

**SECT233R1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.27".

**SECT283K1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.16".

**SECT283R1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.17".

**SECT409K1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.36".

**SECT409R1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.37".

**SECT571K1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.38".

**SECT571R1**
New in version 2.5.
Corresponds to the dotted string "1.3.132.0.39".

cryptography.hazmat.primitives.asymmetric.ec.get_curve_for_oid(oid)
New in version 2.6.
A function that takes an `ObjectIdentifier` and returns the associated elliptic curve class.

**Parameters** `oid` – An instance of `ObjectIdentifier`.

**Returns** The matching elliptic curve class. The returned class conforms to the `EllipticCurve` interface.

**Raises** `LookupError` – Raised if no elliptic curve is found that matches the provided object identifier.
This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

**RSA**

RSA is a public-key algorithm for encrypting and signing messages.

**Generation**

Unlike symmetric cryptography, where the key is typically just a random series of bytes, RSA keys have a complex internal structure with specific mathematical properties.

```python
from cryptography.hazmat.primitives.asymmetric import rsa
generate_private_key(public_exponent, key_size, backend)
```

New in version 0.5.

Generates a new RSA private key using the provided backend. `key_size` describes how many bits long the key should be. Larger keys provide more security; currently 1024 and below are considered breakable while 2048 or 4096 are reasonable default key sizes for new keys. The `public_exponent` indicates what one mathematical property of the key generation will be. Unless you have a specific reason to do otherwise, you should always use 65537.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.asymmetric import rsa
>>> private_key = rsa.generate_private_key(...
...    public_exponent=65537,
...    key_size=2048,
...    backend=default_backend())
```

**Parameters**

- **public_exponent** (*int*) – The public exponent of the new key. Usually one of the small Fermat primes 3, 5, 17, 257, 65537. If in doubt you should use 65537.

- **key_size** (*int*) – The length of the modulus in bits. For keys generated in 2015 it is strongly recommended to be at least 2048 (See page 41). It must not be less than 512. Some backends may have additional limitations.

- **backend** – A backend which implements `RSABackend`.

**Returns** An instance of `RSAPrivateKey`.

**Raises** `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `RSABackend`.

**Key loading**

If you already have an on-disk key in the PEM format (which are recognizable by the distinctive `-----BEGIN (format)-----` and `-----END (format)-----` markers), you can load it:
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import serialization

>>> with open("path/to/key.pem", "rb") as key_file:
...     private_key = serialization.load_pem_private_key(
...         key_file.read(),
...         password=None,
...         backend=default_backend()
... )

Serialized keys may optionally be encrypted on disk using a password. In this example we loaded an unencrypted key, and therefore we did not provide a password. If the key is encrypted we can pass a bytes object as the password argument.

There is also support for loading public keys in the SSH format.

Key serialization

If you have a private key that you’ve loaded or generated which implements the RSAPrivateKeyWithSerialization interface you can use private_bytes() to serialize the key.

```python
>>> from cryptography.hazmat.primitives import serialization
>>> pem = private_key.private_bytes(
...     encoding=serialization.Encoding.PEM,
...     format=serialization.PrivateFormat.PKCS8,
...     encryption_algorithm=serialization.BestAvailableEncryption(b'mypassword')
... )
>>> pem.splitlines()[0]
b'-----BEGIN ENCRYPTED PRIVATE KEY-----'
```

It is also possible to serialize without encryption using NoEncryption.

```python
>>> pem = private_key.private_bytes(
...     encoding=serialization.Encoding.PEM,
...     format=serialization.PrivateFormat.TraditionalOpenSSL,
...     encryption_algorithm=serialization.NoEncryption()
... )
>>> pem.splitlines()[0]
b'-----BEGIN RSA PRIVATE KEY-----'
```

For public keys you can use public_bytes() to serialize the key.

```python
>>> from cryptography.hazmat.primitives import serialization
>>> public_key = private_key.public_key()
>>> pem = public_key.public_bytes(
...     encoding=serialization.Encoding.PEM,
...     format=serialization.PublicFormat.SubjectPublicKeyInfo
... )
>>> pem.splitlines()[0]
b'-----BEGIN PUBLIC KEY-----'
```

Signing

A private key can be used to sign a message. This allows anyone with the public key to verify that the message was created by someone who possesses the corresponding private key. RSA signatures require a specific hash function, and
padding to be used. Here is an example of signing message using RSA, with a secure hash function and padding:

```python
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import padding

>>> message = b"A message I want to sign"
>>> signature = private_key.sign(
...    message,
...    padding.PSS(
...        mgf=padding.MGF1(hashes.SHA256()),
...        salt_length=padding.PSS.MAX_LENGTH
...    ),
...    hashes.SHA256()
...)
```

Valid paddings for signatures are `PSS` and `PKCS1v15`. `PSS` is the recommended choice for any new protocols or applications, `PKCS1v15` should only be used to support legacy protocols.

If your data is too large to be passed in a single call, you can hash it separately and pass that value using `Prehashed`.

```python
>>> from cryptography.hazmat.primitives.asymmetric import utils

>>> chosen_hash = hashes.SHA256()
>>> hasher = hashes.Hash(chosen_hash, default_backend())
>>> hasher.update(b"data & ")
>>> hasher.update(b"more data")
>>> digest = hasher.finalize()

>>> sig = private_key.sign(
...    digest,
...    padding.PSS(
...        digest,
...        mgf=padding.MGF1(hashes.SHA256()),
...        salt_length=padding.PSS.MAX_LENGTH
...    ),
...    utils.Prehashed(chosen_hash)
...)
```

**Verification**

The previous section describes what to do if you have a private key and want to sign something. If you have a public key, a message, a signature, and the signing algorithm that was used you can check that the private key associated with a given public key was used to sign that specific message. You can obtain a public key to use in verification using `load_pem_public_key()`, `load_der_public_key()`, `public_key()` , or `public_key()`.

```python
>>> public_key = private_key.public_key()
>>> public_key.verify(
...    signature,
...    message,
...    padding.PSS(
...        mgf=padding.MGF1(hashes.SHA256()),
...        salt_length=padding.PSS.MAX_LENGTH
...    ),
...    hashes.SHA256()
...)
```

If the signature does not match, `verify()` will raise an `InvalidSignature` exception.

If your data is too large to be passed in a single call, you can hash it separately and pass that value using `Prehashed`. 
```python
>>> chosen_hash = hashes.SHA256()
>>> hasher = hashes.Hash(chosen_hash, default_backend())
>>> hasher.update(b"data & ")
>>> digest = hasher.finalize()
```

**Encryption**

RSA encryption is interesting because encryption is performed using the public key, meaning anyone can encrypt data. The data is then decrypted using the private key.

Like signatures, RSA supports encryption with several different padding options. Here’s an example using a secure padding and hash function:

```python
>>> message = b"encrypted data"
>>> ciphertext = public_key.encrypt(
...     message,
...     padding.OAEP(
...         mgf=padding.MGF1(algorithm=hashes.SHA256()),
...         algorithm=hashes.SHA256(),
...         label=None
...     )
... )
```

Valid paddings for encryption are OAEP and PKCS1v15. OAEP is the recommended choice for any new protocols or applications, PKCS1v15 should only be used to support legacy protocols.

**Decryption**

Once you have an encrypted message, it can be decrypted using the private key:

```python
>>> plaintext = private_key.decrypt(
...     ciphertext,
...     padding.OAEP(
...         mgf=padding.MGF1(algorithm=hashes.SHA256()),
...         algorithm=hashes.SHA256(),
...         label=None
...     )
... )
>>> plaintext == message
True
```
Padding

class cryptography.hazmat.primitives.asymmetric.padding.AsymmetricPadding
    New in version 0.2.

name
class cryptography.hazmat.primitives.asymmetric.padding.PSS(mgf, salt_length)
    New in version 0.3.
    Changed in version 0.4: Added salt_length parameter.

PSS (Probabilistic Signature Scheme) is a signature scheme defined in RFC 3447. It is more complex than PKCS1 but possesses a security proof. This is the recommended padding algorithm for RSA signatures. It cannot be used with RSA encryption.

Parameters

• mgf – A mask generation function object. At this time the only supported MGF is MGF1.
• salt_length (int) – The length of the salt. It is recommended that this be set to PSS.MAX_LENGTH.

MAX_LENGTH
Pass this attribute to salt_length to get the maximum salt length available.

class cryptography.hazmat.primitives.asymmetric.padding.OAEP(mgf, algorithm, label)
    New in version 0.4.

OAEP (Optimal Asymmetric Encryption Padding) is a padding scheme defined in RFC 3447. It provides probabilistic encryption and is proven secure against several attack types. This is the recommended padding algorithm for RSA encryption. It cannot be used with RSA signing.

Parameters

• mgf – A mask generation function object. At this time the only supported MGF is MGF1.
• algorithm – An instance of HashAlgorithm.
• label (bytes) – A label to apply. This is a rarely used field and should typically be set to None or b"", which are equivalent.

class cryptography.hazmat.primitives.asymmetric.padding.PKCS1v15
    New in version 0.3.

PKCS1 v1.5 (also known as simply PKCS1) is a simple padding scheme developed for use with RSA keys. It is defined in RFC 3447. This padding can be used for signing and encryption.

It is not recommended that PKCS1v15 be used for new applications, OAEP should be preferred for encryption and PSS should be preferred for signatures.

cryptography.hazmat.primitives.asymmetric.padding.calculate_max_pss_salt_length(key, hash_algorithm)
    New in version 1.5.

Parameters

• key – An RSA public or private key.
• hash_algorithm – A cryptography.hazmat.primitives.hashes.HashAlgorithm.

Returns int The computed salt length.
Computes the length of the salt that \textit{PSS} will use if \textit{PSS.MAX_LENGTH} is used.

**Mask generation functions**

\texttt{class cryptography.hazmat.primitives.asymmetric.padding.MGF1(algorithm)}

New in version 0.3.

Changed in version 0.6: Removed the deprecated \textit{salt_length} parameter.

MGF1 (Mask Generation Function 1) is used as the mask generation function in \textit{PSS} and \textit{OAEP} padding. It takes a hash algorithm.

\textbf{Parameters} \textit{algorithm} – An instance of \texttt{HashAlgorithm}.

**Numbers**

These classes hold the constituent components of an RSA key. They are useful only when more traditional Key Serialization is unavailable.

\texttt{class cryptography.hazmat.primitives.asymmetric.rsa.RSAPublicNumbers(e, n)}

New in version 0.5.

The collection of integers that make up an RSA public key.

\begin{itemize}
  \item \texttt{n} \hspace{1cm} \textbf{Type} int
  \hspace{1cm} The public modulus.
  \item \texttt{e} \hspace{1cm} \textbf{Type} int
  \hspace{1cm} The public exponent.
\end{itemize}

\texttt{public_key(backend)}

\textbf{Parameters} \textit{backend} – An instance of \texttt{RSABackend}.

\textbf{Returns} A new instance of \texttt{RSAPublicKey}.

\texttt{class cryptography.hazmat.primitives.asymmetric.rsa.RSAPrivateNumbers(p, q, d, dmp1, dmq1, iqmp, public_numbers)}

New in version 0.5.

The collection of integers that make up an RSA private key.

**Warning:** With the exception of the integers contained in the \texttt{RSAPublicNumbers} all attributes of this class must be kept secret. Revealing them will compromise the security of any cryptographic operations performed with a key loaded from them.

\texttt{public_numbers}
Type `RSAPublicNumbers`
The `RSAPublicNumbers` which makes up the RSA public key associated with this RSA private key.

\[ P \]
Type `int`
p, one of the two primes composing \( n \).

\[ q \]
Type `int`
q, one of the two primes composing \( n \).

\[ d \]
Type `int`
The private exponent.

\[ dmp1 \]
Type `int`
A Chinese remainder theorem coefficient used to speed up RSA operations. Calculated as: \( d \mod (p-1) \)

\[ dmq1 \]
Type `int`
A Chinese remainder theorem coefficient used to speed up RSA operations. Calculated as: \( d \mod (q-1) \)

\[ iqmp \]
Type `int`
A Chinese remainder theorem coefficient used to speed up RSA operations. Calculated as: \( q^{-1} \mod p \)

`private_key (backend)`

Parameters `backend` – A new instance of `RSABackend`.

Returns An instance of `RSAPrivateKey`.

**Handling partial RSA private keys**

If you are trying to load RSA private keys yourself you may find that not all parameters required by `RSAPrivateNumbers` are available. In particular the Chinese Remainder Theorem (CRT) values \( dmp1, dmq1, iqmp \) may be missing or present in a different form. For example, OpenPGP does not include the \( iqmp, dmp1 \) or \( dmq1 \) parameters.

The following functions are provided for users who want to work with keys like this without having to do the math themselves.

```python
from cryptography.hazmat.primitives.asymmetric.rsa import rsa_crt_iqmp
rsa_crt_iqmp(p, q)
```

New in version 0.4.

Computes the \( iqmp \) (also known as \( qInv \)) parameter from the RSA primes \( p \) and \( q \).

```python
from cryptography.hazmat.primitives.asymmetric.rsa import rsa_crt_dmp1
rsa_crt_dmp1(private_exponent, p)
```

New in version 0.4.

Computes the \( dmp1 \) parameter from the RSA private exponent \( (d) \) and prime \( p \).
cryptography.hazmat.primitives.asymmetric.rsa.rsa_crt_dmq1 (private_exponent, q)
New in version 0.4.
Computes the dmq1 parameter from the RSA private exponent (d) and prime q.

cryptography.hazmat.primitives.asymmetric.rsa.rsa_recover_prime_factors (n, e, d)
New in version 0.8.
Computes the prime factors (p, q) given the modulus, public exponent, and private exponent.

Note: When recovering prime factors this algorithm will always return p and q such that p > q. Note: before 1.5, this function always returned p and q such that p < q. It was changed because libraries commonly require p > q.

Returns A tuple (p, q)

Key interfaces

class cryptography.hazmat.primitives.asymmetric.rsa.RSAPrivateKey
New in version 0.2.
An RSA private key. An RSA private key that is not an opaque key also implements RSAPrivateKeyWithSerialization to provide serialization methods.
decrypt (ciphertext, padding)
New in version 0.4.
Decrypt data that was encrypted with the public key.

Parameters

• ciphertext (bytes) – The ciphertext to decrypt.
• padding – An instance of AsymmetricPadding.

Return bytes Decrypted data.

public_key ()

Returns RSAPublicKey
An RSA public key object corresponding to the values of the private key.

key_size

Type int
The bit length of the modulus.
sign (data, padding, algorithm)
New in version 1.4.
Changed in version 1.6: Prehashed can now be used as an algorithm.
Sign one block of data which can be verified later by others using the public key.

Parameters

• data (bytes) – The message string to sign.
• padding – An instance of AsymmetricPadding.
• **algorithm** – An instance of HashAlgorithm or Prehashed if the data you want to sign has already been hashed.

  **Return bytes** Signature.

```python
class cryptography.hazmat.primitives.asymmetric.rsa.RSAPrivateKeyWithSerialization
New in version 0.8.
```

This interface contains additional methods relating to serialization. Any object with this interface also has all the methods from RSAPrivateKey.

```python
private_numbers()  
Create a RSAPrivateNumbers object.

  **Returns** An RSAPrivateNumbers instance.

private_bytes(encoding, format, encryption_algorithm)  
Allows serialization of the key to bytes. Encoding (PEM or DER), format (TraditionalOpenSSL or PKCS8) and encryption algorithm (such as BestAvailableEncryption or NoEncryption) are chosen to define the exact serialization.

  **Parameters**

    • **encoding** – A value from the Encoding enum.
    • **format** – A value from the PrivateFormat enum.
    • **encryption_algorithm** – An instance of an object conforming to the KeySerializationEncryption interface.

  **Return bytes** Serialized key.
```
• **encoding** – A value from the `Encoding` enum.
• **format** – A value from the `PublicFormat` enum.

Return bytes: Serialized key.

```python
verify(signature, data, padding, algorithm)
```

New in version 1.4.

Changed in version 1.6: `Prehashed` can now be used as an `algorithm`.

Verify one block of data was signed by the private key associated with this public key.

**Parameters**

• `signature` *(bytes)* – The signature to verify.
• `data` *(bytes)* – The message string that was signed.
• `padding` – An instance of `AsymmetricPadding`.
• `algorithm` – An instance of `HashAlgorithm` or `Prehashed` if the `data` you want to verify has already been hashed.

*Raises* `cryptography.exceptions.InvalidSignature` – If the signature does not validate.

```python
class cryptography.hazmat.primitives.asymmetric.rsa.RSAPublicKeyWithSerialization
```

New in version 0.8.

Alias for `RSAPublicKey`.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

---

**Diffie-Hellman key exchange**

**Note:** For security and performance reasons we suggest using `ECDH` instead of DH where possible.

Diffie-Hellman key exchange (D–H) is a method that allows two parties to jointly agree on a shared secret using an insecure channel.

**Exchange Algorithm**

For most applications the `shared_key` should be passed to a key derivation function. This allows mixing of additional information into the key, derivation of multiple keys, and destroys any structure that may be present.

*Warning:* This example does not give forward secrecy and is only provided as a demonstration of the basic Diffie-Hellman construction. For real world applications always use the ephemeral form described after this example.
DHE (or EDH), the ephemeral form of this exchange, is strongly preferred over simple DH and provides forward secrecy when used. You must generate a new private key using `generate_private_key()` for each `exchange()` when performing an DHE key exchange. An example of the ephemeral form:

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import dh
>>> from cryptography.hazmat.primitives.kdf.hkdf import HKDF

# Generate some parameters. These can be reused.
parameters = dh.generate_parameters(generator=2, key_size=2048,
                                      backend=default_backend())

# Generate a private key for use in the exchange.
server_private_key = parameters.generate_private_key()

# In a real handshake the peer_public_key will be received from the other party. For this example we'll generate another private key though. Note that in a DH handshake both peers must agree on a common set of parameters.
peer_private_key = parameters.generate_private_key()

shared_key = server_private_key.exchange(peer_private_key.public_key())

# Perform key derivation.
derived_key = HKDF(
    algorithm=hashes.SHA256(),
    length=32,
    salt=None,
    info=b'handshake data',
    backend=default_backend())

# And now we can demonstrate that the handshake performed in the opposite direction gives the same final value
same_shared_key = peer_private_key.exchange(server_private_key.public_key())

same_derived_key = HKDF(
    algorithm=hashes.SHA256(),
    length=32,
    salt=None,
    info=b'handshake data',
    backend=default_backend())

derived_key == same_derived_key
```

(continues on next page)
To assemble a \texttt{DHParameters} and a \texttt{DHPublicKey} from primitive integers, you must first create the \texttt{DHParameterNumbers} and \texttt{DHPublicNumbers} objects. For example, if \( p \), \( g \), and \( y \) are \texttt{int} objects received from a peer:

\begin{verbatim}
 pn = dh.DHParameterNumbers(p, g)
 parameters = pn.parameters(default_backend())
 peer_public_numbers = dh.DHPublicNumbers(y, pn)
 peer_public_key = peer_public_numbers.public_key(default_backend())
\end{verbatim}

See also the \texttt{DHBackend} API for additional functionality.

**Group parameters**

cryptography.hazmat.primitives.asymmetric.dh.\texttt{generate_parameters}( \texttt{generator}, \texttt{key_size}, \texttt{backend})

New in version 1.7.

Generate a new DH parameter group for use with \texttt{backend}.

Parameters

- \texttt{generator} – The \texttt{int} to use as a generator. Must be 2 or 5.
- \texttt{key_size} – The bit length of the prime modulus to generate.
- \texttt{backend} – A \texttt{DHBackend} instance.

Returns DH parameters as a new instance of \texttt{DHParameters}.

Raises ValueError – If \texttt{key_size} is not at least 512.

class cryptography.hazmat.primitives.asymmetric.dh.\texttt{DHParameters}

New in version 1.7.

\texttt{generate_private_key}()

Generate a DH private key. This method can be used to generate many new private keys from a single set of parameters.

Returns An instance of \texttt{DHPrivateKey}.
**parameter_numbers()**
Return the numbers that make up this set of parameters.

**Returns** A `DHParameterNumbers`.

**parameter_bytes(encoding, format)**
New in version 2.0.
Allows serialization of the parameters to bytes. Encoding (`PEM` or `DER`) and format (`PKCS3`) are chosen to define the exact serialization.

**Parameters**

- **encoding** – A value from the `Encoding` enum.
- **format** – A value from the `ParameterFormat` enum. At the moment only `PKCS3` is supported.

**Returns** bytes Serialized parameters.

**class cryptography.hazmat.primitives.asymmetric.dh.DHParametersWithSerialization**
New in version 1.7.
Alias for `DHParameters`.

### Key interfaces

**class cryptography.hazmat.primitives.asymmetric.dh.DHPrivateKey**
New in version 1.7.
A DH private key that is not an opaque key also implements `DHPrivateKeyWithSerialization` to provide serialization methods.

**key_size**
The bit length of the prime modulus.

**public_key()**
Return the public key associated with this private key.

**Returns** A `DHPublicKey`.

**parameters()**
Return the parameters associated with this private key.

**Returns** A `DHParameters`.

**exchange(peer_public_key)**
New in version 1.7.

**Parameters** `peer_public_key` (`DHPublicKey`) – The public key for the peer.

**Returns** bytes The agreed key. The bytes are ordered in ‘big’ endian.

**class cryptography.hazmat.primitives.asymmetric.dh.DHPrivateKeyWithSerialization**
New in version 1.7.
This interface contains additional methods relating to serialization. Any object with this interface also has all the methods from `DHPrivateKey`.

**private_numbers()**
Return the numbers that make up this private key.

**Returns** A `DHPrivateNumbers`.
private_bytes (encoding, format, encryption_algorithm)
New in version 1.8.

Allows serialization of the key to bytes. Encoding (PEM or DER), format (PKCS8) and encryption algorithm (such as BestAvailableEncryption or NoEncryption) are chosen to define the exact serialization.

Parameters

- encoding – A value from the Encoding enum.
- format – A value from the PrivateFormat enum.
- encryption_algorithm – An instance of an object conforming to the KeySerializationEncryption interface.

Return bytes Serialized key.

class cryptography.hazmat.primitives.asymmetric.dh.DHPublicKey
New in version 1.7.

key_size
The bit length of the prime modulus.

parameters ()
Return the parameters associated with this private key.

Returns A DHParameters.

public_numbers ()
Return the numbers that make up this public key.

Returns A DHPublicNumbers.

public_bytes (encoding, format)
New in version 1.8.

Allows serialization of the key to bytes. Encoding (PEM or DER) and format (SubjectPublicKeyInfo) are chosen to define the exact serialization.

Parameters

- encoding – A value from the Encoding enum.
- format – A value from the PublicFormat enum.

Return bytes Serialized key.

class cryptography.hazmat.primitives.asymmetric.dh.DHPublicKeyWithSerialization
New in version 1.7.

Alias for DHPublicKey.

Numbers

class cryptography.hazmat.primitives.asymmetric.dh.DHParameterNumbers (p, g, q=none)
New in version 0.8.

The collection of integers that define a Diffie-Hellman group.

P

Type int
The prime modulus value.

\( g \)

Type int

The generator value. Must be 2 or greater.

\( q \)

New in version 1.8.

Type int

\( p \) subgroup order value.

\textbf{parameters} \((\text{backend})\)

New in version 1.7.

**Parameters** \texttt{backend} – An instance of \texttt{DHBackend}.

**Returns** A new instance of \texttt{DHParameters}.

\texttt{class cryptography.hazmat.primitives.asymmetric.dh.DHPrivateNumbers(x, public_numbers)}

New in version 0.8.

The collection of integers that make up a Diffie-Hellman private key.

\texttt{public_numbers}

Type \texttt{DHPublicNumbers}

The \texttt{DHPublicNumbers} which makes up the DH public key associated with this DH private key.

\( x \)

Type int

The private value.

\texttt{private_key} \((\text{backend})\)

New in version 1.7.

**Parameters** \texttt{backend} – An instance of \texttt{DHBackend}.

**Returns** A new instance of \texttt{DHPrivateKey}.

\texttt{class cryptography.hazmat.primitives.asymmetric.dh.DHPublicNumbers(y, parameter_numbers)}

New in version 0.8.

The collection of integers that make up a Diffie-Hellman public key.

\texttt{parameter_numbers}

Type \texttt{DHParameterNumbers}

The parameters for this DH group.

\( y \)

Type int

The public value.

\texttt{public_key} \((\text{backend})\)

New in version 1.7.

**Parameters** \texttt{backend} – An instance of \texttt{DHBackend}.

**Returns** A new instance of \texttt{DHPublicKey}.
This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

**DSA**

DSA is a public-key algorithm for signing messages.

**Generation**

cryptography.hazmat.primitives.asymmetric.dsa.generate_private_key(key_size, backend)

New in version 0.5.

Generate a DSA private key from the given key size. This function will generate a new set of parameters and key in one step.

**Parameters**

- **key_size** *(int)* – The length of the modulus in *bits*. It should be either 1024, 2048 or 3072. For keys generated in 2015 this should be at least 2048 (See page 41). Note that some applications (such as SSH) have not yet gained support for larger key sizes specified in FIPS 186-3 and are still restricted to only the 1024-bit keys specified in FIPS 186-2.

- **backend** – An instance of *DSABackend*.

**Returns** An instance of *DSAPrivateKey*.

**Raises** *cryptography.exceptions.UnsupportedAlgorithm* – This is raised if the provided backend does not implement *DSABackend*

cryptography.hazmat.primitives.asymmetric.dsa.generate_parameters(key_size, backend)

New in version 0.5.

Generate DSA parameters using the provided backend.

**Parameters**

- **key_size** *(int)* – The length of *q*. It should be either 1024, 2048 or 3072. For keys generated in 2015 this should be at least 2048 (See page 41). Note that some applications (such as SSH) have not yet gained support for larger key sizes specified in FIPS 186-3 and are still restricted to only the 1024-bit keys specified in FIPS 186-2.

- **backend** – An instance of *DSABackend*.

**Returns** An instance of *DSAParameters*.

**Raises** *cryptography.exceptions.UnsupportedAlgorithm* – This is raised if the provided backend does not implement *DSABackend*

**Signing**

Using a *DSAPrivateKey* instance.
```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import dsa

>>> private_key = dsa.generate_private_key(...    key_size=1024,
...    backend=default_backend())

>>> data = b"this is some data I'd like to sign"

>>> signature = private_key.sign(...    data,
...    hashes.SHA256())

The signature is a bytes object, whose contents is DER encoded as described in RFC 3279. This can be decoded using `decode_dss_signature()`.

If your data is too large to be passed in a single call, you can hash it separately and pass that value using `Prehashed`.

```python
>>> from cryptography.hazmat.primitives.asymmetric import utils

>>> chosen_hash = hashes.SHA256()

>>> hasher = hashes.Hash(chosen_hash, default_backend())

>>> hasher.update(b"data & ")

>>> hasher.update(b"more data")

>>> digest = hasher.finalize()

>>> sig = private_key.sign(...    digest,
...    utils.Prehashed(chosen_hash))

```python

Verification

Verification is performed using a `DSAPublicKey` instance. You can get a public key object with `load_pem_public_key()`, `load_der_public_key()`, `public_key()`, or `public_key()`.

```python
>>> public_key = private_key.public_key()

>>> public_key.verify(...    signature,
...    data,
...    hashes.SHA256())

verify() takes the signature in the same format as is returned by `sign()`.

verify() will raise an `InvalidSignature` exception if the signature isn’t valid.

If your data is too large to be passed in a single call, you can hash it separately and pass that value using `Prehashed`.

```python
>>> chosen_hash = hashes.SHA256()

>>> hasher = hashes.Hash(chosen_hash, default_backend())

>>> hasher.update(b"data & ")

>>> hasher.update(b"more data")

>>> digest = hasher.finalize()

>>> public_key.verify(...    sig,
...    digest,
...    utils.Prehashed(chosen_hash))
```
Numbers

class cryptography.hazmat.primitives.asymmetric.dsa.DSAParameterNumbers(p, q, g)

New in version 0.5.

The collection of integers that make up a set of DSA parameters.

\( p \)

Type int

The public modulus.

\( q \)

Type int

The sub-group order.

\( g \)

Type int

The generator.

\( \text{parameters}(\text{backend}) \)

Parameters backend – An instance of DSABackend.

Returns A new instance of DSAParameters.

class cryptography.hazmat.primitives.asymmetric.dsa.DSAPublicNumbers(y, parameter_numbers)

New in version 0.5.

The collection of integers that make up a DSA public key.

\( y \)

Type int

The public value y.

\( \text{parameter_numbers} \)

Type DSAParameterNumbers

The DSAParameterNumbers associated with the public key.

\( \text{public_key}(\text{backend}) \)

Parameters backend – An instance of DSABackend.

Returns A new instance of DSAPublicKey.

class cryptography.hazmat.primitives.asymmetric.dsa.DSAPrivateNumbers(x, public_numbers)

New in version 0.5.

The collection of integers that make up a DSA private key.
x

Type: int
The private value x.

public_numbers

Type: DSAPublicNumbers
The DSAPublicNumbers associated with the private key.

private_key(backend)

Parameters: backend – An instance of DSABackend.
Returns: A new instance of DSAPrivateKey.

Key interfaces

class cryptography.hazmat.primitives.asymmetric.dsa.DSAPrivateKey
New in version 0.3.
A DSA private key. A DSA private key that is not an opaque key also implements DSAPrivateKeyWithSerialization to provide serialization methods.

public_key()  
Returns: DSAPublicKey
An DSA public key object corresponding to the values of the private key.

parameters()  
Returns: DSAPublicNumbers
The DSAPublicNumbers object associated with this private key.
key_size

Type int
The bit length of $q$.

sign (data, algorithm)
New in version 1.5.

Changed in version 1.6: Prehashed can now be used as an algorithm.
Sign one block of data which can be verified later by others using the public key.

Parameters

- **data (bytes)** – The message string to sign.
- **algorithm** – An instance of HashAlgorithm or Prehashed if the data you want to sign has already been hashed.

Return bytes Signature.

class cryptography.hazmat.primitives.asymmetric.dsa.DSAPrivateKeyWithSerialization

New in version 0.8.
This interface contains additional methods relating to serialization. Any object with this interface also has all the methods from DSAPrivateKey.

private_numbers ()
Create a DSAPrivateNumbers object.

Returns A DSAPrivateNumbers instance.

private_bytes (encoding, format, encryption_algorithm)
Allows serialization of the key to bytes. Encoding (PEM or DER), format (TraditionalOpenSSL or PKCS8) and encryption algorithm (such as BestAvailableEncryption or NoEncryption) are chosen to define the exact serialization.

Parameters

- **encoding** – A value from the Encoding enum.
- **format** – A value from the PrivateFormat enum.
- **encryption_algorithm** – An instance of an object conforming to the KeySerializationEncryption interface.

Return bytes Serialized key.

class cryptography.hazmat.primitives.asymmetric.dsa.DSAPublicKey
New in version 0.3.
A DSA public key.

key_size

Type int
The bit length of $q$.

parameters ()

Returns DSAParameters
The DSAParameters object associated with this public key.

public_numbers ()
Create a DSAPublicNumbers object.
**Returns** A `DSAPublicNumbers` instance.

**public_bytes**(encoding, format)
Allows serialization of the key to bytes. Encoding (PEM or DER) and format (SubjectPublicKeyInfo) are chosen to define the exact serialization.

**Parameters**
- encoding – A value from the Encoding enum.
- format – A value from the PublicFormat enum.

**Return bytes** Serialized key.

**verify**(signature, data, algorithm)
New in version 1.5.
Changed in version 1.6: Prehashed can now be used as an algorithm.
Verify one block of data was signed by the private key associated with this public key.

**Parameters**
- signature (bytes) – The signature to verify.
- data (bytes) – The message string that was signed.
- algorithm – An instance of HashAlgorithm or Prehashed if the data you want to sign has already been hashed.

**Raises** cryptography.exceptions.InvalidSignature – If the signature does not validate.

**class** cryptography.hazmat.primitives.asymmetric.dsa.DSAPublicKeyWithSerialization
New in version 0.8.
Alias for DSAPublicKey.

---

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

---

**Key Serialization**

There are several common schemes for serializing asymmetric private and public keys to bytes. They generally support encryption of private keys and additional key metadata.

Many serialization formats support multiple different types of asymmetric keys and will return an instance of the appropriate type. You should check that the returned key matches the type your application expects when using these methods.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.asymmetric import dsa, rsa
>>> from cryptography.hazmat.primitives.serialization import load_pem_private_key
>>> key = load_pem_private_key(pem_data, password=None, backend=default_backend())
>>> if isinstance(key, rsa.RSAPrivateKey):
...     signature = sign_with_rsa_key(key, message)
... elif isinstance(key, dsa.DSAPrivateKey):
```

(continues on next page)
... signature = sign_with_dsa_key(key, message)
... else:
...     raise TypeError

Key dumping

The serialization module contains functions for loading keys from bytes. To dump a key object to bytes, you must call the appropriate method on the key object. Documentation for these methods is found in the rsa, dsa, and ec module documentation.

PEM

PEM is an encapsulation format, meaning keys in it can actually be any of several different key types. However these are all self-identifying, so you don’t need to worry about this detail. PEM keys are recognizable because they all begin with -----BEGIN {format}----- and end with -----END {format}-----.

Note: A PEM block which starts with -----BEGIN CERTIFICATE----- is not a public or private key, it’s an X.509 Certificate. You can load it using load_pem_x509_certificate() and extract the public key with Certificate.public_key.

cryptography.hazmat.primitives.serialization.load_pem_private_key(data, password, backend)

New in version 0.6.

Deserialize a private key from PEM encoded data to one of the supported asymmetric private key types.

Parameters

- **data** (bytes-like) – The PEM encoded key data.
- **password** – The password to use to decrypt the data. Should be None if the private key is not encrypted.
- **backend** – An instance of PEMSerializationBackend.

Returns One of RSAPrivateKey, DSAPrivateKey, DHPrivateKey, or EllipticCurvePrivateKey depending on the contents of data.

Raises

- **ValueError** – If the PEM data could not be decrypted or if its structure could not be decoded successfully.
- **TypeError** – If a password was given and the private key was not encrypted. Or if the key was encrypted but no password was supplied.
- **cryptography.exceptions.UnsupportedAlgorithm** – If the serialized key is of a type that is not supported by the backend or if the key is encrypted with a symmetric cipher that is not supported by the backend.

cryptography.hazmat.primitives.serialization.load_pem_public_key(data, backend)

New in version 0.6.
Deserializes a public key from PEM encoded data to one of the supported asymmetric public key types. The PEM encoded data is typically a `subjectPublicKeyInfo` payload as specified in RFC 5280.

```python
>>> from cryptography.hazmat.primitives.serialization import load_pem_public_key
>>> key = load_pem_public_key(public_pem_data, backend=default_backend())
>>> isinstance(key, rsa.RSAPublicKey)
True
```

**Parameters**

- `data` *(bytes)* – The PEM encoded key data.
- `backend` – An instance of `PEMSerializationBackend`.

**Returns**

One of `RSAPublicKey`, `DSAPublicKey`, `DHPublicKey`, or `EllipticCurvePublicKey` depending on the contents of `data`.

**Raises**

- `ValueError` – If the PEM data’s structure could not be decoded successfully.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the serialized key is of a type that is not supported by the backend.

cryptography.hazmat.primitives.serialization.load_pem_parameters(data, backend)

New in version 2.0.

Deserializes parameters from PEM encoded data to one of the supported asymmetric parameters types.

```python
>>> from cryptography.hazmat.primitives.serialization import load_pem_parameters
>>> from cryptography.hazmat.primitives.asymmetric import dh
>>> parameters = load_pem_parameters(parameters_pem_data, backend=default_backend())
>>> isinstance(parameters, dh.DHParameters)
True
```

**Parameters**

- `data` *(bytes)* – The PEM encoded parameters data.
- `backend` – An instance of `PEMSerializationBackend`.

**Returns**

Currently only `DHPublicKey` supported.

**Raises**

- `ValueError` – If the PEM data’s structure could not be decoded successfully.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the serialized parameters is of a type that is not supported by the backend.

cryptography.hazmat.primitives.serialization.load_pem_parameters(data, backend)

**DER**

DER is an ASN.1 encoding type. There are no encapsulation boundaries and the data is binary. DER keys may be in a variety of formats, but as long as you know whether it is a public or private key the loading functions will handle the rest.
New in version 0.8.

Deserialize a private key from DER encoded data to one of the supported asymmetric private key types.

**Parameters**

- **data** *(bytes-like)* – The DER encoded key data.
- **password** *(bytes-like)* – The password to use to decrypt the data. Should be `None` if the private key is not encrypted.
- **backend** – An instance of `DERSerializationBackend`.

**Returns** One of `RSAPrivateKey`, `DSAPrivateKey`, `DHPrivateKey`, or `EllipticCurvePrivateKey` depending on the contents of `data`.

**Raises**

- `ValueError` – If the DER data could not be decrypted or if its structure could not be decoded successfully.
- `TypeError` – If a `password` was given and the private key was not encrypted. Or if the key was encrypted but no password was supplied.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the serialized key is of a type that is not supported by the backend or if the key is encrypted with a symmetric cipher that is not supported by the backend.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.asymmetric import rsa
>>> from cryptography.hazmat.primitives.serialization import load_der_private_key
>>> key = load_der_private_key(der_data, password=None, backend=default_backend())
>>> isinstance(key, rsa.RSAPrivateKey)
True
```

New in version 0.8.

Deserialize a public key from DER encoded data to one of the supported asymmetric public key types. The DER encoded data is typically a `subjectPublicKeyInfo` payload as specified in [RFC 5280](https://tools.ietf.org/html/rfc5280).

**Parameters**

- **data** *(bytes)* – The DER encoded key data.
- **backend** – An instance of `DERSerializationBackend`.

**Returns** One of `RSAPublicKey`, `DSAPublicKey`, `DHPublicKey`, or `EllipticCurvePublicKey` depending on the contents of `data`.

**Raises**

- `ValueError` – If the DER data’s structure could not be decoded successfully.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the serialized key is of a type that is not supported by the backend.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.asymmetric import rsa
>>> from cryptography.hazmat.primitives.serialization import load_der_public_key
```
```python
>>> key = load_der_public_key(public_der_data, backend=default_backend())
>>> isinstance(key, rsa.RSAPublicKey)
True
```

cryptography.hazmat.primitives.serialization.load_der_parameters

New in version 2.0.

Deserialize parameters from DER encoded data to one of the supported asymmetric parameters types.

**Parameters**

- `data` *(bytes)* – The DER encoded parameters data.
- `backend` – An instance of `DERSerializationBackend`.

**Returns** Currently only `DHParameters` supported.

**Raises**

- `ValueError` – If the DER data’s structure could not be decoded successfully.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the serialized key is of a type that is not supported by the backend.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.asymmetric import dh
>>> from cryptography.hazmat.primitives.serialization import load_der_parameters

>>> parameters = load_der_parameters(parameters_der_data, backend=default_backend())
>>> isinstance(parameters, dh.DHParameters)
True
```

OpenSSH Public Key

The format used by OpenSSH to store public keys, as specified in **RFC 4253**.

An example RSA key in OpenSSH format (line breaks added for formatting purposes):

```
ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAABAQDDu/XRP1kyK6Cgt36gts9XAk
FiiuiLW6RU0j3KKVZ2s17723UmU9/9aVh/rZV43WQQG8jaR6kkcP4stO0D3t1l
PD7aZRBnriHPsQYQ74A2aAoIjgkv7DBfsoE6gDOQub0PFJwyryYQJhtOLQsK
vY/G0vtziRL3juawWmCfKT3W3XvwAdqGk7li61Hr +deOPNEPN2H58E4odrZ2f
sxn/adpDqfb2sM0kPWqs0aWvrrKGvUaustkivQE4XWiSFb0oJ/1KK/CRKVuy
///ImSCGHQRvhwariN2tvZ6CBNSlh31QqeB0AkyJ1ng7MXB2qYq/Ci2FUYryCX
2Mzhvnbv testkey@localhost
```

DSA keys look almost identical but begin with `ssh-dss` rather than `ssh-rsa`. ECDSA keys have a slightly different format, they begin with `ecdsa-sha2-{curve}`.

cryptography.hazmat.primitives.serialization.load_ssh_public_key

New in version 0.7.

Deserialize a public key from OpenSSH (**RFC 4253**) encoded data to an instance of the public key type for the specified backend.

**Parameters**

- `data` *(bytes)* – The OpenSSH encoded key data.
• **backend** – A backend which implements **RSABackend**, **DSABackend**, or **EllipticCurveBackend** depending on the key’s type.

**Returns** One of **RSAPublicKey**, **DSAPublicKey**, **EllipticCurvePublicKey**, or **Ed25519PublicKey**, depending on the contents of `data`.

**Raises**

- **ValueError** – If the OpenSSH data could not be properly decoded or if the key is not in the proper format.

- **cryptography.exceptions.UnsupportedAlgorithm** – If the serialized key is of a type that is not supported.

## PKCS12

PKCS12 is a binary format described in [RFC 7292](https://tools.ietf.org/html/rfc7292). It can contain certificates, keys, and more. PKCS12 files commonly have a `pfx` or `p12` file suffix.

**Note:** `cryptography` only supports a single private key and associated certificates when parsing PKCS12 files at this time.

```python

cryptography.hazmat.primitives.serialization.pkcs12.load_key_and_certificates(data, password, backend)
```

New in version 2.5.

Deserialize a PKCS12 blob.

**Parameters**

- **`data`** *(bytes-like)* – The binary data.

- **`password`** *(bytes-like)* – The password to use to decrypt the data. `None` if the PKCS12 is not encrypted.

- **`backend`** – A backend instance.

**Returns** A tuple of (`private_key`, `certificate`, `additional_certificates`). `private_key` is a private key type or `None`, `certificate` is either the `Certificate` whose public key matches the private key in the PKCS 12 object or `None`, and `additional_certificates` is a list of all other `Certificate` instances in the PKCS12 object.

## Serialization Formats

**class** `cryptography.hazmat.primitives.serialization.pkcs12.PrivateFormat`

New in version 0.8.

An enumeration for private key formats. Used with the `private_bytes` method available on `RSAPrivateKeyWithSerialization`, `EllipticCurvePrivateKeyWithSerialization`, `DHPrivateKeyWithSerialization` and `DSAPrivateKeyWithSerialization`.

**TraditionalOpenSSL**

Frequently known as PKCS#1 format. Still a widely used format, but generally considered legacy.
A PEM encoded RSA key will look like:

```
-----BEGIN RSA PRIVATE KEY-----
...
-----END RSA PRIVATE KEY-----
```

PKCS8

A more modern format for serializing keys which allows for better encryption. Choose this unless you have explicit legacy compatibility requirements.

A PEM encoded key will look like:

```
-----BEGIN PRIVATE KEY-----
...
-----END PRIVATE KEY-----
```

Raw

New in version 2.5.

A raw format used by X448 key exchange. It is a binary format and is invalid for other key types.

```python
class cryptography.hazmat.primitives.serialization.PublicFormat
```

New in version 0.8.

An enumeration for public key formats. Used with the `public_bytes` method available on `RSAPublicKeyWithSerialization`, `EllipticCurvePublicKeyWithSerialization`, `DHPublicKeyWithSerialization`, and `DSAPublicKeyWithSerialization`.

SubjectPublicKeyInfo

This is the typical public key format. It consists of an algorithm identifier and the public key as a bit string. Choose this unless you have specific needs.

A PEM encoded key will look like:

```
-----BEGIN PUBLIC KEY-----
...
-----END PUBLIC KEY-----
```

PKCS1

Just the public key elements (without the algorithm identifier). This format is RSA only, but is used by some older systems.

A PEM encoded key will look like:

```
-----BEGIN RSA PUBLIC KEY-----
...
-----END RSA PUBLIC KEY-----
```

OpenSSH

New in version 1.4.

The public key format used by OpenSSH (e.g. as found in `~/.ssh/id_rsa.pub` or `~/.ssh/authorized_keys`).

Raw

New in version 2.5.

A raw format used by X448 key exchange. It is a binary format and is invalid for other key types.

CompressedPoint

New in version 2.5.
A compressed elliptic curve public key as defined in ANSI X9.62 section 4.3.6 (as well as SECG v2.0).

**UncompressedPoint**
New in version 2.5.

An uncompressed elliptic curve public key as defined in ANSI X9.62 section 4.3.6 (as well as SECG v2.0).

```python
class cryptography.hazmat.primitives.serialization.ParameterFormat
```
New in version 2.0.

An enumeration for parameters formats. Used with the `parameter_bytes` method available on `DHParametersWithSerialization`.

**PKCS3**
ASN1 DH parameters sequence as defined in PKCS3.

### Serialization Encodings

```python
class cryptography.hazmat.primitives.serialization.Encoding
```
An enumeration for encoding types. Used with the `private_bytes` method available on `RSAPrivateKeyWithSerialization`, `EllipticCurvePrivateKeyWithSerialization`, `DHPrivateKeyWithSerialization`, `DSAPrivateKeyWithSerialization`, and `X448PrivateKey` as well as `public_bytes` on `RSAKeyUpKey`, `DHPublicKey`, `EllipticCurvePublicKey`, and `X448PublicKey`.

**PEM**
New in version 0.8.

For PEM format. This is a base64 format with delimiters.

**DER**
New in version 0.9.

For DER format. This is a binary format.

**OpenSSH**
New in version 1.4.

The format used by OpenSSH public keys. This is a text format.

**Raw**
New in version 2.5.

A raw format used by X448 key exchange. It is a binary format and is invalid for other key types.

**X962**
New in version 2.5.

The format used by elliptic curve point encodings. This is a binary format.

### Serialization Encryption Types

```python
class cryptography.hazmat.primitives.serialization.KeySerializationEncryption
```
Objects with this interface are usable as encryption types with methods like `private_bytes` available on `RSAPrivateKeyWithSerialization`, `EllipticCurvePrivateKeyWithSerialization`, `DHPrivateKeyWithSerialization`, and `DSAPrivateKeyWithSerialization`. All other classes in this section represent the available choices for encryption and have this interface. They are used with `private_bytes`. 

---

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The `BestAvailableEncryption` class encrypts data using the best available encryption method for a given key's backend. This encryption choice is curated and may change over time.

**Parameters**
- `password` *(bytes)*: The password to use for encryption.

The `NoEncryption` class represents the absence of encryption.

This module is considered hazardous and should be used with extreme caution. Only use it if you are 100% certain of what you are doing, as it contains many hazards like land mines, dragons, and dinosaurs with laser guns.

### Asymmetric Utilities

#### `decode_dss_signature`

This function takes signatures generated by the DSA/ECDSA signers and returns a tuple `(r, s)`. These signatures are ASN.1 encoded Dss-Sig-Value sequences (as defined in RFC 3279).

**Parameters**
- `signature` *(bytes)*: The signature to decode.

**Returns**
The decoded tuple `(r, s)`.

**Raises**
`ValueError` – Raised if the signature is malformed.

#### `encode_dss_signature`

This function creates an ASN.1 encoded Dss-Sig-Value (as defined in RFC 3279) from raw `r` and `s` values.

**Parameters**
- `r` *(int)*: The raw signature value `r`.
- `s` *(int)*: The raw signature value `s`.

**Returns**
The encoded signature.

#### `Prehashed`

This class can be used in RSA `sign()` and `verify()` methods as well as DSA `sign()` and `verify()` methods for elliptic curves.

**Parameters**
- `algorithm` *(instance of HashAlgorithm)*: An instance of the hash algorithm.

```python
>>> import hashlib
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.asymmetric import padding, rsa, utils

>>> private_key = rsa.generate_private_key(...
...   public_exponent=65537,
...   key_size=2048,
...   backend=default_backend()...

>>> prehashed_msg = hashlib.sha256(b"A message I want to sign").digest()
>>> signature = private_key.sign(...)  # (continues on next page)
```
... prehashed_msg,
... padding.PSS(
...     mgf=padding.MGF1(hashes.SHA256()),
...     salt_length=padding.PSS.MAX_LENGTH
... ),
... utils.Prehashed(hashes.SHA256())
... )
>>> public_key = private_key.public_key()
>>> public_key.verify(
...     signature,
...     prehashed_msg,
...     padding.PSS(
...         mgf=padding.MGF1(hashes.SHA256()),
...         salt_length=padding.PSS.MAX_LENGTH
...     ),
...     utils.Prehashed(hashes.SHA256())
... )

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

2.3.3 Constant time functions

This module contains functions for operating with secret data in a way that does not leak information about that data through how long it takes to perform the operation. These functions should be used whenever operating on secret data along with data that is user supplied.

An example would be comparing a HMAC signature received from a client to the one generated by the server code for authentication purposes.

For more information about this sort of issue, see Coda Hale’s blog post about the timing attacks on KeyCzar and Java’s MessageDigest.isEqual().

cryptography.hazmat.primitives.constant_time.bytes_eq(a, b)

Compares a and b with one another. If a and b have different lengths, this returns False immediately. Otherwise it compares them in a way that takes the same amount of time, regardless of how many characters are the same between the two.

>>> from cryptography.hazmat.primitives import constant_time
>>> constant_time.bytes_eq(b"foo", b"foo")
True
>>> constant_time.bytes_eq(b"foo", b"bar")
False

Parameters

- a (bytes) – The left-hand side.
- b (bytes) – The right-hand side.

Returns bool True if a has the same bytes as b, otherwise False.

Raises TypeError This exception is raised if a or b is not bytes.
This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

### 2.3.4 Key derivation functions

Key derivation functions derive bytes suitable for cryptographic operations from passwords or other data sources using a pseudo-random function (PRF). Different KDFs are suitable for different tasks such as:

- **Cryptographic key derivation**
  Deriving a key suitable for use as input to an encryption algorithm. Typically this means taking a password and running it through an algorithm such as PBKDF2HMAC or HKDF. This process is typically known as key stretching.

- **Password storage**
  When storing passwords you want to use an algorithm that is computationally intensive. Legitimate users will only need to compute it once (for example, taking the user’s password, running it through the KDF, then comparing it to the stored value), while attackers will need to do it billions of times. Ideal password storage KDFs will be demanding on both computational and memory resources.

```python
class cryptography.hazmat.primitives.kdf.pbkdf2.PBKDF2HMAC(algorithm, length, salt, iterations, backend)
```

New in version 0.2.

PBKDF2 (Password Based Key Derivation Function 2) is typically used for deriving a cryptographic key from a password. It may also be used for key storage, but an alternate key storage KDF such as Scrypt is generally considered a better solution.

This class conforms to the `KeyDerivationFunction` interface.

```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.pbkdf2 import PBKDF2HMAC
>>> from cryptography.hazmat.backends import default_backend

>>> backend = default_backend()

>>> # Salts should be randomly generated
>>> salt = os.urandom(16)

>>> # derive
>>> kdf = PBKDF2HMAC(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=salt,
...     iterations=100000,
...     backend=backend
... )

>>> key = kdf.derive(b"my great password")

>>> # verify
>>> kdf = PBKDF2HMAC(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=salt,
...     iterations=100000,
...     backend=backend
... )

>>> kdf.verify(b"my great password", key)
```
Parameters

- **algorithm** – An instance of `HashAlgorithm`.
- **length (int)** – The desired length of the derived key in bytes. Maximum is \((2^{32} - 1) * \text{algorithm.digest_size} \).
- **salt (bytes)** – A salt. Secure values\(^1\) are 128-bits (16 bytes) or longer and randomly generated.
- **iterations (int)** – The number of iterations to perform of the hash function. This can be used to control the length of time the operation takes. Higher numbers help mitigate brute force attacks against derived keys. See OWASP's Password Storage Cheat Sheet for more detailed recommendations if you intend to use this for password storage.
- **backend** – An instance of `PBKDF2HMACBackend`.

**Raises**

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided `backend` does not implement `PBKDF2HMACBackend`.
- `TypeError` – This exception is raised if `salt` is not `bytes`.

**derive** *(key_material)*

**Parameters**

- **key_material (bytes-like)** – The input key material. For PBKDF2 this should be a password.

**Return**

- bytes the derived key.

**Raises**

- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.
- `TypeError` – This exception is raised if `key_material` is not `bytes`.

This generates and returns a new key from the supplied password.

**verify** *(key_material, expected_key)*

**Parameters**

- **key_material (bytes)** – The input key material. This is the same as `key_material` in `derive()`.
- **expected_key (bytes)** – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**

- `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.
- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match. This can be used for checking whether the password a user provides matches the stored derived key.

\(^1\) See NIST SP 800-132.
class cryptography.hazmat.primitives.kdf.hkdf.HKDF(algorithm, length, salt, info, backend)

New in version 0.2.

HKDF (HMAC-based Extract-and-Expand Key Derivation Function) is suitable for deriving keys of a fixed size used for other cryptographic operations.

Warning: HKDF should not be used for password storage.

```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.hkdf import HKDF
>>> from cryptography.hazmat.backends import default_backend

>>> backend = default_backend()
>>> salt = os.urandom(16)
>>> info = b"hkdf-example"
>>> hkdf = HKDF(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=salt,
...     info=info,
...     backend=backend
... )
>>> key = hkdf.derive(b"input key")
>>> hkdf = HKDF(
...     algorithm=hashes.SHA256(),
...     length=32,
...     salt=salt,
...     info=info,
...     backend=backend
... )
>>> hkdf.verify(b"input key", key)
```

Parameters

- **algorithm** – An instance of `HashAlgorithm`.
- **length** *(int)* – The desired length of the derived key in bytes. Maximum is \(255 \times (algorithm.digest_size // 8)\).
- **salt** *(bytes)* – A salt. Randomizes the KDF’s output. Optional, but highly recommended. Ideally as many bits of entropy as the security level of the hash: often that means cryptographically random and as long as the hash output. Worse (shorter, less entropy) salt values can still meaningfully contribute to security. May be reused. Does not have to be secret, but may cause stronger security guarantees if secret; see RFC 5869 and the HKDF paper for more details. If `None` is explicitly passed a default salt of `algorithm.digest_size // 8` null bytes will be used.
- **info** *(bytes)* – Application specific context information. If `None` is explicitly passed an empty byte string will be used.
- **backend** – An instance of `HMACBackend`.

Raises

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided `backend` does not implement `HMACBackend`
• **TypeError** – This exception is raised if `salt` or `info` is not `bytes`.

**derive** *(key_material)*

**Parameters**

- **key_material** *(bytes-like)* – The input key material.

  **Return** bytes The derived key.

**Raises** **TypeError** – This exception is raised if `key_material` is not `bytes`.

Derives a new key from the input key material by performing both the extract and expand operations.

**verify** *(key_material, expected_key)*

**Parameters**

- **key_material** *(bytes)* – The input key material. This is the same as `key_material` in `derive()`.
- **expected_key** *(bytes)* – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**

- **cryptography.exceptions.InvalidKey** – This is raised when the derived key does not match the expected key.
- **cryptography.exceptions.AlreadyFinalized** – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match.

**Warning:** HKDFExpand should only be used if the key material is cryptographically strong. You should use **HKDF** if you are unsure.

```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.hkdf import HKDFExpand
>>> from cryptography.hazmat.backends import default_backend

>>> backend = default_backend()
>>> info = b"hkdf-example"
>>> key_material = os.urandom(16)
>>> hkdf = HKDFExpand(
...     algorithm=hashes.SHA256(),
...     length=32,
...     info=info,
...     backend=backend
... )
>>> key = hkdf.derive(key_material)
>>> hkdf = HKDFExpand(
...     algorithm=hashes.SHA256(),
...     length=32,
... )
```
... info=info,
... backend=backend
...

```python
>>> hkdf.verify(key_material, key)
```

## Parameters

- **algorithm** – An instance of `HashAlgorithm`
- **length** (`int`) – The desired length of the derived key in bytes. Maximum is $255 \times (algorithm.digest_size // 8)$.
- **info** (`bytes`) – Application specific context information. If `None` is explicitly passed an empty byte string will be used.
- **backend** – An instance of `HMACBackend`.

## Raises

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided `backend` does not implement `HMACBackend`
- `TypeError` – This exception is raised if `info` is not `bytes`.

### derive

```python
derive(key_material)
```

**Parameters**

- **key_material** (`bytes`) – The input key material.

**Return** `bytes` The derived key.

**Raises** `TypeError` – This exception is raised if `key_material` is not `bytes`.

Derives a new key from the input key material by performing both the extract and expand operations.

### verify

```python
verify(key_material, expected_key)
```

**Parameters**

- **key_material** (`bytes`) – The input key material. This is the same as `key_material` in `derive()`.
- **expected_key** (`bytes`) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**

- `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.
- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.
- `TypeError` – This is raised if the provided `key_material` is a `unicode` object

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match.

```python
class cryptography.hazmat.primitives.kdf.concatkdf.ConcatKDFHash(algorithm, length, otherinfo, backend)
```

New in version 1.0.
ConcatKDFHash (Concatenation Key Derivation Function) is defined by the NIST Special Publication NIST SP 800-56Ar2 document, to be used to derive keys for use after a Key Exchange negotiation operation.

**Warning:** ConcatKDFHash should not be used for password storage.

```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.concatkdf import ConcatKDFHash
>>> from cryptography.hazmat.backends import default_backend

>>> backend = default_backend()
>>> otherinfo = b"concatkdf-example"
>>> ckdf = ConcatKDFHash(
...     algorithm=hashes.SHA256(),
...     length=32,
...     otherinfo=otherinfo,
...     backend=backend
...)
>>> key = ckdf.derive(b"input key")
>>> ckdf = ConcatKDFHash(
...     algorithm=hashes.SHA256(),
...     length=32,
...     otherinfo=otherinfo,
...     backend=backend
...)
>>> ckdf.verify(b"input key", key)
```

**Parameters**

- **algorithm** – An instance of `HashAlgorithm`.
- **length** *(int)* – The desired length of the derived key in bytes. Maximum is `hashlen * (2^32 -1)`.
- **otherinfo** *(bytes)* – Application specific context information. If `None` is explicitly passed an empty byte string will be used.
- **backend** – An instance of `HashBackend`.

**Raises**

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `HashBackend`
- `TypeError` – This exception is raised if `otherinfo` is not `bytes`.

**derive** *(key_material)*

**Parameters**

- **key_material** *(bytes-like)* – The input key material.

**Return** bytes

**Raises** `TypeError` – This exception is raised if `key_material` is not `bytes`.

Derives a new key from the input key material.

**verify** *(key_material, expected_key)*

**Parameters**
• **key_material** (*bytes*) – The input key material. This is the same as `key_material` in `derive()`.

• **expected_key** (*bytes*) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**

• `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.

• `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match.

```python
class cryptography.hazmat.primitives.kdf.concatkdf.ConcatKDFHMAC(algorithm, length, salt, otherinfo, backend)

New in version 1.0.

Similar to ConcatKDFHash but uses an HMAC function instead.

**Warning:** ConcatKDFHMAC should not be used for password storage.

```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.concatkdf import ConcatKDFHMAC
>>> from cryptography.hazmat.backends import default_backend

>>> backend = default_backend()
>>> salt = os.urandom(16)
>>> otherinfo = b"concatkdf-example"

>>> ckdf = ConcatKDFHMAC(
    ...     algorithm=hashes.SHA256(),
    ...     length=32,
    ...     salt=salt,
    ...     otherinfo=otherinfo,
    ...     backend=backend
    ... )

>>> key = ckdf.derive(b"input key")

>>> ckdf = ConcatKDFHMAC(
    ...     algorithm=hashes.SHA256(),
    ...     length=32,
    ...     salt=salt,
    ...     otherinfo=otherinfo,
    ...     backend=backend
    ... )

>>> ckdf.verify(b"input key", key)
```

**Parameters**

• **algorithm** – An instance of `HashAlgorithm`.

• **length** (*int*) – The desired length of the derived key in bytes. Maximum is `hashlen * (2^32 -1)`.

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• **salt** (*bytes*) – A salt. Randomizes the KDF’s output. Optional, but highly recommended. Ideally as many bits of entropy as the security level of the hash: often that means cryptographically random and as long as the hash output. Does not have to be secret, but may cause stronger security guarantees if secret: If `None` is explicitly passed a default salt of `algorithm.block_size` null bytes will be used.

• **otherinfo** (*bytes*) – Application specific context information. If `None` is explicitly passed an empty byte string will be used.

• **backend** – An instance of `HMACBackend`.

**Raises**

• `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided `backend` does not implement `HMACBackend`

• `TypeError` – This exception is raised if `salt` or `otherinfo` is not `bytes`.

**derive** (*key_material*)

**Parameters**

- **key_material** (*bytes*) – The input key material.

**Return**

- bytes The derived key.

**Raises**

- `TypeError` – This exception is raised if `key_material` is not `bytes`.

Derives a new key from the input key material.

**verify** (*key_material*, *expected_key*)

**Parameters**

- **key_material** (*bytes*) – The input key material. This is the same as `key_material` in `derive()`.

- **expected_key** (*bytes*) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**

- `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.

- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match.

**Warning:** `X963KDF` should not be used for password storage.
```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.x963kdf import X963KDF
>>> from cryptography.hazmat.backends import default_backend

>>> backend = default_backend()

>>> sharedinfo = b"ANSI X9.63 Example"

>>> xkdf = X963KDF(
...     algorithm=hashes.SHA256(),
...     length=32,
...     sharedinfo=sharedinfo,
...     backend=backend
... )

>>> key = xkdf.derive(b"input key")

>>> xkdf = X963KDF(
...     algorithm=hashes.SHA256(),
...     length=32,
...     sharedinfo=sharedinfo,
...     backend=backend
... )

>>> xkdf.verify(b"input key", key)
```

Parameters

- **algorithm** – An instance of `HashAlgorithm`.
- **length** (`int`) – The desired length of the derived key in bytes. Maximum is `hashlen * (2^32 -1)`.
- **sharedinfo** (`bytes`) – Application specific context information. If `None` is explicitly passed an empty byte string will be used.
- **backend** – A cryptography backend `HashBackend` instance.

Raises

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided `backend` does not implement `HashBackend`
- `TypeError` – This exception is raised if `sharedinfo` is not `bytes`.

`derive` (`key_material`)  
**Parameters** `key_material` (`bytes-like`) – The input key material.  
**Return** `bytes` The derived key.  
**Raises** `TypeError` – This exception is raised if `key_material` is not `bytes`.

Derives a new key from the input key material.

`verify` (`key_material`, `expected_key`)  
**Parameters**  
- `key_material` (`bytes`) – The input key material. This is the same as `key_material` in `derive()`.  
- `expected_key` (`bytes`) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**
• `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.

• `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match.

class cryptography.hazmat.primitives.kdf.kbkdf.KBKDFHMAC(algorithm, mode, length, rlen, llen, location, label, context, fixed, backend)

New in version 1.4.

KBKDF (Key Based Key Derivation Function) is defined by the NIST SP 800-108 document, to be used to derive additional keys from a key that has been established through an automated key-establishment scheme.

Warning: KBKDFHMAC should not be used for password storage.

```python
>>> import os
>>> from cryptography.hazmat.primitives import hashes
>>> from cryptography.hazmat.primitives.kdf.kbkdf import KBKDFHMAC
>>> from cryptography.hazmat.backends import default_backend
>>> backend = default_backend()
>>> label = b"KBKDF HMAC Label"
>>> context = b"KBKDF HMAC Context"
>>> kdf = KBKDFHMAC(
...     algorithm=hashes.SHA256(),
...     mode=Mode.CounterMode,
...     length=32,
...     rlen=4,
...     llen=4,
...     location=CounterLocation.BeforeFixed,
...     label=label,
...     context=context,
...     fixed=None,
...     backend=backend
... )
>>> key = kdf.derive(b"input key")
>>> kdf = KBKDFHMAC(
...     algorithm=hashes.SHA256(),
...     mode=Mode.CounterMode,
...     length=32,
...     rlen=4,
...     llen=4,
...     location=CounterLocation.BeforeFixed,
...     label=label,
...     context=context,
...     fixed=None,
...     backend=backend
... )
>>> kdf.verify(b"input key", key)
```
• **algorithm** – An instance of `HashAlgorithm`.
• **mode** – The desired mode of the PRF. A value from the `Mode` enum.
• **length** (`int`) – The desired length of the derived key in bytes.
• **rlen** (`int`) – An integer that indicates the length of the binary representation of the counter in bytes.
• **llen** (`int`) – An integer that indicates the binary representation of the length in bytes.
• **location** – The desired location of the counter. A value from the `CounterLocation` enum.
• **label** (`bytes`) – Application specific label information. If `None` is explicitly passed an empty byte string will be used.
• **context** (`bytes`) – Application specific context information. If `None` is explicitly passed an empty byte string will be used.
• **fixed** (`bytes`) – Instead of specifying `label` and `context` you may supply your own fixed data. If `fixed` is specified, `label` and `context` is ignored.
• **backend** – A cryptography backend `HashBackend` instance.

** Raises**

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `HashBackend`
- `TypeError` – This exception is raised if `label` or `context` is not `bytes`. Also raised if `rlen` or `llen` is not `int`.
- `ValueError` – This exception is raised if `rlen` or `llen` is greater than 4 or less than 1. This exception is also raised if you specify a `label` or `context` and `fixed`.

**derive** (*key_material*)

**Parameters**

- **key_material** (`bytes-like`) – The input key material.

**Return** bytes The derived key.

** Raises** `TypeError` – This exception is raised if `key_material` is not `bytes`.

Derives a new key from the input key material.

**verify** (*key_material, expected_key*)

**Parameters**

- **key_material** (`bytes`) – The input key material. This is the same as `key_material` in `derive()`.
- **expected_key** (`bytes`) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

** Raises**

- `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.
- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match.
```python
>>> import os
>>> from cryptography.hazmat.primitives.kdf.scrypt import Scrypt
>>> backend = default_backend()
>>> salt = os.urandom(16)
>>> # derive
>>> kdf = Scrypt(
...     salt=salt,
...     length=32,
...     n=2**14,
...     r=8,
...     p=1,
...     backend=backend
... )
>>> key = kdf.derive(b"my great password")
>>> # verify
>>> kdf = Scrypt(
...     salt=salt,
...     length=32,
...     n=2**14,
...     r=8,
...     p=1,
...     backend=backend
... )
>>> kdf.verify(b"my great password", key)
```

### Parameters

- **salt** *(bytes)* – A salt.
- **length** *(int)* – The desired length of the derived key in bytes.
- **n** *(int)* – CPU/Memory cost parameter. It must be larger than 1 and be a power of 2.
- **r** *(int)* – Block size parameter.
- **p** *(int)* – Parallelization parameter.
The computational and memory cost of Scrypt can be adjusted by manipulating the 3 parameters: n, r, and p. In general, the memory cost of Scrypt is affected by the values of both n and r, while n also determines the number of iterations performed. p increases the computational cost without affecting memory usage. A more in-depth explanation of the 3 parameters can be found here.

RFC 7914 recommends values of r=8 and p=1 while scaling n to a number appropriate for your system. The scrypt paper suggests a minimum value of n=2**14 for interactive logins (t < 100ms), or n=2**20 for more sensitive files (t < 5s).

**Parameters**
- `backend` – An instance of `ScryptBackend`.

**Raises**
- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided `backend` does not implement `ScryptBackend`.
- `TypeError` – This exception is raised if `salt` is not `bytes`.
- `ValueError` – This exception is raised if `n` is less than 2, if `n` is not a power of 2, if `r` is less than 1 or if `p` is less than 1.

**derive** *(key_material)*

**Parameters**
- `key_material` (*bytes-like*) – The input key material.

**Return**
- `bytes` the derived key.

**Raises**
- `TypeError` – This exception is raised if `key_material` is not `bytes`.
- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This generates and returns a new key from the supplied password.

**verify** *(key_material, expected_key)*

**Parameters**
- `key_material` (*bytes*) – The input key material. This is the same as `key_material` in `derive()`.
- `expected_key` (*bytes*) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

**Raises**
- `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.
- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match. This can be used for checking whether the password a user provides matches the stored derived key.

**Interface**

```python
class cryptography.hazmat.primitives.kdf.KeyDerivationFunction
    New in version 0.2.
    
    derive (key_material)
```
Parameters **key_material** (*bytes*) – The input key material. Depending on what key derivation function you are using this could be either random bytes, or a user supplied password.

Returns The new key.

Raises `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This generates and returns a new key from the supplied key material.

```
verify(key_material, expected_key)
```

Parameters

- **key_material** (*bytes*) – The input key material. This is the same as `key_material` in `derive()`.
- **expected_key** (*bytes*) – The expected result of deriving a new key, this is the same as the return value of `derive()`.

Raises

- `cryptography.exceptions.InvalidKey` – This is raised when the derived key does not match the expected key.
- `cryptography.exceptions.AlreadyFinalized` – This is raised when `derive()` or `verify()` is called more than once.

This checks whether deriving a new key from the supplied `key_material` generates the same key as the `expected_key`, and raises an exception if they do not match. This can be used for something like checking whether a user’s password attempt matches the stored derived key.

This is a “Hazardous Materials” module. You should **ONLY** use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

### 2.3.5 Key wrapping

Key wrapping is a cryptographic construct that uses symmetric encryption to encapsulate key material. Key wrapping algorithms are occasionally utilized to protect keys at rest or transmit them over insecure networks. Many of the protections offered by key wrapping are also offered by using authenticated symmetric encryption.

```
cryptography.hazmat.primitives.keywrap.aes_key_wrap(wrapping_key, key_to_wrap, backend)
```

New in version 1.1.

This function performs AES key wrap (without padding) as specified in RFC 3394.

Parameters

- **wrapping_key** (*bytes*) – The wrapping key.
- **key_to_wrap** (*bytes*) – The key to wrap.
- **backend** – A `CipherBackend` instance that supports AES.

Return bytes The wrapped key as bytes.

```
cryptography.hazmat.primitives.keywrap.aes_key_unwrap(wrapping_key, wrapped_key, backend)
```

New in version 1.1.
This function performs AES key unwrap (without padding) as specified in RFC 3394.

**Parameters**

- `wrapping_key` (*bytes*) – The wrapping key.
- `wrapped_key` (*bytes*) – The wrapped key.
- `backend` – A `CipherBackend` instance that supports AES.

**Return bytes** The unwrapped key as bytes.

**Raises** `cryptography.hazmat.primitives.keywrap.InvalidUnwrap` – This is raised if the key is not successfully unwrapped.

New in version 2.2.

This function performs AES key wrap with padding as specified in RFC 5649.

**Parameters**

- `wrapping_key` (*bytes*) – The wrapping key.
- `key_to_wrap` (*bytes*) – The key to wrap.
- `backend` – A `CipherBackend` instance that supports AES.

**Return bytes** The wrapped key as bytes.

New in version 2.2.

This function performs AES key unwrap with padding as specified in RFC 5649.

**Parameters**

- `wrapping_key` (*bytes*) – The wrapping key.
- `wrapped_key` (*bytes*) – The wrapped key.
- `backend` – A `CipherBackend` instance that supports AES.

**Return bytes** The unwrapped key as bytes.

**Raises** `cryptography.hazmat.primitives.keywrap.InvalidUnwrap` – This is raised if the key is not successfully unwrapped.

**Exceptions**

`cryptography.hazmat.primitives.keywrap.InvalidUnwrap` This is raised when a wrapped key fails to unwrap. It can be caused by a corrupted or invalid wrapped key or an invalid wrapping key.

This is a “Hazardous Materials” module. You should **ONLY** use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.
2.3.6 Message authentication codes

While cryptography supports multiple MAC algorithms, we strongly recommend that HMAC should be used unless you have a very specific need.

For more information on why HMAC is preferred, see Use cases for CMAC vs. HMAC?

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

Cipher-based message authentication code (CMAC)

Cipher-based message authentication codes (or CMACs) are a tool for calculating message authentication codes using a block cipher coupled with a secret key. You can use an CMAC to verify both the integrity and authenticity of a message.

A subset of CMAC with the AES-128 algorithm is described in RFC 4493.

class cryptography.hazmat.primitives.cmac.CMAC(algorithm, backend)

New in version 0.4.

CMAC objects take a BlockCipherAlgorithm instance.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import cmac
>>> from cryptography.hazmat.primitives.ciphers import algorithms

>>> c = cmac.CMAC(algorithms.AES(key), backend=default_backend())
>>> c.update(b"message to authenticate")
>>> c.finalize()

b'CT\x1d\xc8\x0e\x15\xbe4e\xdb\xb6\x84\xca\xd9Xk'
```

If the backend doesn’t support the requested algorithm an UnsupportedAlgorithm exception will be raised.

If algorithm isn’t a BlockCipherAlgorithm instance then TypeError will be raised.

To check that a given signature is correct use the verify() method. You will receive an exception if the signature is wrong:

```python
>>> c = cmac.CMAC(algorithms.AES(key), backend=default_backend())
>>> c.update(b"message to authenticate")
>>> c.verify(b"an incorrect signature")
Traceback (most recent call last):
... cryptography.exceptions.InvalidSignature: Signature did not match digest.
```

Parameters

- **algorithm** – An instance of BlockCipherAlgorithm.
- **backend** – An instance of CMACBackend.

Raises

- **TypeError** – This is raised if the provided algorithm is not an instance of BlockCipherAlgorithm.
• `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `CMACBackend`

`update(data)`

Parameters `data(bytes)` – The bytes to hash and authenticate.

Raises

• `cryptography.exceptions.AlreadyFinalized` – See `finalize()`
  • `TypeError` – This exception is raised if `data` is not `bytes`.

`copy()`

Copy this `CMAC` instance, usually so that we may call `finalize()` to get an intermediate value while we continue to call `update()` on the original instance.

Returns A new instance of `CMAC` that can be updated and finalized independently of the original instance.

Raises `cryptography.exceptions.AlreadyFinalized` – See `finalize()`

`verify(signature)`

Finalize the current context and securely compare the MAC to `signature`.

Parameters `signature(bytes)` – The bytes to compare the current CMAC against.

Raises

• `cryptography.exceptions.AlreadyFinalized` – See `finalize()`
  • `cryptography.exceptions.InvalidSignature` – If `signature` does not match digest
  • `TypeError` – This exception is raised if `signature` is not `bytes`.

`finalize()`

Finalize the current context and return the message authentication code as bytes.

After `finalize` has been called this object can no longer be used and `update()`, `copy()`, `verify()` and `finalize()` will raise an `AlreadyFinalized` exception.

Returns `bytes` The message authentication code as bytes.

Raises `cryptography.exceptions.AlreadyFinalized` –

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

Hash-based message authentication codes (HMAC)

Hash-based message authentication codes (or HMACs) are a tool for calculating message authentication codes using a cryptographic hash function coupled with a secret key. You can use an HMAC to verify both the integrity and authenticity of a message.

`class cryptography.hazmat.primitives.hmac.HMAC(key, algorithm, backend)`

HMAC objects take a `key` and a `HashAlgorithm` instance. The `key` should be randomly generated `bytes` and is recommended to be equal in length to the `digest_size` of the hash function chosen. You must keep the `key` secret.
This is an implementation of RFC 2104.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes, hmac

>>> h = hmac.HMAC(key, hashes.SHA256(), backend=default_backend())
>>> h.update(b"message to hash")
>>> h.finalize()

b'#F	I\x8b"e\xc4\xf1\xbb\x9a\x8fc\xf5\xdf.\xbc\xcd/+\x8a\x86\x1d\x84\n\xc3\xa6\xda\xe6J'

If the backend doesn’t support the requested algorithm an UnsupportedAlgorithm exception will be raised.

If algorithm isn’t a HashAlgorithm instance then TypeError will be raised.

To check that a given signature is correct use the verify() method. You will receive an exception if the signature is wrong:

```python
>>> h = hmac.HMAC(key, hashes.SHA256(), backend=default_backend())
>>> h.update(b"message to hash")
>>> h.verify(b"an incorrect signature")
Traceback (most recent call last):
 ... 
cryptography.exceptions.InvalidSignature: Signature did not match digest.
```

**Parameters**

- **key** *(bytes-like)* – Secret key as bytes.

- **algorithm** – An HashAlgorithm instance such as those described in Cryptographic Hashes.

- **backend** – An HMACBackend instance.

**Raises** cryptography.exceptions.UnsupportedAlgorithm – This is raised if the provided backend does not implement HMACBackend

**update** *(msg)*

Parameters **msg** *(bytes-like)* – The bytes to hash and authenticate.

**Raises**

- cryptography.exceptions.AlreadyFinalized – See finalize()

- TypeError – This exception is raised if msg is not bytes.

**copy** ()

Copy this HMAC instance, usually so that we may call finalize() to get an intermediate digest value while we continue to call update() on the original instance.

**Returns** A new instance of HMAC that can be updated and finalized independently of the original instance.

**Raises** cryptography.exceptions.AlreadyFinalized – See finalize()

**verify** *(signature)*

Finalize the current context and securely compare digest to signature.

**Parameters** **signature** *(bytes)* – The bytes to compare the current digest against.

**Raises** cryptography.exceptions.AlreadyFinalized – See finalize()
• `cryptography.exceptions.AlreadyFinalized` – See `finalize()`
• `cryptography.exceptions.InvalidSignature` – If signature does not match digest
• `TypeError` – This exception is raised if `signature` is not bytes.

`finalize()`
Finalize the current context and return the message digest as bytes.

After `finalize` has been called this object can no longer be used and `update()`, `copy()`, `verify()` and `finalize()` will raise an `AlreadyFinalized` exception.

**Return** bytes  The message digest as bytes.

**Raises** `cryptography.exceptions.AlreadyFinalized` –

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

**Poly1305**

Poly1305 is an authenticator that takes a 32-byte key and a message and produces a 16-byte tag. This tag is used to authenticate the message. Each key must only be used once. Using the same key to generate tags for multiple messages allows an attacker to forge tags. Poly1305 is described in RFC 7539.

```python
class cryptography.hazmat.primitives.poly1305.Poly1305(key)
```

New in version 2.7.

**Warning:** Using the same key to generate tags for multiple messages allows an attacker to forge tags. Always generate a new key per message you want to authenticate. If you are using this as a MAC for symmetric encryption please use `ChaCha20Poly1305` instead.

```python
>>> from cryptography.hazmat.primitives import poly1305
>>> p = poly1305.Poly1305(key)
>>> p.update(b"message to authenticate")
>>> p.finalize()
b'T\xe
>>> p.verify(b"an incorrect tag")
Traceback (most recent call last):
... cryptography.exceptions.InvalidSignature: Value did not match computed tag.
```

**Parameters**  

**key** *(bytes-like)* – Secret key as bytes.

** Raises **  

`cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the version of OpenSSL cryptography is compiled against does not support this algorithm.
**update** *(data)*

**Parameters**
- `data` *(bytes-like)* – The bytes to hash and authenticate.

**Raises**
- `cryptography.exceptions.AlreadyFinalized` – See `finalize()`
- `TypeError` – This exception is raised if `data` is not `bytes`.

**verify** *(tag)*

Finalize the current context and securely compare the MAC to `tag`.

**Parameters**
- `tag` *(bytes)* – The bytes to compare against.

**Raises**
- `cryptography.exceptions.AlreadyFinalized` – See `finalize()`
- `cryptography.exceptions.InvalidSignature` – If `tag` does not match.
- `TypeError` – This exception is raised if `tag` is not `bytes`.

**finalize()**

Finalize the current context and return the message authentication code as bytes.

After `finalize` has been called this object can no longer be used and `update()`, `verify()`, and `finalize()` will raise an `AlreadyFinalized` exception.

**Return**
- `bytes` The message authentication code as bytes.

**Raises**
- `cryptography.exceptions.AlreadyFinalized` –

This is a “Hazardous Materials” module. You should **ONLY** use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

### 2.3.7 Message digests (Hashing)

**class** `cryptography.hazmat.primitives.hashes.Hash` *(algorithm, backend)*

A cryptographic hash function takes an arbitrary block of data and calculates a fixed-size bit string (a digest), such that different data results (with a high probability) in different digests.

This is an implementation of `HashContext` meant to be used with `HashAlgorithm` implementations to provide an incremental interface to calculating various message digests.

```python
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives import hashes
>>> digest = hashes.Hash(hashes.SHA256(), backend=default_backend())
>>> digest.update(b"abc")
>>> digest.update(b"123")
>>> digest.finalize()
b'\xa1=R\xcap\xc8\xe0\xf0\xbb\x10\xe8b2\x89\xe8bM\xe5\x1d\xb2\xd29
\x93\xaf\x84\x11\x80\x90'
```

If the backend doesn’t support the requested `algorithm` an `UnsupportedAlgorithm` exception will be raised.

Keep in mind that attacks against cryptographic hashes only get stronger with time, and that often algorithms that were once thought to be strong, become broken. Because of this it’s important to include a plan for upgrading the hash algorithm you use over time. For more information, see Lifetimes of cryptographic hash functions.
Parameters

- **algorithm** – A HashAlgorithm instance such as those described in below.
- **backend** – A HashBackend instance.

Raises cryptography.exceptions.UnsupportedAlgorithm – This is raised if the provided backend does not implement HashBackend

**update**(data)**

Parameters **data**(bytes) – The bytes to be hashed.

Raises

- cryptography.exceptions.AlreadyFinalized – See finalize().
- TypeError – This exception is raised if data is not bytes.

**copy()**

Copy this Hash instance, usually so that you may call finalize() to get an intermediate digest value while we continue to call update() on the original instance.

Returns A new instance of Hash that can be updated and finalized independently of the original instance.

Raises cryptography.exceptions.AlreadyFinalized – See finalize().

**finalize()**

Finalize the current context and return the message digest as bytes.

After finalize has been called this object can no longer be used and update(), copy(), and finalize() will raise an AlreadyFinalized exception.

Return bytes The message digest as bytes.

**SHA-2 family**

class cryptography.hazmat.primitives.hashes.SHA224

SHA-224 is a cryptographic hash function from the SHA-2 family and is standardized by NIST. It produces a 224-bit message digest.

class cryptography.hazmat.primitives.hashes.SHA256

SHA-256 is a cryptographic hash function from the SHA-2 family and is standardized by NIST. It produces a 256-bit message digest.

class cryptography.hazmat.primitives.hashes.SHA384

SHA-384 is a cryptographic hash function from the SHA-2 family and is standardized by NIST. It produces a 384-bit message digest.

class cryptography.hazmat.primitives.hashes.SHA512

SHA-512 is a cryptographic hash function from the SHA-2 family and is standardized by NIST. It produces a 512-bit message digest.

class cryptography.hazmat.primitives.hashes.SHA512_224

New in version 2.5.

SHA-512/224 is a cryptographic hash function from the SHA-2 family and is standardized by NIST. It produces a 224-bit message digest.

class cryptography.hazmat.primitives.hashes.SHA512_256

New in version 2.5.
SHA-512/256 is a cryptographic hash function from the SHA-2 family and is standardized by NIST. It produces a 256-bit message digest.

**BLAKE2**

BLAKE2 is a cryptographic hash function specified in [RFC 7693](https://tools.ietf.org/html/rfc7693). BLAKE2’s design makes it immune to length-extension attacks, an advantage over the SHA-family of hashes.

*Note:* While the RFC specifies keying, personalization, and salting features, these are not supported at this time due to limitations in OpenSSL 1.1.0.

```python
class cryptography.hazmat.primitives.hashes.BLAKE2b(digest_size)
BLAKE2b is optimized for 64-bit platforms and produces an 1 to 64-byte message digest.

Parameters digest_size (int) – The desired size of the hash output in bytes. Only 64 is supported at this time.

Raises ValueError – If the digest_size is invalid.
```

```python
class cryptography.hazmat.primitives.hashes.BLAKE2s(digest_size)
BLAKE2s is optimized for 8 to 32-bit platforms and produces a 1 to 32-byte message digest.

Parameters digest_size (int) – The desired size of the hash output in bytes. Only 32 is supported at this time.

Raises ValueError – If the digest_size is invalid.
```

**SHA-3 family**

SHA-3 is the most recent NIST secure hash algorithm standard. Despite the larger number SHA-3 is not considered to be better than SHA-2. Instead, it uses a significantly different internal structure so that if an attack appears against SHA-2 it is unlikely to apply to SHA-3. SHA-3 is significantly slower than SHA-2 so at this time most users should choose SHA-2.

```python
class cryptography.hazmat.primitives.hashes.SHA3_224
New in version 2.5.

SHA3/224 is a cryptographic hash function from the SHA-3 family and is standardized by NIST. It produces a 224-bit message digest.
```

```python
class cryptography.hazmat.primitives.hashes.SHA3_256
New in version 2.5.

SHA3/256 is a cryptographic hash function from the SHA-3 family and is standardized by NIST. It produces a 256-bit message digest.
```

```python
class cryptography.hazmat.primitives.hashes.SHA3_384
New in version 2.5.

SHA3/384 is a cryptographic hash function from the SHA-3 family and is standardized by NIST. It produces a 384-bit message digest.
```

```python
class cryptography.hazmat.primitives.hashes.SHA3_512
New in version 2.5.

SHA3/512 is a cryptographic hash function from the SHA-3 family and is standardized by NIST. It produces a 512-bit message digest.
```
class cryptography.hazmat.primitives.hashes.SHAKE128(digest_size)
   New in version 2.5.

   SHAKE128 is an extendable output function (XOF) based on the same core permutations as SHA3. It allows the
caller to obtain an arbitrarily long digest length. Longer lengths, however, do not increase security or collision
resistance and lengths shorter than 128 bit (16 bytes) will decrease it.

   Parameters digest_size(int) – The length of output desired. Must be greater than zero.

   Raises ValueError – If the digest_size is invalid.

class cryptography.hazmat.primitives.hashes.SHAKE256(digest_size)
   New in version 2.5.

   SHAKE256 is an extendable output function (XOF) based on the same core permutations as SHA3. It allows the
caller to obtain an arbitrarily long digest length. Longer lengths, however, do not increase security or collision
resistance and lengths shorter than 256 bit (32 bytes) will decrease it.

   Parameters digest_size(int) – The length of output desired. Must be greater than zero.

   Raises ValueError – If the digest_size is invalid.

SHA-1

Warning: SHA-1 is a deprecated hash algorithm that has practical known collision attacks. You are strongly
discouraged from using it. Existing applications should strongly consider moving away.

class cryptography.hazmat.primitives.hashes.SHA1
   SHA-1 is a cryptographic hash function standardized by NIST. It produces an 160-bit message digest. Crypt-
analysis of SHA-1 has demonstrated that it is vulnerable to practical collision attacks, and collisions have been
demonstrated.

MD5

Warning: MD5 is a deprecated hash algorithm that has practical known collision attacks. You are strongly
discouraged from using it. Existing applications should strongly consider moving away.

class cryptography.hazmat.primitives.hashes.MD5
   MD5 is a deprecated cryptographic hash function. It produces a 128-bit message digest and has practical known
collision attacks.

Interfaces

class cryptography.hazmat.primitives.hashes.HashAlgorithm

   name
       
       Type: str

       The standard name for the hash algorithm, for example: "sha256" or "blake2b".

   digest_size
Type int
The size of the resulting digest in bytes.

class cryptography.hazmat.primitives.hashes.HashContext

    algorithm
    A HashAlgorithm that will be used by this context.

    update(data)
    Parameters data (bytes) – The data you want to hash.

    finalize()
    Returns The final digest as bytes.

    copy()
    Returns A HashContext that is a copy of the current context.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

You may instead be interested in Fernet (symmetric encryption).

2.3.8 Symmetric encryption

Symmetric encryption is a way to encrypt or hide the contents of material where the sender and receiver both use the same secret key. Note that symmetric encryption is not sufficient for most applications because it only provides secrecy but not authenticity. That means an attacker can’t see the message but an attacker can create bogus messages and force the application to decrypt them.

For this reason it is strongly recommended to combine encryption with a message authentication code, such as HMAC, in an “encrypt-then-MAC” formulation as described by Colin Percival. cryptography includes a recipe named Fernet (symmetric encryption) that does this for you. To minimize the risk of security issues you should evaluate Fernet to see if it fits your needs before implementing anything using this module.

    class cryptography.hazmat.primitives.ciphers.Cipher(algorithm, mode, backend)
    Cipher objects combine an algorithm such as AES with a mode like CBC or CTR. A simple example of encrypting and then decrypting content with AES is:

    >>> import os
    >>> from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes
    >>> from cryptography.hazmat.backends import default_backend
    >>> backend = default_backend()
    >>> key = os.urandom(32)
    >>> iv = os.urandom(16)
    >>> cipher = Cipher(algorithms.AES(key), modes.CBC(iv), backend=backend)
    >>> encryptor = cipher.encryptor()
    >>> ct = encryptor.update(b"a secret message") + encryptor.finalize()
    >>> decryptor = cipher.decryptor()
    >>> decryptor.update(ct) + decryptor.finalize()
    b'a secret message'

Parameters
• **algorithms** – A `CipherAlgorithm` instance such as those described below.
• **mode** – A `Mode` instance such as those described below.
• **backend** – A `CipherBackend` instance.

**Raises** `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `CipherBackend`

**encryptor()**

*Returns* An encrypting `CipherContext` instance.

If the backend doesn’t support the requested combination of cipher and mode an `UnsupportedAlgorithm` exception will be raised.

**decryptor()**

*Returns* A decrypting `CipherContext` instance.

If the backend doesn’t support the requested combination of cipher and mode an `UnsupportedAlgorithm` exception will be raised.

### Algorithms

**class** `cryptography.hazmat.primitives.ciphers.algorithms.AES(key)`

AES (Advanced Encryption Standard) is a block cipher standardized by NIST. AES is both fast, and cryptographically strong. It is a good default choice for encryption.

*Parameters*

*key* (*bytes-like*) – The secret key. This must be kept secret. Either 128, 192, or 256 bits long.

**class** `cryptography.hazmat.primitives.ciphers.algorithms.Camellia(key)`

Camellia is a block cipher approved for use by CRYPTREC and ISO/IEC. It is considered to have comparable security and performance to AES but is not as widely studied or deployed.

*Parameters*

*key* (*bytes-like*) – The secret key. This must be kept secret. Either 128, 192, or 256 bits long.

**class** `cryptography.hazmat.primitives.ciphers.algorithms.ChaCha20(key)`

New in version 2.1.

**Note:** In most cases users should use `ChaCha20Poly1305` instead of this class. `ChaCha20` alone does not provide integrity so it must be combined with a MAC to be secure. `ChaCha20Poly1305` does this for you.

ChaCha20 is a stream cipher used in several IETF protocols. It is standardized in RFC 7539.

**Parameters**

* • **key** (*bytes-like*) – The secret key. This must be kept secret. 256 bits (32 bytes) in length.

* • **nonce** – Should be unique, a nonce. It is critical to never reuse a nonce with a given key. Any reuse of a nonce with the same key compromises the security of every message encrypted with that key. The nonce does not need to be kept secret and may be included with the ciphertext. This must be 128 bits in length.

```python
>>> from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes
>>> from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes
>>> from cryptography.hazmat.backends import default_backend
>>> nonce = os.urandom(16)
```
>>> algorithm = algorithms.ChaCha20(key, nonce)
>>> cipher = Cipher(algorithm, mode=None, backend=default_backend())
>>> encryptor = cipher.encryptor()
>>> ct = encryptor.update(b"a secret message")
>>> decryptor = cipher.decryptor()
>>> decryptor.update(ct)
b'a secret message'

class cryptography.hazmat.primitives.ciphers.algorithms.TripleDES(key)

Triple DES (Data Encryption Standard), sometimes referred to as 3DES, is a block cipher standardized by
NIST. Triple DES has known crypto-analytic flaws, however none of them currently enable a practical attack.
Nonetheless, Triple DES is not recommended for new applications because it is incredibly slow; old applications
should consider moving away from it.

Parameters key (bytes-like) – The secret key. This must be kept secret. Either 64, 128, or 192
bits long. DES only uses 56, 112, or 168 bits of the key as there is a parity byte in each
component of the key. Some writing refers to there being up to three separate keys that are each
56 bits long, they can simply be concatenated to produce the full key.

class cryptography.hazmat.primitives.ciphers.algorithms.CAST5(key)

New in version 0.2.

CAST5 (also known as CAST-128) is a block cipher approved for use in the Canadian government by the
Communications Security Establishment. It is a variable key length cipher and supports keys from 40-128 bits
in length.

Parameters key (bytes-like) – The secret key. This must be kept secret. 40 to 128 bits in length in
increments of 8 bits.

class cryptography.hazmat.primitives.ciphers.algorithms.SEED(key)

New in version 0.4.

SEED is a block cipher developed by the Korea Information Security Agency (KISA). It is defined in RFC 4269
and is used broadly throughout South Korean industry, but rarely found elsewhere.

Parameters key (bytes-like) – The secret key. This must be kept secret. 128 bits in length.

Weak ciphers

Warning: These ciphers are considered weak for a variety of reasons. New applications should avoid their use
and existing applications should strongly consider migrating away.

class cryptography.hazmat.primitives.ciphers.algorithms.Blowfish(key)

Blowfish is a block cipher developed by Bruce Schneier. It is known to be susceptible to attacks when using
weak keys. The author has recommended that users of Blowfish move to newer algorithms such as AES.

Parameters key (bytes-like) – The secret key. This must be kept secret. 32 to 448 bits in length in
increments of 8 bits.

class cryptography.hazmat.primitives.ciphers.algorithms.ARC4(key)

ARC4 (Alleged RC4) is a stream cipher with serious weaknesses in its initial stream output. Its use is strongly
discouraged. ARC4 does not use mode constructions.

Parameters key (bytes-like) – The secret key. This must be kept secret. Either 40, 56, 64, 80,
128, 192, or 256 bits in length.
Cryptography Documentation, Release 2.8.dev1

```python
>>> from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes
>>> from cryptography.hazmat.backends import default_backend

>>> algorithm = algorithms.ARC4(key)
>>> cipher = Cipher(algorithm, mode=None, backend=default_backend())
>>> encryptor = cipher.encryptor()
>>> ct = encryptor.update(b"a secret message")
>>> decryptor = cipher.decryptor()
>>> decryptor.update(ct)
'b\'a secret message''
```

class cryptography.hazmat.primitives.ciphers.algorithms.IDEA(key)

IDEA (International Data Encryption Algorithm) is a block cipher created in 1991. It is an optional component of the OpenPGP standard. This cipher is susceptible to attacks when using weak keys. It is recommended that you do not use this cipher for new applications.

**Parameters**

**key** *(bytes-like)* – The secret key. This must be kept secret. **128 bits** in length.

**Modes**

class cryptography.hazmat.primitives.ciphers.modes.CBC(initialization_vector)

CBC (Cipher Block Chaining) is a mode of operation for block ciphers. It is considered cryptographically strong.

Padding is required when using this mode.

**Parameters**

**initialization_vector** *(bytes-like)* – Must be **random bytes**. They do not need to be kept secret and they can be included in a transmitted message. Must be the same number of bytes as the **block_size** of the cipher. Each time something is encrypted a new **initialization_vector** should be generated. Do not reuse an **initialization_vector** with a given **key**, and particularly do not use a constant **initialization_vector**.

A good construction looks like:

```python
>>> import os
>>> from cryptography.hazmat.primitives.ciphers.modes import CBC

>>> iv = os.urandom(16)
>>> mode = CBC(iv)
```

While the following is bad and will leak information:

```python
>>> from cryptography.hazmat.primitives.ciphers.modes import CBC

>>> iv = b"a" * 16
>>> mode = CBC(iv)
```

class cryptography.hazmat.primitives.ciphers.modes.CTR(nonce)

**Warning:** Counter mode is not recommended for use with block ciphers that have a block size of less than 128-**bits**.

CTR (Counter) is a mode of operation for block ciphers. It is considered cryptographically strong. It transforms a block cipher into a stream cipher.

This mode does not require padding.
Parameters **nonce** *(bytes-like)* – Should be unique, a *nonce*. It is critical to never reuse a *nonce* with a given key. Any reuse of a nonce with the same key compromises the security of every message encrypted with that key. Must be the same number of bytes as the *block_size* of the cipher with a given key. The nonce does not need to be kept secret and may be included with the ciphertext.

```python
class cryptography.hazmat.primitives.ciphers.modes.OFB(initialization_vector)
```

OFB (Output Feedback) is a mode of operation for block ciphers. It transforms a block cipher into a stream cipher.

**This mode does not require padding.**

Parameters **initialization_vector** *(bytes-like)* – Must be *random bytes*. They do not need to be kept secret and they can be included in a transmitted message. Must be the same number of bytes as the *block_size* of the cipher. Do not reuse an *initialization_vector* with a given key.

```python
class cryptography.hazmat.primitives.ciphers.modes.CFB(initialization_vector)
```

CFB (Cipher Feedback) is a mode of operation for block ciphers. It transforms a block cipher into a stream cipher.

**This mode does not require padding.**

Parameters **initialization_vector** *(bytes-like)* – Must be *random bytes*. They do not need to be kept secret and they can be included in a transmitted message. Must be the same number of bytes as the *block_size* of the cipher. Do not reuse an *initialization_vector* with a given key.

```python
class cryptography.hazmat.primitives.ciphers.modes.CFB8(initialization_vector)
```

CFB (Cipher Feedback) is a mode of operation for block ciphers. It transforms a block cipher into a stream cipher. The CFB8 variant uses an 8-bit shift register.

**This mode does not require padding.**

Parameters **initialization_vector** *(bytes-like)* – Must be *random bytes*. They do not need to be kept secret and they can be included in a transmitted message. Must be the same number of bytes as the *block_size* of the cipher. Do not reuse an *initialization_vector* with a given key.

```python
class cryptography.hazmat.primitives.ciphers.modes.GCM(initialization_vector, tag=None, min_tag_length=16)
```

Danger: If you are encrypting data that can fit into memory you should strongly consider using *AESGCM* instead of this.

When using this mode you **must** not use the decrypted data until the appropriate finalization method *(finalize() or finalize_with_tag())* has been called. GCM provides **no** guarantees of ciphertext integrity until decryption is complete.

GCM (Galois Counter Mode) is a mode of operation for block ciphers. An AEAD (authenticated encryption with additional data) mode is a type of block cipher mode that simultaneously encrypts the message as well as authenticating it. Additional unencrypted data may also be authenticated. Additional means of verifying integrity such as *HMAC* are not necessary.

**This mode does not require padding.**

Parameters **initialization_vector** *(bytes-like)* – Must be unique, a *nonce*. They do not need to be kept secret and they can be included in a transmitted message. NIST recommends a
96-bit IV length for performance critical situations but it can be up to $2^{64} - 1$ bits. Do not reuse an initialization_vector with a given key.

Note: Cryptography will generate a 128-bit tag when finalizing encryption. You can shorten a tag by truncating it to the desired length but this is not recommended as it makes it easier to forge messages, and also potentially leaks the key (NIST SP-800-38D recommends 96-bits or greater). Applications wishing to allow truncation can pass the min_tag_length parameter.

Changed in version 0.5: The min_tag_length parameter was added in 0.5, previously truncation down to 4 bytes was always allowed.

Parameters

• **tag** *(bytes)* – The tag bytes to verify during decryption. When encrypting this must be None. When decrypting, it may be None if the tag is supplied on finalization using finalize_with_tag(). Otherwise, the tag is mandatory.

• **min_tag_length** *(int)* – The minimum length tag must be. By default this is 16, meaning tag truncation is not allowed. Allowing tag truncation is strongly discouraged for most applications.

Raises

• **ValueError** – This is raised if \( \text{len(tag)} < \text{min_tag_length} \) or the initialization_vector is too short.

• **NotImplementedError** – This is raised if the version of the OpenSSL backend used is 1.0.1 or earlier.

An example of securely encrypting and decrypting data with AES in the GCM mode looks like:

```python
import os
from cryptography.hazmat.backends import default_backend
from cryptography.hazmat.primitives.ciphers import (Cipher, algorithms, modes)

def encrypt(key, plaintext, associated_data):
    # Generate a random 96-bit IV.
    iv = os.urandom(12)

    # Construct an AES-GCM Cipher object with the given key and a
    # randomly generated IV.
    encryptor = Cipher(
        algorithms.AES(key),
        modes.GCM(iv),
        backend=default_backend()
    ).encryptor()

    # associated_data will be authenticated but not encrypted,
    # it must also be passed in on decryption.
    encryptor.authenticate_additional_data(associated_data)

    # Encrypt the plaintext and get the associated ciphertext.
    # GCM does not require padding.
    ciphertext = encryptor.update(plaintext) + encryptor.finalize()
```

(continues on next page)
\begin{verbatim}
    return (iv, ciphertext, encryptor.tag)

def decrypt(key, associated_data, iv, ciphertext, tag):
    # Construct a Cipher object, with the key, iv, and additionally the
    # GCM tag used for authenticating the message.
    decryptor = Cipher(
        algorithms.AES(key),
        modes.GCM(iv, tag),
        backend=default_backend()
    ).decryptor()

    # We put associated_data back in or the tag will fail to verify
    # when we finalize the decryptor.
    decryptor.authenticate_additional_data(associated_data)

    # Decryption gets us the authenticated plaintext.
    # If the tag does not match an InvalidTag exception will be raised.
    return decryptor.update(ciphertext) + decryptor.finalize()

iv, ciphertext, tag = encrypt(
    key, b"a secret message!", b"authenticated but not encrypted payload"
)

print(decrypt(
    key, b"authenticated but not encrypted payload", iv, ciphertext, tag
))
\end{verbatim}

\texttt{b'a secret message!'}

class cryptography.hazmat.primitives.ciphers.modes.XTS\texttt{(tweak)}

New in version 2.1.

\begin{warning}
\textbf{Warning:} XTS mode is meant for disk encryption and should not be used in other contexts. cryptography only supports XTS mode with AES.
\end{warning}

\textbf{Note:} AES XTS keys are double length. This means that to do AES-128 encryption in XTS mode you need a 256-bit key. Similarly, AES-256 requires passing a 512-bit key. AES 192 is not supported in XTS mode.

XTS (XEX-based tweaked-codebook mode with ciphertext stealing) is a mode of operation for the AES block cipher that is used for disk encryption.

This mode does not require padding.

\begin{itemize}
    \item \textbf{Parameters \texttt{tweak} (bytes-like)} – The tweak is a 16 byte value typically derived from something like the disk sector number. A given \texttt{(tweak, key)} pair should not be reused, although doing so is less catastrophic than in CTR mode.
\end{itemize}
Insecure modes

**Warning:** These modes are insecure. New applications should never make use of them, and existing applications should strongly consider migrating away.

```python
class cryptography.hazmat.primitives.ciphers.modes.ECB
```

ECB (Electronic Code Book) is the simplest mode of operation for block ciphers. Each block of data is encrypted in the same way. This means identical plaintext blocks will always result in identical ciphertext blocks, which can leave significant patterns in the output.

Padding is required when using this mode.

Interfaces

```python
class cryptography.hazmat.primitives.ciphers.CipherContext
```

When calling `encryptor()` or `decryptor()` on a Cipher object the result will conform to the CipherContext interface. You can then call `update(data)` with data until you have fed everything into the context. Once that is done call `finalize()` to finish the operation and obtain the remainder of the data.

Block ciphers require that the plaintext or ciphertext always be a multiple of their block size. Because of that padding is sometimes required to make a message the correct size. CipherContext will not automatically apply any padding; you’ll need to add your own. For block ciphers the recommended padding is PKCS7. If you are using a stream cipher mode (such as CTR) you don’t have to worry about this.

`update(data)`

**Parameters**

- `data` *(bytes-like)* – The data you wish to pass into the context.

**Return**

- `bytes` Returns the data that was encrypted or decrypted.

**Raises**

- `cryptography.exceptions.AlreadyFinalized` – See `finalize()`

When the Cipher was constructed in a mode that turns it into a stream cipher (e.g. CTR), this will return bytes immediately, however in other modes it will return chunks whose size is determined by the cipher’s block size.

`update_into(data, buf)`

New in version 1.8.

**Warning:** This method allows you to avoid a memory copy by passing a writable buffer and reading the resulting data. You are responsible for correctly sizing the buffer and properly handling the data. This method should only be used when extremely high performance is a requirement and you will be making many small calls to `update_into`.

**Parameters**

- `data` *(bytes-like)* – The data you wish to pass into the context.

- `buf` – A writable Python buffer that the data will be written into. This buffer should be `len(data) + n - 1` bytes where `n` is the block size (in bytes) of the cipher and mode combination.

**Return**

- `int` Number of bytes written.

**Raises**
NotImplementedError – This is raised if the version of cffi used is too old (this can happen on older PyPy releases).

ValueError – This is raised if the supplied buffer is too small.

```python
>>> import os
>>> from cryptography.hazmat.primitives.ciphers import Cipher, algorithms,
  modes
>>> from cryptography.hazmat.backends import default_backend
>>> backend = default_backend()
>>> key = os.urandom(32)
>>> iv = os.urandom(16)
>>> cipher = Cipher(algorithms.AES(key), modes.CBC(iv), backend=backend)
>>> encryptor = cipher.encryptor()
>>> # the buffer needs to be at least len(data) + n - 1 where n is cipher/mode block size in bytes
>>> buf = bytearray(31)
>>> len_encrypted = encryptor.update_into(b"a secret message", buf)
>>> ct = bytes(buf[:len_encrypted]) + encryptor.finalize()
>>> decryptor = cipher.decryptor()
>>> len_decrypted = decryptor.update_into(ct, buf)
>>> bytes(buf[:len_decrypted]) + decryptor.finalize()
'b\'a secret message\'`
```

**finalize()**

Return bytes Returns the remainder of the data.

Raises ValueError – This is raised when the data provided isn’t a multiple of the algorithm’s block size.

Once finalize is called this object can no longer be used and update() and finalize() will raise an AlreadyFinalized exception.

class cryptography.hazmat.primitives.ciphers.AEADCipherContext

When calling encryptor or decryptor on a Cipher object with an AEAD mode (e.g. GCM) the result will conform to the AEADCipherContext and CipherContext interfaces. If it is an encryption or decryption context it will additionally be an AEADEncryptionContext or AEADDecryptionContext instance, respectively. AEADCipherContext contains an additional method authenticate_additional_data() for adding additional authenticated but unencrypted data (see note below). You should call this before calls to update. When you are done call finalize to finish the operation.

**authenticate_additional_data(data)**

Parameters data (bytes-like) – Any data you wish to authenticate but not encrypt.

Raises AlreadyFinalized

class cryptography.hazmat.primitives.ciphers.AEADEncryptionContext

When creating an encryption context using encryptor on a Cipher object with an AEAD mode such as GCM
an object conforming to both the `AEADEncyptionContext` and `AEADCipherContext` interfaces will be returned. This interface provides one additional attribute `tag`. `tag` can only be obtained after `finalize` has been called.

```
tag
```

**Return bytes** Returns the tag value as bytes.

**Raises** `NotYetFinalized` if called before the context is finalized.

```class cryptography.hazmat.primitives.ciphers.AEADDecryptionContext
```

New in version 1.9.

When creating an encryption context using `decryptor` on a `Cipher` object with an AEAD mode such as `GCM` an object conforming to both the `AEADDecryptionContext` and `AEADCipherContext` interfaces will be returned. This interface provides one additional method `finalize_with_tag()` that allows passing the authentication tag for validation after the ciphertext has been decrypted.

```
finalize_with_tag(tag)
```

**Note:** This method is not supported when compiled against OpenSSL 1.0.1.

**Parameters**

- `tag` *(bytes)* – The tag bytes to verify after decryption.

**Return bytes** Returns the remainder of the data.

**Raises**

- `ValueError` – This is raised when the data provided isn’t a multiple of the algorithm’s block size, if `min_tag_length` is less than 4, or if `len(tag) < min_tag_length`. `min_tag_length` is an argument to the `GCM` constructor.

- `NotImplementedError` – This is raised if the version of the OpenSSL backend used is 1.0.1 or earlier.

If the authentication tag was not already supplied to the constructor of the `GCM` mode object, this method must be used instead of `finalize()`.

```class cryptography.hazmat.primitives.ciphers.CipherAlgorithm
```

A named symmetric encryption algorithm.

```
name
```

**Type** `str`

The standard name for the mode, for example, “AES”, “Camellia”, or “Blowfish”.

```key_size
```

**Type** `int`

The number of `bits` in the key being used.

```class cryptography.hazmat.primitives.ciphers.BlockCipherAlgorithm
```

A block cipher algorithm.

```
block_size
```

**Type** `int`

The number of `bits` in a block.
Interfaces used by the symmetric cipher modes described in *Symmetric Encryption Modes*.

```python
class cryptography.hazmat.primitives.ciphers.modes.Mode
    A named cipher mode.

    name
        Type str
        This should be the standard shorthand name for the mode, for example Cipher-Block Chaining mode is "CBC".
        The name may be used by a backend to influence the operation of a cipher in conjunction with the algorithm's name.

    validate_for_algorithm(algorithm)

        Parameters algorithm (cryptography.hazmat.primitives.ciphers.CipherAlgorithm) –
        Checks that the combination of this mode with the provided algorithm meets any necessary invariants.
        This should raise an exception if they are not met.
        For example, the CBC mode uses this method to check that the provided initialization vector's length matches the block size of the algorithm.
```

```python
class cryptography.hazmat.primitives.ciphers.modes.ModeWithInitializationVector
    A cipher mode with an initialization vector.

    initialization_vector
        Type bytes-like
        Exact requirements of the initialization are described by the documentation of individual modes.
```

```python
class cryptography.hazmat.primitives.ciphers.modes.ModeWithNonce
    A cipher mode with a nonce.

    nonce
        Type bytes-like
        Exact requirements of the nonce are described by the documentation of individual modes.
```

```python
class cryptography.hazmat.primitives.ciphers.modes.ModeWithAuthenticationTag
    A cipher mode with an authentication tag.

    tag
        Type bytes-like
        Exact requirements of the tag are described by the documentation of individual modes.
```

```python
class cryptography.hazmat.primitives.ciphers.modes.ModeWithTweak
    New in version 2.1.
    A cipher mode with a tweak.

    tweak
        Type bytes-like
        Exact requirements of the tweak are described by the documentation of individual modes.
```
Exceptions

class cryptography.exceptions.InvalidTag
   This is raised if an authenticated encryption tag fails to verify during decryption.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what
you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

2.3.9 Symmetric Padding

Padding is a way to take data that may or may not be a multiple of the block size for a cipher and extend it out so that
it is. This is required for many block cipher modes as they require the data to be encrypted to be an exact multiple of
the block size.

class cryptography.hazmat.primitives.padding.PKCS7(block_size)
   PKCS7 padding is a generalization of PKCS5 padding (also known as standard padding). PKCS7 padding
   works by appending \(N\) bytes with the value of \(\text{chr}(N)\), where \(N\) is the number of bytes required to make
   the final block of data the same size as the block size. A simple example of padding is:

   ```python
   >>> from cryptography.hazmat.primitives import padding
   >>> padder = padding.PKCS7(128).padder()
   >>> padded_data = padder.update(b"11111111111111112222222222")
   >>> padded_data += padder.finalize()
   >>> padded_data
   b'11111111111111112222222222\x06\x06\x06\x06\x06\x06'
   >>> unpadder = padding.PKCS7(128).unpadder()
   >>> data = unpadder.update(padded_data)
   >>> data
   b'1111111111111111'
   >>> data + unpadder.finalize()
   b'11111111111111112222222222'
   ```

   Parameters block_size – The size of the block in bits that the data is being padded to.
   
   Raises ValueError – Raised if block size is not a multiple of 8 or is not between 0 and 2040
   inclusive.

   padder()
   
   Returns A padding PaddingContext instance.

   unpadder()
   
   Returns An unpadding PaddingContext instance.

class cryptography.hazmat.primitives.padding.ANSIX923(block_size)
   ANSI X.923 padding works by appending \(N-1\) bytes with the value of 0 and a last byte with the value of
   \(\text{chr}(N)\), where \(N\) is the number of bytes required to make the final block of data the same size as the block
   size. A simple example of padding is:
```python
>>> padder = padding.ANSIX923(128).padder()
>>> padded_data = padder.update(b"11111111111112222222222")
>>> padded_data
b'111111111111'
>>> padded_data += padder.finalize()
>>> padded_data
b'1111111111112222222222\x00\x00\x00\x00\x00\x06'
>>> unpadder = padding.ANSIX923(128).unpadder()
>>> data = unpadder.update(padded_data)
>>> data
b'111111111111'
>>> data + unpadder.finalize()
'b'111111111111122222222222'
```

Parameters

- **block_size** – The size of the block in bits that the data is being padded to.

Raises

- **ValueError** – Raised if block size is not a multiple of 8 or is not between 0 and 2040 inclusive.

**padder()**

Returns A padding `PaddingContext` instance.

**unpadder()**

Returns An unpadding `PaddingContext` instance.

class cryptography.hazmat.primitives.padding.PaddingContext

When calling `padder()` or `unpadder()` the result will conform to the `PaddingContext` interface. You can then call `update(data)` with data until you have fed everything into the context. Once that is done call `finalize()` to finish the operation and obtain the remainder of the data.

**update(data)**

Parameters

- **data (bytes)** – The data you wish to pass into the context.

Return bytes Returns the data that was padded or unpadded.

Raises

- **TypeError** – Raised if data is not bytes.
- **cryptography.exceptions.AlreadyFinalized** – See `finalize()`.
- **TypeError** – This exception is raised if `data` is not `bytes`.

**finalize()**

Finalize the current context and return the rest of the data.

After `finalize` has been called this object can no longer be used; `update()` and `finalize()` will raise an `AlreadyFinalized` exception.

Return bytes Returns the remainder of the data.

Raises

- **TypeError** – Raised if data is not bytes.
- **ValueError** – When trying to remove padding from incorrectly padded data.
This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

### 2.3.10 Two-factor authentication

This module contains algorithms related to two-factor authentication. Currently, it contains an algorithm for generating and verifying one time password values based on Hash-based message authentication codes (HMAC).

```python
>>> import os
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.twofactor.hotp import HOTP
>>> from cryptography.hazmat.primitives.hashes import SHA1

>>> key = os.urandom(20)
>>> hotp = HOTP(key, 6, SHA1(), backend=default_backend())
>>> hotp_value = hotp.generate(0)
>>> hotp.verify(hotp_value, 0)
```

**Parameters**

- **key**: Per-user secret key. This value must be kept secret and be at least 128 bits. It is recommended that the key be 160 bits.
- **length**: Length of generated one time password as int.
- **backend**: A HMACBackend instance.
- **enforce_key_length**: A boolean flag defaulting to True that toggles whether a minimum key length of 128 bits is enforced. This exists to work around the fact that as documented in Issue #2915, the Google Authenticator PAM module by default generates 80 bit keys. If this flag is set to False, the application develop should implement additional checks of the key length before passing it into HOTP.

**Raises**

- **ValueError**: This is raised if the provided key is shorter than 128 bits or if the length parameter is not 6, 7 or 8.
• **TypeError** – This is raised if the provided algorithm is not `SHA1()`, `SHA256()` or `SHA512()` or if the length parameter is not an integer.

• `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `HMACBackend`

**generate**(counter)

Parameters

- **counter** *(int)* – The counter value used to generate the one time password.

Return bytes A one time password value.

**verify**(hotp, counter)

Parameters

- **hotp** *(bytes)* – The one time password value to validate.

- **counter** *(int)* – The counter value to validate against.

Raises `cryptography.hazmat.primitives.twofactor.InvalidToken` – This is raised when the supplied HOTP does not match the expected HOTP.

**get_provisioning_uri**(account_name, counter, issuer)

New in version 1.0.

Parameters

- **account_name** *(text)* – The display name of account, such as 'Alice Smith' or 'alice@example.com'.

- **issuer** *(text or None)* – The optional display name of issuer. This is typically the provider or service the user wants to access using the OTP token.

- **counter** *(int)* – The current value of counter.

Returns A URI string.

**Throttling**

Due to the fact that the HOTP algorithm generates rather short tokens that are 6 - 8 digits long, brute force attacks are possible. It is highly recommended that the server that validates the token implement a throttling scheme that locks out the account for a period of time after a number of failed attempts. The number of allowed attempts should be as low as possible while still ensuring that usability is not significantly impacted.

**Re-synchronization of the counter**

The server’s counter value should only be incremented on a successful HOTP authentication. However, the counter on the client is incremented every time a new HOTP value is requested. This can lead to the counter value being out of synchronization between the client and server.

Due to this, it is highly recommended that the server sets a look-ahead window that allows the server to calculate the next $x$ HOTP values and check them against the supplied HOTP value. This can be accomplished with something similar to the following code:

```python
def verify(hotp, counter, look_ahead):
    assert look_ahead >= 0
    correct_counter = None

    otp = HOTP(key, 6, default_backend())
```

(continues on next page)
for count in range(counter, counter + look_ahead):
    try:
        otp.verify(hotp, count)
        correct_counter = count
    except InvalidToken:
        pass
return correct_counter

class cryptography.hazmat.primitives.twofactor.totp.TOTP(key, length, algorithm, time_step, backend, enforce_key_length=True):

TOTP objects take a key, length, algorithm and time_step parameter. The key should be randomly generated bytes and is recommended to be as long as your hash function’s output (e.g 256-bit for SHA256). The length parameter controls the length of the generated one time password and must be >= 6 and <= 8.

This is an implementation of RFC 6238.

>>> import os
>>> import time
>>> from cryptography.hazmat.backends import default_backend
>>> from cryptography.hazmat.primitives.twofactor.totp import TOTP
>>> from cryptography.hazmat.primitives.hashes import SHA1

>>> key = os.urandom(20)
>>> totp = TOTP(key, 8, SHA1(), 30, backend=default_backend())
>>> time_value = time.time()
>>> totp_value = totp.generate(time_value)
>>> totp.verify(totp_value, time_value)

Parameters

- **key (bytes-like)** – Per-user secret key. This value must be kept secret and be at least 128 bits. It is recommended that the key be 160 bits.

- **length (int)** – Length of generated one time password as int.

- **algorithm** (cryptography.hazmat.primitives.hashes.HashAlgorithm) – A hashes instance.

- **time_step (int)** – The time step size. The recommended size is 30.

- **backend** – A HMACBackend instance.

- **enforce_key_length** – A boolean flag defaulting to True that toggles whether a minimum key length of 128 bits is enforced. This exists to work around the fact that as documented in Issue #2915, the Google Authenticator PAM module by default generates 80 bit keys. If this flag is set to False, the application developer should implement additional checks of the key length before passing it into TOTP.

New in version 1.5.

Raises

- **ValueError** – This is raised if the provided key is shorter than 128 bits or if the length parameter is not 6, 7 or 8.

- **TypeError** – This is raised if the provided algorithm is not SHA1(), SHA256() or SHA512() or if the length parameter is not an integer.
• `cryptography.exceptions.UnsupportedAlgorithm` – This is raised if the provided backend does not implement `HMACBackend`.

generate(time)

Parameters:
- `time(int)` – The time value used to generate the one time password.

Return: bytes A one time password value.

verify(totp, time)

Parameters:
- `totp(bytes)` – The one time password value to validate.
- `time(int)` – The time value to validate against.

Raises `cryptography.hazmat.primitives.twofactor.InvalidToken` – This is raised when the supplied TOTP does not match the expected TOTP.

get_provisioning_uri(account_name, issuer)

New in version 1.0.

Parameters:
- `account_name(text)` – The display name of account, such as 'Alice Smith' or 'alice@example.com'.
- `issuer(text or None)` – The optional display name of issuer. This is typically the provider or service the user wants to access using the OTP token.

Returns: A URI string.

Provisioning URI

The provisioning URI of HOTP and TOTP is a feature of Google Authenticator and not actually part of the HOTP or TOTP RFCs. However, it is widely supported by web sites and mobile applications which are using Two-Factor authentication.

For generating a provisioning URI you can use the `get_provisioning_uri` method of HOTP/TOTP instances.

counter = 5
account_name = 'alice@example.com'
issuer_name = 'Example Inc'

hotp_uri = hotp.get_provisioning_uri(account_name, counter, issuer_name)
totp_uri = totp.get_provisioning_uri(account_name, issuer_name)

A common usage is encoding the provisioning URI into QR code and guiding users to scan it with Two-Factor authentication applications in their mobile devices.

2.4 Exceptions

class cryptography.exceptions.UnsupportedAlgorithm

Raised when the requested algorithm, or combination of algorithms is not supported.

class cryptography.exceptions.AlreadyFinalized

This is raised when a context is used after being finalized.
class cryptography.exceptions.InvalidSignature
This is raised when signature verification fails. This can occur with HMAC or asymmetric key signature validation.

class cryptography.exceptions.NotYetFinalized
This is raised when the AEAD tag property is accessed on a context before it is finalized.

class cryptography.exceptions.AlreadyUpdated
This is raised when additional data is added to a context after update has already been called.

class cryptography.exceptions.InvalidKey
This is raised when the verify method of a key derivation function’s computed key does not match the expected key.

2.5 Random number generation

When generating random data for use in cryptographic operations, such as an initialization vector for encryption in CBC mode, you do not want to use the standard random module APIs. This is because they do not provide a cryptographically secure random number generator, which can result in major security issues depending on the algorithms in use.

Therefore, it is our recommendation to always use your operating system’s provided random number generator, which is available as os.urandom(). For example, if you need 16 bytes of random data for an initialization vector, you can obtain them with:

```python
>>> import os
>>> iv = os.urandom(16)
```

This will use /dev/urandom on UNIX platforms, and CryptGenRandom on Windows.

If you need your random number as an integer (for example, for serial_number()), you can use int. from_bytes to convert the result of os.urandom:

```python
>>> serial = int.from_bytes(os.urandom(20), byteorder="big")
```

Starting with Python 3.6 the standard library includes the secrets module, which can be used for generating cryptographically secure random numbers, with specific helpers for text-based formats.

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

2.6 Backends

2.6.1 Getting a backend

cryptography was originally designed to support multiple backends, but this design has been deprecated.

You can get the default backend by calling default_backend().

cryptography.hazmat.backends.default_backend()

    Returns An object that provides at least CipherBackend, HashBackend, and HMACBackend.
2.6.2 Individual backends

This is a “Hazardous Materials” module. You should **ONLY** use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

**OpenSSL backend**

The OpenSSL C library. Cryptography supports OpenSSL version 1.0.1 and greater.

cryptography.hazmat.backends.openssl.backend
   This is the exposed API for the OpenSSL backend.

   It implements the following interfaces:
   - CipherBackend
   - CMACBackend
   - DERSerializationBackend
   - DHBackend
   - DSABackend
   - EllipticCurveBackend
   - HashBackend
   - HMACBackend
   - PBKDF2HMACBackend
   - RSABackend
   - PEMSerializationBackend
   - X509Backend

   It also implements the following interface for OpenSSL versions 1.1.0 and above.
   - ScryptBackend

   It also exposes the following:

   name
      The string name of this backend: "openssl"

   openssl_version_text()
      Return text The friendly string name of the loaded OpenSSL library. This is not necessarily the same version as it was compiled against.

   openssl_version_number()
      New in version 1.8.
      Return int The integer version of the loaded OpenSSL library. This is defined in opensslv.h as OPENSSL_VERSION_NUMBER and is typically shown in hexadecimal (e.g. 0x1010003f). This is not necessarily the same version as it was compiled against.

   activate_osrandom_engine()
      Activates the OS random engine. This will effectively disable OpenSSL’s default CSPRNG.
osrandom_engine_implementation()

New in version 1.7.

Returns the implementation of OS random engine.

activate_builtin_random()

This will activate the default OpenSSL CSPRNG.

OS random engine

By default OpenSSL uses a user-space CSPRNG that is seeded from system random (\(/\text{dev/urandom}\) or CryptGenRandom). This CSPRNG is not reseeded automatically when a process calls fork(). This can result in situations where two different processes can return similar or identical keys and compromise the security of the system.

The approach this project has chosen to mitigate this vulnerability is to include an engine that replaces the OpenSSL default CSPRNG with one that sources its entropy from \(/\text{dev/urandom}\) on UNIX-like operating systems and uses CryptGenRandom on Windows. This method of pulling from the system pool allows us to avoid potential issues with initializing the RNG as well as protecting us from the fork() weakness.

This engine is active by default when importing the OpenSSL backend. When active this engine will be used to generate all the random data OpenSSL requests.

When importing only the binding it is added to the engine list but not activated.

OS random sources

On macOS and FreeBSD \(/\text{dev/urandom}\) is an alias for \(/\text{dev/random}\). The implementation on macOS uses the Yarrow algorithm. FreeBSD uses the Fortuna algorithm.

On Windows the implementation of CryptGenRandom depends on which version of the operation system you are using. See the Microsoft documentation for more details.

Linux uses its own PRNG design. \(/\text{dev/urandom}\) is a non-blocking source seeded from the same pool as \(/\text{dev/random}\).

<table>
<thead>
<tr>
<th>Windows</th>
<th>CryptGenRandom()</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linux &gt;= 3.17 with working SYS_getrandom syscall</td>
<td>getrandom(GRND_NONBLOCK)</td>
</tr>
<tr>
<td>OpenBSD &gt;= 5.6</td>
<td>getentropy()</td>
</tr>
<tr>
<td>BSD family (including macOS 10.12+) with SYS_getentropy in sys/syscall.h</td>
<td>getentropy()</td>
</tr>
<tr>
<td>fallback</td>
<td>/dev/urandom with cached file descriptor</td>
</tr>
</tbody>
</table>

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

Backend interfaces

Backend implementations may provide a number of interfaces to support operations such as Symmetric encryption, Message digests (Hashing), and Hash-based message authentication codes (HMAC).
A specific backend may provide one or more of these interfaces.

```python
class cryptography.hazmat.backends.interfaces.CipherBackend
A backend that provides methods for using ciphers for encryption and decryption.
```

The following backends implement this interface:

- **OpenSSL backend**

```python
cipher_supported(cipher, mode)
Check if a cipher and mode combination is supported by this backend.

Parameters
- cipher – An instance of CipherAlgorithm.
- mode – An instance of Mode.

Returns True if the specified cipher and mode combination is supported by this backend, otherwise False
```

```python
create_symmetric_encryption_ctx(cipher, mode)
Create a CipherContext that can be used for encrypting data with the symmetric cipher using the given mode.

Parameters
- cipher – An instance of CipherAlgorithm.
- mode – An instance of Mode.

Returns CipherContext

Raises ValueError – When tag is not None in an AEAD mode
```

```python
create_symmetric_decryption_ctx(cipher, mode)
Create a CipherContext that can be used for decrypting data with the symmetric cipher using the given mode.

Parameters
- cipher – An instance of CipherAlgorithm.
- mode – An instance of Mode.

Returns CipherContext

Raises ValueError – When tag is None in an AEAD mode
```

```python
class cryptography.hazmat.backends.interfaces.HashBackend
A backend with methods for using cryptographic hash functions.
```

The following backends implement this interface:

- **OpenSSL backend**

```python
hash_supported(algorithm)
Check if the specified algorithm is supported by this backend.

Parameters algorithm – An instance of HashAlgorithm.

Returns True if the specified algorithm is supported by this backend, otherwise False.
```

```python
create_hash_ctx(algorithm)
Create a HashContext that uses the specified algorithm to calculate a message digest.

Parameters algorithm – An instance of HashAlgorithm.
```
Returns HashContext

class cryptography.hazmat.backends.interfaces.HMACBackend
A backend with methods for using cryptographic hash functions as message authentication codes.

The following backends implement this interface:

- OpenSSL backend

hmac_supported(algorithm)
Check if the specified algorithm is supported by this backend.

Parameters algorithm – An instance of HashAlgorithm.

Returns True if the specified algorithm is supported for HMAC by this backend, otherwise False.

create_hmac_ctx(key, algorithm)
Create a HashContext that uses the specified algorithm to calculate a hash-based message authentication code.

Parameters
- key (bytes) – Secret key as bytes.
- algorithm – An instance of HashAlgorithm.

Returns HashContext

class cryptography.hazmat.backends.interfaces.CMACBackend
New in version 0.4.
A backend with methods for using CMAC

cmac_algorithm_supported(algorithm)
Parameters algorithm – An instance of BlockCipherAlgorithm.

Returns Returns True if the block cipher is supported for CMAC by this backend

create_cmac_ctx(algorithm)
Create a context that uses the specified algorithm to calculate a message authentication code.

Parameters algorithm – An instance of BlockCipherAlgorithm.

Returns CMAC object.

class cryptography.hazmat.backends.interfaces.PBKDF2HMACBackend
New in version 0.2.
A backend with methods for using PBKDF2 using HMAC as a PRF.

The following backends implement this interface:

- OpenSSL backend

pbkdf2_hmac_supported(algorithm)
Check if the specified algorithm is supported by this backend.

Parameters algorithm – An instance of HashAlgorithm.

Returns True if the specified algorithm is supported for PBKDF2 HMAC by this backend, otherwise False.

derive_pbkdf2_hmac(self, algorithm, length, salt, iterations, key_material)
Parameters
• **algorithm** – An instance of `HashAlgorithm`.

• **length (int)** – The desired length of the derived key. Maximum is \((2^{32} - 1) \times \text{algorithm.digest_size}\)

• **salt (bytes)** – A salt.

• **iterations (int)** – The number of iterations to perform of the hash function. This can be used to control the length of time the operation takes. Higher numbers help mitigate brute force attacks against derived keys.

• **key_material (bytes)** – The key material to use as a basis for the derived key. This is typically a password.

    **Return bytes** Derived key.

class cryptography.hazmat.backends.interfaces.RSABackend

    New in version 0.2.

    A backend with methods for using RSA.

    **generate_rsa_private_key (public_exponent, key_size)**

        **Parameters**

            • **public_exponent (int)** – The public exponent of the new key. Often one of the small Fermat primes 3, 5, 17, 257 or 65537.

            • **key_size (int)** – The length in bits of the modulus. Should be at least 2048.

        **Returns** A new instance of `RSAPrivateKey`.

        **Raises** `ValueError` – If the public_exponent is not valid.

    **rsa_padding_supported (padding)**

        Check if the specified padding is supported by the backend.

        **Parameters** padding – An instance of `AsymmetricPadding`.

        **Returns** True if the specified padding is supported by this backend, otherwise False.

    **generate_rsa_parameters_supported (public_exponent, key_size)**

        Check if the specified parameters are supported for key generation by the backend.

        **Parameters**

            • **public_exponent (int)** – The public exponent.

            • **key_size (int)** – The bit length of the generated modulus.

    **load_rsa_private_numbers (numbers)**

        **Parameters** numbers – An instance of `RSAPrivateNumbers`.

        **Returns** An instance of `RSAPrivateKey`.

        **Raises**

            • `ValueError` – This is raised when the values of p, q, private_exponent, public_exponent, or modulus do not match the bounds specified in RFC 3447.

            • `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

    **load_rsa_public_numbers (numbers)**

        **Parameters** numbers – An instance of `RSAPublicNumbers`.

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Returns  An instance of `RSAPublicKey`.

Raises

- `ValueError` – This is raised when the values of `public_exponent` or `modulus` do not match the bounds specified in RFC 3447.

- `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

class `cryptography.hazmat.backends.interfaces.DSABackend`

New in version 0.4.

A backend with methods for using DSA.

```
def generate_dsa_parameters(key_size)
    Parameters key_size (int) – The length of the modulus in bits. It should be either 1024, 2048 or 3072. For keys generated in 2015 this should be at least 2048. Note that some applications (such as SSH) have not yet gained support for larger key sizes specified in FIPS 186-3 and are still restricted to only the 1024-bit keys specified in FIPS 186-2.

    Returns A new instance of `DSAParameters`.

def generate_dsa_private_key(parameters)
    Parameters parameters – An instance of `DSAParameters`.

    Returns A new instance of `DSAPrivateKey`.

    Raises `ValueError` – This is raised if the key size is not one of 1024, 2048, or 3072.

def generate_dsa_private_key_and_parameters(key_size)
    Parameters key_size (int) – The length of the modulus in bits. It should be either 1024, 2048 or 3072. For keys generated in 2015 this should be at least 2048. Note that some applications (such as SSH) have not yet gained support for larger key sizes specified in FIPS 186-3 and are still restricted to only the 1024-bit keys specified in FIPS 186-2.

    Returns A new instance of `DSAPrivateKey`.

    Raises `ValueError` – This is raised if the key size is not supported by the backend.

def dsa_hash_supported(algorithm)
    Parameters algorithm – An instance of `HashAlgorithm`.

    Returns True if the specified `algorithm` is supported by this backend, otherwise False.

def dsa_parameters_supported(p, q, g)
    Parameters

    • p (int) – The p value of a DSA key.
    • q (int) – The q value of a DSA key.
    • g (int) – The g value of a DSA key.

    Returns True if the given values of p, q, and g are supported by this backend, otherwise False.

def load_dsa_parameter_numbers(numbers)
    Parameters numbers – An instance of `DSAParameterNumbers`.

    Returns An instance of `DSAParameters`.
Raises `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

### load_dsa_private_numbers(numbers)

Parameters **numbers** – An instance of `DSAPrivateNumbers`.

Returns An instance of `DSAPrivateKey`.

Raises `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

### load_dsa_public_numbers(numbers)

Parameters **numbers** – An instance of `DSAPublicNumbers`.

Returns An instance of `DSAPublicKey`.

Raises `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

class `cryptography.hazmat.backends.interfaces.EllipticCurveBackend`

New in version 0.5.

#### elliptic_curve_supported(curve)

Parameters **curve** – An instance of `EllipticCurve`.

Returns True if the elliptic curve is supported by this backend.

#### elliptic_curve_signature_algorithm_supported(signature_algorithm, curve)

Parameters

- **signature_algorithm** – An instance of `EllipticCurveSignatureAlgorithm`.
- **curve** – An instance of `EllipticCurve`.

Returns True if the signature algorithm and curve are supported by this backend.

#### generate_elliptic_curve_private_key(curve)

Parameters **curve** – An instance of `EllipticCurve`.

#### load_elliptic_curve_private_numbers(numbers)

Parameters **numbers** – An instance of `EllipticCurvePrivateNumbers`.

Returns An instance of `EllipticCurvePrivateKey`.

#### load_elliptic_curve_public_numbers(numbers)

Parameters **numbers** – An instance of `EllipticCurvePublicNumbers`.

Returns An instance of `EllipticCurvePublicKey`.

#### derive_elliptic_curve_private_key(private_value, curve)

Parameters

- **private_value** – A secret scalar value.
- **curve** – An instance of `EllipticCurve`.

Returns An instance of `EllipticCurvePrivateKey`.

class `cryptography.hazmat.backends.interfaces.PEMSerializationBackend`

New in version 0.6.

A backend with methods for working with any PEM encoded keys.
`load_pem_private_key` *(data, password)*

Parameters

- `data` *(bytes)* – PEM data to load.
- `password` *(bytes)* – The password to use if the data is encrypted. Should be `None` if the data is not encrypted.

Returns A new instance of the appropriate type of private key that the serialized data contains.

Raises

- `ValueError` – If the data could not be deserialized.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the data is encrypted with an unsupported algorithm.

`load_pem_public_key` *(data)*

Parameters `data` *(bytes)* – PEM data to load.

Returns A new instance of the appropriate type of public key serialized data contains.

Raises `ValueError` – If the data could not be deserialized.

`load_pem_parameters` *(data)*

New in version 2.0.

Parameters `data` *(bytes)* – PEM data to load.

Returns A new instance of the appropriate type of asymmetric parameters the serialized data contains.

Raises `ValueError` – If the data could not be deserialized.

`class cryptography.hazmat.backends.interfaces.DERSerializationBackend`

New in version 0.8.

A backend with methods for working with DER encoded keys.

`load_der_private_key` *(data, password)*

Parameters

- `data` *(bytes)* – DER data to load.
- `password` *(bytes)* – The password to use if the data is encrypted. Should be `None` if the data is not encrypted.

Returns A new instance of the appropriate type of private key that the serialized data contains.

Raises

- `ValueError` – If the data could not be deserialized.
- `cryptography.exceptions.UnsupportedAlgorithm` – If the data is encrypted with an unsupported algorithm.

`load_der_public_key` *(data)*

Parameters `data` *(bytes)* – DER data to load.

Returns A new instance of the appropriate type of public key serialized data contains.

Raises `ValueError` – If the data could not be deserialized.

`load_der_parameters` *(data)*

New in version 2.0.
Parameters `data` (`bytes`) – DER data to load.

Returns A new instance of the appropriate type of asymmetric parameters the serialized data contains.

Raises `ValueError` – If the data could not be deserialized.

class `cryptography.hazmat.backends.interfaces.X509Backend`  
New in version 0.7.
A backend with methods for working with X.509 objects.

`load_pem_x509_certificate`(`data`)  
Parameters `data` (`bytes`) – PEM formatted certificate data.

Returns An instance of `Certificate`.

`load_der_x509_certificate`(`data`)  
Parameters `data` (`bytes`) – DER formatted certificate data.

Returns An instance of `Certificate`.

`load_pem_x509_csr`(`data`)  
New in version 0.9.

Parameters `data` (`bytes`) – PEM formatted certificate signing request data.

Returns An instance of `CertificateSigningRequest`.

`load_der_x509_csr`(`data`)  
New in version 0.9.

Parameters `data` (`bytes`) – DER formatted certificate signing request data.

Returns An instance of `CertificateSigningRequest`.

`create_x509_csr`(`builder`, `private_key`, `algorithm`)  
New in version 1.0.

Parameters

- `builder` – An instance of `CertificateSigningRequestBuilder`.
- `private_key` – The `RSAPrivateKey`, `DSAPrivateKey` or `EllipticCurvePrivateKey` that will be used to sign the request. When the request is signed by a certificate authority, the private key’s associated public key will be stored in the resulting certificate.
- `algorithm` – The `HashAlgorithm` that will be used to generate the request signature.

Returns A new instance of `CertificateSigningRequest`.

`create_x509_certificate`(`builder`, `private_key`, `algorithm`)  
New in version 1.0.

Parameters

- `builder` – An instance of `CertificateBuilder`.
- `private_key` – The `RSAPrivateKey`, `DSAPrivateKey` or `EllipticCurvePrivateKey` that will be used to sign the certificate.
- `algorithm` – The `HashAlgorithm` that will be used to generate the certificate signature.

Returns A new instance of `Certificate`. 

2.6. Backends
create_x509_crl (builder, private_key, algorithm)
New in version 1.2.
Parameters
• builder – An instance of CertificateRevocationListBuilder.
• private_key – The RSAPrivateKey, DSAPrivateKey or EllipticCurvePrivateKey that will be used to sign the CRL.
• algorithm – The HashAlgorithm that will be used to generate the CRL signature.

create_x509_revoked_certificate (builder)
New in version 1.2.
Parameters builder – An instance of RevokedCertificateBuilder.
Returns A new instance of RevokedCertificate.

x509_name_bytes (name)
New in version 1.6.
Parameters name – An instance of Name.
Return bytes The DER encoded bytes.

class cryptography.hazmat.backends.interfaces.DHBackend
New in version 0.9.
A backend with methods for doing Diffie-Hellman key exchange.

generate_dh_parameters (generator, key_size)
Parameters
• generator (int) – The generator to use. Often 2 or 5.
• key_size (int) – The bit length of the prime modulus to generate.
Returns A new instance of DHParameters.
Raises ValueError – If key_size is not at least 512.

generate_dh_private_key (parameters)
Parameters parameters – An instance of DHParameters.
Returns A new instance of DHPrivateKey.

generate_dh_private_key_and_parameters (generator, key_size)
Parameters
• generator (int) – The generator to use. Often 2 or 5.
• key_size (int) – The bit length of the prime modulus to generate.
Returns A new instance of DHPrivateKey.
Raises ValueError – If key_size is not at least 512.

load_dh_private_numbers (numbers)
Parameters numbers – A DHPrivateNumbers instance.
Returns A new instance of DHPrivateKey.
Raises `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

```python
load_dh_public_numbers(numbers)
```

Parameters `numbers` – A `DHPublicNumbers` instance.

Returns A new instance of `DHPublicKey`.

Raises `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

```python
load_dh_parameter_numbers(numbers)
```

Parameters `numbers` – A `DHParameterNumbers` instance.

Returns A new instance of `DHParameters`.

Raises `cryptography.exceptions.UnsupportedAlgorithm` – This is raised when any backend specific criteria are not met.

```python
dh_parameters_supported(p, g, q=None)
```

Parameters

- `p (int)` – The p value of the DH key.
- `g (int)` – The g value of the DH key.
- `q (int)` – The q value of the DH key.

Returns True if the given values of p, g and q are supported by this backend, otherwise False.

New in version 1.8.

```python
dh_x942_serialization_supported()
```

Returns True if serialization of DH objects with subgroup order (q) is supported by this backend.

```python
class cryptography.hazmat.backends.interfaces.ScryptBackend
```

New in version 1.6.

A backend with methods for using Scrypt.

The following backends implement this interface:

- OpenSSL backend

```python
derive_scrypt(self, key_material, salt, length, n, r, p)
```

Parameters

- `key_material (bytes)` – The key material to use as a basis for the derived key. This is typically a password.
- `salt (bytes)` – A salt.
- `length (int)` – The desired length of the derived key.
- `n (int)` – CPU/Memory cost parameter. It must be larger than 1 and be a power of 2.
- `r (int)` – Block size parameter.
- `p (int)` – Parallelization parameter.

Return bytes Derived key.
This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

2.7 Bindings

cryptography aims to provide low-level CFFI based bindings to multiple native C libraries. These provide no automatic initialization of the library and may not provide complete wrappers for its API.

Using these functions directly is likely to require you to be careful in managing memory allocation, locking and other resources.

2.7.1 Individual bindings

This is a “Hazardous Materials” module. You should ONLY use it if you’re 100% absolutely sure that you know what you’re doing because this module is full of land mines, dragons, and dinosaurs with laser guns.

OpenSSL binding

These are CFFI bindings to the OpenSSL C library. Cryptography supports OpenSSL version 1.0.1 and greater.

class cryptography.hazmat.bindings.openssl.binding.Binding

This is the exposed API for the OpenSSL bindings. It has two public attributes:

ffi

This is a cffi.FFI instance. It can be used to allocate and otherwise manipulate OpenSSL structures.

lib

This is a cffi library. It can be used to call OpenSSL functions, and access constants.

classmethod init_static_locks()

Enables the best available locking callback for OpenSSL. See Threading.

Threading

cryptography enables OpenSSLs thread safety facilities in several different ways depending on the configuration of your system. For users on OpenSSL 1.1.0 or newer (including anyone who uses a binary wheel) the OpenSSL internal locking callbacks are automatically used. Otherwise, we first attempt to use the callbacks provided by your Python implementation specifically for OpenSSL. This will work in every case except where cryptography is linked against a different version of OpenSSL than the one used by your Python implementation. For this final case we have a C-based locking callback.

2.8 Installation

You can install cryptography with pip:
2.8.1 Supported platforms

Currently we test cryptography on Python 2.7, 3.4+, and PyPy 5.4+ on these operating systems.

- x86-64 CentOS 7.x
- x86-64 Fedora (latest)
- macOS 10.13 High Sierra, 10.14 Mojave
- x86-64 Ubuntu 14.04, 16.04, and rolling
- x86-64 Debian Jessie (8.x), Stretch (9.x), Buster (10.x), and Sid (unstable)
- x86-64 Alpine (latest)
- 32-bit and 64-bit Python on 64-bit Windows Server 2019

We test compiling with clang as well as gcc and use the following OpenSSL releases:

- OpenSSL 1.0.1
- OpenSSL 1.0.1e-fips (RHEL/CentOS 7)
- OpenSSL 1.0.1f
- OpenSSL 1.0.2-latest
- OpenSSL 1.1.0-latest
- OpenSSL 1.1.1-latest

**Warning:** Cryptography 2.4 has deprecated support for OpenSSL 1.0.1.

2.8.2 Building cryptography on Windows

The wheel package on Windows is a statically linked build (as of 0.5) so all dependencies are included. To install cryptography, you will typically just run

```
$ pip install cryptography
```

If you prefer to compile it yourself you’ll need to have OpenSSL installed. You can compile OpenSSL yourself as well or use the binaries we build for our own infrastructure. Be sure to download the proper version for your architecture and Python (2010 works for Python 2.7, 3.3, and 3.4 while 2015 is required for 3.5 and above). Wherever you place your copy of OpenSSL you’ll need to set the LIB and INCLUDE environment variables to include the proper locations. For example:

```
C:\> \path\to\vcvarsall.bat x86_amd64
C:\> set LIB=C:\OpenSSL-win64\lib;%LIB%
C:\> set INCLUDE=C:\OpenSSL-win64\include;%INCLUDE%
C:\> pip install cryptography
```

As of OpenSSL 1.1.0 the library names have changed from libeay32 and ssleay32 to libcrypto and libssl (matching their names on all other platforms). cryptography links against the new 1.1.0 names by default. If you need to compile cryptography against an older version then you must set CRYPTOGRAPHY_WINDOWS_LINK_LEGACY_OPENSSL or else installation will fail.
2.8.3 Building cryptography on Linux

cryptography ships manylinux wheels (as of 2.0) so all dependencies are included. For users on pip 8.1 or above running on a manylinux1 or manylinux2010 compatible distribution (almost everything except Alpine) all you should need to do is:

$ pip install cryptography

If you are on Alpine or just want to compile it yourself then cryptography requires a compiler, headers for Python (if you’re not using pypy), and headers for the OpenSSL and libffi libraries available on your system.

Alpine

Replace python3-dev with python-dev if you’re using Python 2.

$ sudo apk add gcc musl-dev python3-dev libffi-dev openssl-dev

If you get an error with openssl-dev you may have to use libressl-dev.

Debian/Ubuntu

Replace python3-dev with python-dev if you’re using Python 2.

$ sudo apt-get install build-essential libssl-dev libffi-dev python3-dev

RHEL/CentOS

$ sudo yum install redhat-rpm-config gcc libffi-devel python-devel openssl-devel

Building

You should now be able to build and install cryptography. To avoid getting the pre-built wheel on manylinux compatible distributions you’ll need to use --no-binary.

$ pip install cryptography --no-binary cryptography

Using your own OpenSSL on Linux

Python links to OpenSSL for its own purposes and this can sometimes cause problems when you wish to use a different version of OpenSSL with cryptography. If you want to use cryptography with your own build of OpenSSL you will need to make sure that the build is configured correctly so that your version of OpenSSL doesn’t conflict with Python’s.

The options you need to add allow the linker to identify every symbol correctly even when multiple versions of the library are linked into the same program. If you are using your distribution’s source packages these will probably be patched in for you already, otherwise you’ll need to use options something like this when configuring OpenSSL:
You’ll also need to generate your own `openssl.ld` file. For example:

```bash
OPENSSL_1.1.0E_CUSTOM {
  global:
  *
};
```

You should replace the version string on the first line as appropriate for your build.

## Static Wheels

Cryptography ships statically-linked wheels for macOS, Windows, and Linux (via `manylinux`). This allows compatible environments to use the most recent OpenSSL, regardless of what is shipped by default on those platforms. Some Linux distributions (most notably Alpine) are not `manylinux` compatible so we cannot distribute wheels for them.

However, you can build your own statically-linked wheels that will work on your own systems. This will allow you to continue to use relatively old Linux distributions (such as LTS releases), while making sure you have the most recent OpenSSL available to your Python programs.

To do so, you should find yourself a machine that is as similar as possible to your target environment (e.g. your production environment): for example, spin up a new cloud server running your target Linux distribution. On this machine, install the Cryptography dependencies as mentioned in Building cryptography on Linux. Please also make sure you have `virtualenv` installed: this should be available from your system package manager.

Then, paste the following into a shell script. You’ll need to populate the `OPENSSL_VERSION` variable. To do that, visit openssl.org and find the latest non-FIPS release version number, then set the string appropriately. For example, for OpenSSL 1.0.2k, use `OPENSSL_VERSION="1.0.2k"`.

When this shell script is complete, you’ll find a collection of wheel files in a directory called `wheelhouse`. These wheels can be installed by a sufficiently-recent version of `pip`. The Cryptography wheel in this directory contains a statically-linked OpenSSL binding, which ensures that you have access to the most-recent OpenSSL releases without corrupting your system dependencies.

```bash
set -e
OPENSSL_VERSION="VERSIONGOESHERE"
CWD=$(pwd)

virtualenv env
. env/bin/activate
pip install -U setuptools
pip install -U wheel
pip install -U pip

curl -O https://www.openssl.org/source/openssl-$OPENSSL_VERSION.tar.gz

tar xvf openssl-$OPENSSL_VERSION.tar.gz

cd openssl-$OPENSSL_VERSION

./config no-shared no-ssl2 no-ssl3 -fPIC --prefix=$CWD/openssl

make && make install

cd ..

CFLAGS="-I$CWD/openssl/include" LDFLAGS="-L$CWD/openssl/lib" pip wheel --no-binary :all: cryptography
```

### 2.8.4 Building cryptography on macOS
Note: If installation gives a fatal error: 'openssl/aes.h' file not found see the FAQ for information about how to fix this issue.

The wheel package on macOS is a statically linked build (as of 1.0.1) so for users with pip 8 or above you only need one step:

```
$ pip install cryptography
```

If you want to build cryptography yourself or are on an older macOS version, cryptography requires the presence of a C compiler, development headers, and the proper libraries. On macOS much of this is provided by Apple's Xcode development tools. To install the Xcode command line tools (on macOS 10.9+) open a terminal window and run:

```
$ xcode-select --install
```

This will install a compiler (clang) along with (most of) the required development headers.

You’ll also need OpenSSL, which you can obtain from Homebrew or MacPorts. Cryptography does not support Apple's deprecated OpenSSL distribution.

To build cryptography and dynamically link it:

**Homebrew**

```
$ brew install openssl@1.1
$ env LDFLAGS="-L$(brew --prefix openssl@1.1)/lib" CFLAGS="-I$(brew --prefix openssl@1.1)/include" pip install cryptography
```

**MacPorts**

```
$ sudo port install openssl
$ env LDFLAGS="-L/opt/local/lib" CFLAGS="-I/opt/local/include" pip install cryptography
```

You can also build cryptography statically:

**Homebrew**

```
$ brew install openssl@1.1
$ env CRYPTOGRAPHY_SUPPRESS_LINK_FLAGS=1 LDFLAGS="$(brew --prefix openssl@1.1)/lib/" libssl.a $(brew --prefix openssl@1.1)/lib/libcrypto.a" CFLAGS="-I$(brew --prefix openssl@1.1)/include" pip install cryptography
```

**MacPorts**

```
$ sudo port install openssl
$ env CRYPTOGRAPHY_SUPPRESS_LINK_FLAGS=1 LDFLAGS="/opt/local/lib/libssl.a /opt/local/" lib/libcrypto.a" CFLAGS="-I/opt/local/include" pip install cryptography
```

If you need to rebuild cryptography for any reason be sure to clear the local wheel cache.

## 2.9 Changelog

### 2.9.1 2.8 - master
Note: This version is not yet released and is under active development.

- We now ship manylinux2010 wheels in addition to our manylinux1 wheels.

### 2.9.2 2.7 - 2019-05-30

- **BACKWARDS INCOMPATIBLE:** We no longer distribute 32-bit manylinux1 wheels. Continuing to produce them was a maintenance burden.

- **BACKWARDS INCOMPATIBLE:** Removed the cryptography.hazmat.primitives.mac.MACContext interface. The CMAC and HMAC APIs have not changed, but they are no longer registered as MACContext instances.

- Updated Windows, macOS, and manylinux1 wheels to be compiled with OpenSSL 1.1.1c.

- Removed support for running our tests with `setup.py test`. Users interested in running our tests can continue to follow the directions in our [development documentation](#).

- Add support for `Poly1305` when using OpenSSL 1.1.1 or newer.


- Correctly allow passing a `SubjectKeyIdentifier` to `from_issuer_subject_key_identifier()` and deprecate passing an `Extension` object. The documentation always required `SubjectKeyIdentifier` but the implementation previously required an `Extension`.

### 2.9.3 2.6.1 - 2019-02-27

- Resolved an error in our build infrastructure that broke our Python3 wheels for macOS and Linux.

### 2.9.4 2.6 - 2019-02-27

- **BACKWARDS INCOMPATIBLE:** Removed `cryptography.hazmat.primitives.asymmetric.utils.encode_rfc6979_signature` and `cryptography.hazmat.primitives.asymmetric.utils.decode_rfc6979_signature`, which had been deprecated for nearly 4 years. Use `encode_dss_signature()` and `decode_dss_signature()` instead.

- **BACKWARDS INCOMPATIBLE:** Removed `cryptography.x509.Certificate.serial`, which had been deprecated for nearly 3 years. Use `serial_number` instead.

- Updated Windows, macOS, and manylinux1 wheels to be compiled with OpenSSL 1.1.1b.

- Added support for `Ed448 signing` when using OpenSSL 1.1.1b or newer.

- Added support for `Ed25519 signing` when using OpenSSL 1.1.1b or newer.

- `load_ssh_public_key()` can now load `ed25519` public keys.

- Add support for easily mapping an object identifier to its elliptic curve class via `get_curve_for_oid()`.

- Add support for OpenSSL when compiled with the `no-engine` (`OPENSSL_NO_ENGINE`) flag.
2.9.5 2.5 - 2019-01-22

- **BACKWARDS INCOMPATIBLE:** *U-label* strings were deprecated in version 2.1, but this version removes the default *idna* dependency as well. If you still need this deprecated path please install cryptography with the *idna* extra: `pip install cryptography[extra].`

- **BACKWARDS INCOMPATIBLE:** The minimum supported PyPy version is now 5.4.

- Numerous classes and functions have been updated to allow *bytes-like* types for keying material and passwords, including symmetric algorithms, AEAD ciphers, KDFs, loading asymmetric keys, and one time password classes.

- Updated Windows, macOS, and *manylinux1* wheels to be compiled with OpenSSL 1.1.1a.

- Added support for *SHA512_224* and *SHA512_256* when using OpenSSL 1.1.1.

- Added support for *SHA3_224*, *SHA3_256*, *SHA3_384*, and *SHA3_512* when using OpenSSL 1.1.1.

- Added support for *X448 key exchange* when using OpenSSL 1.1.1.

- Added support for *SHAKE128* and *SHAKE256* when using OpenSSL 1.1.1.

- Added initial support for parsing PKCS12 files with *load_key_and_certificates()*.

- Added support for *IssuingDistributionPoint*.

- Added *rfc4514_string()* method to *x509.Name*, *x509.RelativeDistinguishedName*, and *x509.NameAttribute* to format the name or component an RFC 4514 Distinguished Name string.

- Added *from_encoded_point()* which immediately checks if the point is on the curve and supports compressed points. Deprecated the previous method *from_encoded_point()*.

- Added *signature_hash_algorithm* to *OCSPResponse*.

- Updated *X25519 key exchange* support to allow additional serialization methods. Calling *public_bytes()* with no arguments has been deprecated.

- Added support for encoding compressed and uncompressed points via *public_bytes()*. Deprecated the previous method *encode_point()*.

2.9.6 2.4.2 - 2018-11-21

- Updated Windows, macOS, and *manylinux1* wheels to be compiled with OpenSSL 1.1.0j.

2.9.7 2.4.1 - 2018-11-11

- Fixed a build breakage in our *manylinux1* wheels.

2.9.8 2.4 - 2018-11-11

- **BACKWARDS INCOMPATIBLE:** Dropped support for LibreSSL 2.4.x.

- Deprecated OpenSSL 1.0.1 support. OpenSSL 1.0.1 is no longer supported by the OpenSSL project. At this time there is no time table for dropping support, however we strongly encourage all users to upgrade or install cryptography from a wheel.

- Added initial *OCSP* support.

- Added support for *PrecertPoison*. 
2.9.9 2.3.1 - 2018-08-14

- Updated Windows, macOS, and manylinux1 wheels to be compiled with OpenSSL 1.1.0i.

2.9.10 2.3 - 2018-07-18

- **SECURITY ISSUE:** `finalize_with_tag()` allowed tag truncation by default which can allow tag forgery in some cases. The method now enforces the `min_tag_length` provided to the `GCM` constructor. **CVE-2018-10903**
- Added support for Python 3.7.
- Added `extract_timestamp()` to get the authenticated timestamp of a `Fernet` token.
- Support for Python 2.7.x without `hmac.compare_digest` has been deprecated. We will require Python 2.7.7 or higher (or 2.7.6 on Ubuntu) in the next cryptography release.
- Fixed multiple issues preventing cryptography from compiling against LibreSSL 2.7.x.
- Added `get_revoked_certificate_by_serial_number` for quick serial number searches in CRLs.
- The `RelativeDistinguishedName` class now preserves the order of attributes. Duplicate attributes now raise an error instead of silently discarding duplicates.
- `aes_key_unwrap()` and `aes_key_unwrap_with_padding()` now raise `InvalidUnwrap` if the wrapped key is an invalid length, instead of `ValueError`.

2.9.11 2.2.2 - 2018-03-27

- Updated Windows, macOS, and manylinux1 wheels to be compiled with OpenSSL 1.1.0h.

2.9.12 2.2.1 - 2018-03-20

- Reverted a change to `GeneralNames` which prohibited having zero elements, due to breakages.
- Fixed a bug in `aes_key_unwrap_with_padding()` that caused it to raise `InvalidUnwrap` when key length modulo 8 was zero.

2.9.13 2.2 - 2018-03-19

- **BACKWARDS INCOMPATIBLE:** Support for Python 2.6 has been dropped.
- Resolved a bug in `HKDF` that incorrectly constrained output size.
- Added `BrainpoolP256R1`, `BrainpoolP384R1`, and `BrainpoolP512R1` to support inter-operating with systems like German smart meters.
- Added token rotation support to `Fernet` with `rotate()`.
- Fixed a memory leak in `derive_private_key()`.
- Added support for AES key wrapping with padding via `aes_key_wrap_with_padding()` and `aes_key_unwrap_with_padding()`.
- Allow loading DSA keys with 224 bit q.
2.9.14 2.1.4 - 2017-11-29

- Added `X509_up_ref` for an upcoming `pyOpenSSL` release.

2.9.15 2.1.3 - 2017-11-02

- Updated Windows, macOS, and `manylinux1` wheels to be compiled with OpenSSL 1.1.0g.

2.9.16 2.1.2 - 2017-10-24

- Corrected a bug with the `manylinux1` wheels where OpenSSL's stack was marked executable.

2.9.17 2.1.1 - 2017-10-12

- Fixed support for install with the system `pip` on Ubuntu 16.04.

2.9.18 2.1 - 2017-10-11

- **FINAL DEPRECATION** Python 2.6 support is deprecated, and will be removed in the next release of `cryptography`.

- **BACKWARDS INCOMPATIBLE:** `Whirlpool`, `RIPEMD160`, and `UnsupportedExtension` have been removed in accordance with our API stability policy.

- **BACKWARDS INCOMPATIBLE:** `DNSName.value`, `RFC822Name.value`, and `UniformResourceIdentifier.value` will now return an `A-label` string when parsing a certificate containing an internationalized domain name (IDN) or if the caller passed a `U-label` to the constructor. See below for additional deprecations related to this change.

- Installing `cryptography` now requires `pip` 6 or newer.

- Deprecated passing `U-label` strings to the `DNSName`, `UniformResourceIdentifier`, and `RFC822Name` constructors. Instead, users should pass values as `A-label` strings with `idna` encoding if necessary. This change will not affect anyone who is not processing internationalized domains.

- Added support for `ChaCha20`. In most cases users should choose `ChaCha20Poly1305` rather than using this unauthenticated form.

- Added `is_signature_valid()` to `CertificateRevocationList`.

- Support `BLAKE2b` and `BLAKE2s` with `HMAC`.

- Added support for `XTS` mode for AES.

- Added support for using labels with `OAEP` when using OpenSSL 1.0.2 or greater.

- Improved compatibility with NSS when issuing certificates from an issuer that has a subject with non-UTF8String string types.

- Add support for the `DeltaCRLIndicator` extension.

- Add support for the `TLSFeature` extension. This is commonly used for enabling OCSP Must-Staple in certificates.

- Add support for the `FreshestCRL` extension.
2.9.19 2.0.3 - 2017-08-03

• Fixed an issue with weak linking symbols when compiling on macOS versions older than 10.12.

2.9.20 2.0.2 - 2017-07-27

• Marked all symbols as hidden in the manylinux1 wheel to avoid a bug with symbol resolution in certain scenarios.

2.9.21 2.0.1 - 2017-07-26

• Fixed a compilation bug affecting OpenBSD.
• Altered the manylinux1 wheels to statically link OpenSSL instead of dynamically linking and bundling the shared object. This should resolve crashes seen when using uwsgi or other binaries that link against OpenSSL independently.
• Fixed the stack level for the signer and verifier warnings.

2.9.22 2.0 - 2017-07-17

• BACKWARDS INCOMPATIBLE: Support for Python 3.3 has been dropped.
• We now ship manylinux1 wheels linked against OpenSSL 1.1.0f. These wheels will be automatically used with most Linux distributions if you are running the latest pip.
• Deprecated the use of signer on RSAPrivatekey, DSAPrivateKey, and EllipticCurvePrivateKey in favor of sign.
• Deprecated the use of verifier on RSAPublicKey, DSAPublicKey, and EllipticCurvePublicKey in favor of verify.
• Added support for parsing SignedCertificateTimestamp objects from X.509 certificate extensions.
• Added support for ChaCha20Poly1305.
• Added support for AESGCM.
• Added AESGCM, a “one shot” API for AES GCM encryption.
• Added support for X25519 key exchange.
• Added support for serializing and deserializing Diffie-Hellman parameters with load_pem_parameters(), load_der_parameters(), and parameter_bytes().
• The extensions attribute on Certificate, CertificateSigningRequest, CertificateRevocationList, and RevokedCertificate now caches the computed Extensions object. There should be no performance change, just a performance improvement for programs accessing the extensions attribute multiple times.

2.9.23 1.9 - 2017-05-29

• BACKWARDS INCOMPATIBLE: Elliptic Curve signature verification no longer returns True on success. This brings it in line with the interface’s documentation, and our intent. The correct way to use verify() has always been to check whether or not InvalidSignature was raised.
• BACKWARDS INCOMPATIBLE: Dropped support for macOS 10.7 and 10.8.
• **BACKWARDS INCOMPATIBLE**: The minimum supported PyPy version is now 5.3.
• Python 3.3 support has been deprecated, and will be removed in the next cryptography release.
• Add support for providing tag during GCM finalization via finalize_with_tag().
• Fixed an issue preventing cryptography from compiling against LibreSSL 2.5.x.
• Added key_size() and key_size() as convenience methods for determining the bit size of a secret scalar for the curve.
• Accessing an unrecognized extension marked critical on an X.509 object will no longer raise an UnsupportedExtension exception, instead an UnrecognizedExtension object will be returned. This behavior was based on a poor reading of the RFC, unknown critical extensions only need to be rejected on certificate verification.
• The CommonCrypto backend has been removed.
• MultiBackend has been removed.
• Whirlpool and RIPEMD160 have been deprecated.

**2.9.24 1.8.2 - 2017-05-26**

• Fixed a compilation bug affecting OpenSSL 1.1.0f.
• Updated Windows and macOS wheels to be compiled against OpenSSL 1.1.0f.

**2.9.25 1.8.1 - 2017-03-10**

• Fixed macOS wheels to properly link against 1.1.0 rather than 1.0.2.

**2.9.26 1.8 - 2017-03-09**

• Added support for Python 3.6.
• Windows and macOS wheels now link against OpenSSL 1.1.0.
• macOS wheels are no longer universal. This change significantly shrinks the size of the wheels. Users on macOS 32-bit Python (if there are any) should migrate to 64-bit or build their own packages.
• Changed ASN.1 dependency from pyasn1 to asn1crypto resulting in a general performance increase when encoding/decoding ASN.1 structures. Also, the pyasn1_modules test dependency is no longer required.
• Added support for update_into() on CipherContext.
• Added private_bytes() to DHPublicKeyWithSerialization.
• Added public_bytes() to DHPublicKey.
• load_pem_private_key() and load_der_private_key() now require that password must be bytes if provided. Previously this was documented but not enforced.
• Added support for subgroup order in Diffie-Hellman key exchange.

**2.9.27 1.7.2 - 2017-01-27**

• Updated Windows and macOS wheels to be compiled against OpenSSL 1.0.2k.
2.9.28 1.7.1 - 2016-12-13

- Fixed a regression in \texttt{int\_from\_bytes} where it failed to accept \texttt{bytearray}.

2.9.29 1.7 - 2016-12-12

- Support for OpenSSL 1.0.0 has been removed. Users on older version of OpenSSL will need to upgrade.
- Added support for Diffie-Hellman key exchange using \texttt{exchange()}.
- The OS random engine for OpenSSL has been rewritten to improve compatibility with embedded Python and other edge cases. More information about this change can be found in the pull request.

2.9.30 1.6 - 2016-11-22

- Deprecated support for OpenSSL 1.0.0. Support will be removed in \texttt{cryptography 1.7}.
- Replaced the Python-based OpenSSL locking callbacks with a C version to fix a potential deadlock that could occur if a garbage collection cycle occurred while inside the lock.
- Added support for \texttt{BLAKE2b} and \texttt{BLAKE2s} when using OpenSSL 1.1.0.
- Added \texttt{signature\_algorithm\_oid} support to \texttt{Certificate}.
- Added \texttt{signature\_algorithm\_oid} support to \texttt{CertificateSigningRequest}.
- Added \texttt{signature\_algorithm\_oid} support to \texttt{CertificateRevocationList}.
- Added support for \texttt{Scrypt} when using OpenSSL 1.1.0.
- Added a workaround to improve compatibility with Python application bundling tools like \texttt{PyInstaller} and \texttt{cx\_freeze}.
- Added support for generating a \texttt{random\_serial\_number()}.
- Added support for encoding \texttt{IPv4Network} and \texttt{IPv6Network} in X.509 certificates for use with \texttt{NameConstraints}.
- Added \texttt{public\_bytes()} to \texttt{Name}.
- Added \texttt{RelativeDistinguishedName}
- \texttt{DistributionPoint} now accepts \texttt{RelativeDistinguishedName} for \texttt{relative\_name}. Deprecated use of \texttt{Name} as \texttt{relative\_name}.
- \texttt{Name} now accepts an iterable of \texttt{RelativeDistinguishedName}. RDNs can be accessed via the \texttt{rdns} attribute. When constructed with an iterable of \texttt{NameAttribute}, each attribute becomes a single-valued RDN.
- Added \texttt{derive\_private\_key()}.
- Added support for signing and verifying RSA, DSA, and ECDSA signatures with \texttt{Prehashed} digests.

2.9.31 1.5.3 - 2016-11-05

- \textbf{SECURITY ISSUE}: Fixed a bug where \texttt{HKDF} would return an empty byte-string if used with a \texttt{length} less than \texttt{algorithm\_digest\_size}. Credit to \textit{Markus Döring} for reporting the issue. \textit{CVE-2016-9243}
2.9.32 1.5.2 - 2016-09-26

- Updated Windows and OS X wheels to be compiled against OpenSSL 1.0.2j.

2.9.33 1.5.1 - 2016-09-22

- Updated Windows and OS X wheels to be compiled against OpenSSL 1.0.2i.
- Resolved a `UserWarning` when used with cffi 1.8.3.
- Fixed a memory leak in name creation with X.509.
- Added a workaround for old versions of setuptools.
- Fixed an issue preventing `cryptography` from compiling against OpenSSL 1.0.2i.

2.9.34 1.5 - 2016-08-26

- Added `calculate_max_pss_salt_length()`.
- Added “one shot” `sign()` and `verify()` methods to DSA keys.
- Added “one shot” `sign()` and `verify()` methods to ECDSA keys.
- Switched back to the older callback model on Python 3.5 in order to mitigate the locking callback problem with OpenSSL <1.1.0.
- `cryptography` now supports OpenSSL 1.1.0 as a compilation target.

2.9.35 1.4 - 2016-06-04

- Support for OpenSSL 0.9.8 has been removed. Users on older versions of OpenSSL will need to upgrade.
- Added `KBKDFHMAC`.
- Added support for OpenSSH public key serialization.
- Added support for SHA-2 in RSA `OAEP` when using OpenSSL 1.0.2 or greater.
- Added “one shot” `sign()` and `verify()` methods to RSA keys.
- Deprecated the `serial` attribute on `Certificate`, in favor of `serial_number`.

2.9.36 1.3.4 - 2016-06-03

- Added another OpenSSL function to the bindings to support an upcoming pyOpenSSL release.

2.9.37 1.3.3 - 2016-06-02

- Added two new OpenSSL functions to the bindings to support an upcoming pyOpenSSL release.
2.9.38 1.3.2 - 2016-05-04

- Updated Windows and OS X wheels to be compiled against OpenSSL 1.0.2h.
- Fixed an issue preventing cryptography from compiling against LibreSSL 2.3.x.

2.9.39 1.3.1 - 2016-03-21

- Fixed a bug that caused an AttributeError when using mock to patch some cryptography modules.

2.9.40 1.3 - 2016-03-18

- Added support for padding ANSI X.923 with ANSIX923.
- Deprecated support for OpenSSL 0.9.8. Support will be removed in cryptography 1.4.
- Added support for the PolicyConstraints X.509 extension including both parsing and generation using CertificateBuilder and CertificateSigningRequestBuilder.
- Added is_signature_valid to CertificateSigningRequest.
- Fixed an intermittent AssertionError when performing an RSA decryption on an invalid ciphertext, ValueError is now correctly raised in all cases.
- Added from_issuer_subject_key_identifier().

2.9.41 1.2.3 - 2016-03-01

- Updated Windows and OS X wheels to be compiled against OpenSSL 1.0.2g.

2.9.42 1.2.2 - 2016-01-29

- Updated Windows and OS X wheels to be compiled against OpenSSL 1.0.2f.

2.9.43 1.2.1 - 2016-01-08

- Reverts a change to an OpenSSL EVP_PKEY object that caused errors with pyOpenSSL.

2.9.44 1.2 - 2016-01-08

- BACKWARDS INCOMPATIBLE: RevokedCertificate extensions now uses extension classes rather than returning raw values inside the Extension value. The new classes are:
  - CertificateIssuer
  - CRLReason
  - InvalidityDate
- Deprecated support for OpenSSL 0.9.8 and 1.0.0. At this time there is no time table for actually dropping support, however we strongly encourage all users to upgrade, as those versions no longer receive support from the OpenSSL project.
- The Certificate class now has signature and tbs_certificate_bytes attributes.

2.9. Changelog
• The CertificateSigningRequest class now has signature and tbs_certrequest_bytes attributes.

• The CertificateRevocationList class now has signature and tbs_certlist_bytes attributes.

• NameConstraints are now supported in the CertificateBuilder and CertificateSigningRequestBuilder.


• Add support for parsing CertificateRevocationList extensions() in the OpenSSL backend. The following extensions are currently supported:

  – AuthorityInformationAccess
  – AuthorityKeyIdentifier
  – CRLNumber
  – IssuerAlternativeName

• Added CertificateRevocationListBuilder and RevokedCertificateBuilder to allow creation of CRLs.

• Unrecognized non-critical X.509 extensions are now parsed into an UnrecognizedExtension object.

2.9.45 1.1.2 - 2015-12-10

• Fixed a SIGBUS crash with the OS X wheels caused by redefinition of a method.

• Fixed a runtime error undefined symbol EC_GFp_nistp224_method that occurred with some OpenSSL installations.

• Updated Windows and OS X wheels to be compiled against OpenSSL 1.0.2e.

2.9.46 1.1.1 - 2015-11-19

• Fixed several small bugs related to compiling the OpenSSL bindings with unusual OpenSSL configurations.

• Resolved an issue where, depending on the method of installation and which Python interpreter they were using, users on El Capitan (OS X 10.11) may have seen an InternalError on import.

2.9.47 1.1 - 2015-10-28

• Added support for Elliptic Curve Diffie-Hellman with ECDH.

• Added X963KDF.

• Added support for parsing certificate revocation lists (CRLs) using load_pem_x509_crl() and load_der_x509_crl().

• Add support for AES key wrapping with aes_key_wrap() and aes_key_unwrap().

• Added a __hash__ method to Name.

• Add support for encoding and decoding elliptic curve points to a byte string form using encode_point() and from_encoded_point().

• Added get_extension_for_class().
• CertificatePolicies are now supported in the CertificateBuilder.
• countryName is now encoded as a PrintableString when creating subject and issuer distinguished names with the Certificate and CSR builder classes.

2.9.48 1.0.2 - 2015-09-27
• SECURITY ISSUE: The OpenSSL backend prior to 1.0.2 made extensive use of assertions to check response codes where our tests could not trigger a failure. However, when Python is run with -O these asserts are optimized away. If a user ran Python with this flag and got an invalid response code this could result in undefined behavior or worse. Accordingly, all response checks from the OpenSSL backend have been converted from assert to a true function call. Credit Emilia Käsper (Google Security Team) for the report.

2.9.49 1.0.1 - 2015-09-05
• We now ship OS X wheels that statically link OpenSSL by default. When installing a wheel on OS X 10.10+ (and using a Python compiled against the 10.10 SDK) users will no longer need to compile. See Installation for alternate installation methods if required.
• Set the default string mask to UTF-8 in the OpenSSL backend to resolve character encoding issues with older versions of OpenSSL.
• Several new OpenSSL bindings have been added to support a future pyOpenSSL release.
• Raise an error during install on PyPy < 2.6. 1.0+ requires PyPy 2.6+.

2.9.50 1.0 - 2015-08-12
• Switched to the new cffi set_source out-of-line API mode for compilation. This results in significantly faster imports and lowered memory consumption. Due to this change we no longer support PyPy releases older than 2.6 nor do we support any released version of PyPy3 (until a version supporting cffi 1.0 comes out).
• Fix parsing of OpenSSH public keys that have spaces in comments.
• Support serialization of certificate signing requests using the public_bytes method of CertificateSigningRequest.
• Support serialization of certificates using the public_bytes method of Certificate.
• Add get_provisioning_uri method to HOTP and TOTP for generating provisioning URIs.
• Add ConcatKDFHash and ConcatKDFHMAC.
• Raise a TypeError when passing objects that are not text as the value to NameAttribute.
• Add support for OtherName as a general name type.
• Added new X.509 extension support in Certificate. The following new extensions are now supported:
  – OCSPNoCheck
  – InhibitAnyPolicy
  – IssuerAlternativeName
  – NameConstraints
• Extension support was added to CertificateSigningRequest.
• Add support for creating signed certificates with CertificateBuilder. This includes support for the following extensions:
  
  - BasicConstraints
  - SubjectAlternativeName
  - KeyUsage
  - ExtendedKeyUsage
  - SubjectKeyIdentifier
  - AuthorityKeyIdentifier
  - AuthorityInformationAccess
  - CRLDistributionPoints
  - InhibitAnyPolicy
  - IssuerAlternativeName
  - OCSPNoCheck

• Add support for creating certificate signing requests with CertificateSigningRequestBuilder. This includes support for the same extensions supported in the CertificateBuilder.

• Deprecate encode_rfc6979_signature and decode_rfc6979_signature in favor of encode_dss_signature() and decode_dss_signature().

2.9.51 0.9.3 - 2015-07-09

• Updated Windows wheels to be compiled against OpenSSL 1.0.2d.

2.9.52 0.9.2 - 2015-07-04

• Updated Windows wheels to be compiled against OpenSSL 1.0.2c.

2.9.53 0.9.1 - 2015-06-06

• SECURITY ISSUE: Fixed a double free in the OpenSSL backend when using DSA to verify signatures. Note that this only affects PyPy 2.6.0 and (presently unreleased) CFFI versions greater than 1.1.0.

2.9.54 0.9 - 2015-05-13

• Removed support for Python 3.2. This version of Python is rarely used and caused support headaches. Users affected by this should upgrade to 3.3+.

• Deprecated support for Python 2.6. At the time there is no time table for actually dropping support, however we strongly encourage all users to upgrade their Python, as Python 2.6 no longer receives support from the Python core team.

• Add support for the SECP256K1 elliptic curve.

• Fixed compilation when using an OpenSSL which was compiled with the no-comp (OPENSSL_NO_COMP) option.
• Support DER serialization of public keys using the `public_bytes` method of `RSAPublicKeyWithSerialization`, `DSAPublicKeyWithSerialization`, and `EllipticCurvePublicKeyWithSerialization`.

• Support DER serialization of private keys using the `private_bytes` method of `RSAKeyWithSerialization`, `DSAPrivateKeyWithSerialization`, and `EllipticCurvePrivateKeyWithSerialization`.

• Add support for parsing X.509 certificate signing requests (CSRs) with `load_pem_x509_csr()` and `load_der_x509_csr()`.

• Moved `cryptography.exceptions.InvalidToken` to `cryptography.hazmat.primitives.twofactor.InvalidToken` and deprecated the old location. This was moved to minimize confusion between this exception and `cryptography.fernet.InvalidToken`.

• Added support for X.509 extensions in `Certificate` objects. The following extensions are supported as of this release:
  - `BasicConstraints`
  - `AuthorityKeyIdentifier`
  - `SubjectKeyIdentifier`
  - `KeyUsage`
  - `SubjectAlternativeName`
  - `ExtensionKeyUsage`
  - `CRLDistributionPoints`
  - `AuthorityInformationAccess`
  - `CertificatePolicies`

  Note that unsupported extensions with the critical flag raise `UnsupportedExtension` while unsupported extensions set to non-critical are silently ignored. Read the `X.509 documentation` for more information.

2.9.55 0.8.2 - 2015-04-10

• Fixed a race condition when initializing the OpenSSL or CommonCrypto backends in a multi-threaded scenario.

2.9.56 0.8.1 - 2015-03-20

• Updated Windows wheels to be compiled against OpenSSL 1.0.2a.

2.9.57 0.8 - 2015-03-08

• `load_ssh_public_key()` can now load elliptic curve public keys.
• Added `signature_hash_algorithm` support to `Certificate`.
• Added `rsa_recover_prime_factors()`.
• `KeyDerivationFunction` was moved from `cryptography.hazmat.primitives.interfaces` to `kdf`.
• Added support for parsing X.509 names. See the `X.509 documentation` for more information.
• Added `load_der_private_key()` to support loading of DER encoded private keys and `load_der_public_key()` to support loading DER encoded public keys.

• Fixed building against LibreSSL, a compile-time substitute for OpenSSL.

• FreeBSD 9.2 was removed from the continuous integration system.

• Updated Windows wheels to be compiled against OpenSSL 1.0.2.

• `load_pem_public_key()` and `load_der_public_key()` now support PKCS1 RSA public keys (in addition to the previous support for SubjectPublicKeyInfo format for RSA, EC, and DSA).

• Added `EllipticCurvePrivateKeyWithSerialization` and deprecated `EllipticCurvePrivateKeyWithNumbers`.

• Added `private_bytes()` to `EllipticCurvePrivateKeyWithSerialization`.

• Added `RSAPrivateKeyWithSerialization` and deprecated `RSAPrivateKeyWithNumbers`.

• Added `private_bytes()` to `RSAPrivateKeyWithSerialization`.

• Added `DSAPrivateKeyWithSerialization` and deprecated `DSAPrivateKeyWithNumbers`.

• Added `private_bytes()` to `DSAPrivateKeyWithSerialization`.

• Added `RSAPublicKeyWithSerialization` and deprecated `RSAPublicKeyWithNumbers`.

• Added `public_bytes` to `RSAPublicKeyWithSerialization`.

• Added `EllipticCurvePublicKeyWithSerialization` and deprecated `EllipticCurvePublicKeyWithNumbers`.

• Added `public_bytes` to `EllipticCurvePublicKeyWithSerialization`.

• Added `DSAPublicKeyWithSerialization` and deprecated `DSAPublicKeyWithNumbers`.

• Added `public_bytes` to `DSAPublicKeyWithSerialization`.

• `HashAlgorithm` and `HashContext` were moved from `cryptography.hazmat.primitives.interfaces` to `hashes`.

• `CipherContext`, `AEADCipherContext`, `AEADEncryptionContext`, `CipherAlgorithm`, and `BlockCipherAlgorithm` were moved from `cryptography.hazmat.primitives.interfaces` to `ciphers`.

• `Mode`, `ModeWithInitializationVector`, `ModeWithNonce`, and `ModeWithAuthenticationTag` were moved from `cryptography.hazmat.primitives.interfaces` to `modes`.

• `PaddingContext` was moved from `cryptography.hazmat.primitives.interfaces` to `padding`.

• `AsymmetricPadding` was moved from `cryptography.hazmat.primitives.interfaces` to `padding`.

• `AsymmetricSignatureContext` and `AsymmetricVerificationContext` were moved from `cryptography.hazmat.primitives.interfaces` to `cryptography.hazmat.primitives.asymmetric`.

• `DSAPrivateKey`, `DSAPrivateKeyWithNumbers`, `DSAPublicKey`, and `DSAPublicKeyWithNumbers` were moved from `cryptography.hazmat.primitives.interfaces` to `dsa`.

• `EllipticCurve`, `EllipticCurveSignatureAlgorithm`, `EllipticCurvePrivateKey`, `EllipticCurvePrivateKeyWithNumbers`, `EllipticCurvePublicKey`, and
EllipticCurvePublicKeyWithNumbers were moved from cryptography.hazmat.primitives.interfaces to ec.

- RSAPrivateKey, RSAPrivateKeyWithNumbers, RSAPublicKey and RSAPublicKeyWithNumbers were moved from cryptography.hazmat.primitives.interfaces to rsa.

2.9.58 0.7.2 - 2015-01-16

- Updated Windows wheels to be compiled against OpenSSL 1.0.11.
- enum34 is no longer installed on Python 3.4, where it is included in the standard library.
- Added a new function to the OpenSSL bindings to support additional functionality in pyOpenSSL.

2.9.59 0.7.1 - 2014-12-28

- Fixed an issue preventing compilation on platforms where OPENSSL_NO_SSL3 was defined.

2.9.60 0.7 - 2014-12-17

- Cryptography has been relicensed from the Apache Software License, Version 2.0, to being available under either the Apache Software License, Version 2.0, or the BSD license.
- Added key-rotation support to Fernet with MultiFernet.
- More bit-lengths are now supported for p and q when loading DSA keys from numbers.
- Added MACContext as a common interface for CMAC and HMAC and deprecated CMACContext.
- Added support for encoding and decoding RFC 6979 signatures in Asymmetric Utilities.
- Added load_ssh_public_key() to support the loading of OpenSSH public keys (RFC 4253). Only RSA and DSA keys are currently supported.
- Added initial support for X.509 certificate parsing. See the X.509 documentation for more information.

2.9.61 0.6.1 - 2014-10-15

- Updated Windows wheels to be compiled against OpenSSL 1.0.1j.
- Fixed an issue where OpenSSL 1.0.1j changed the errors returned by some functions.
- Added our license file to the cryptography-vectors package.
- Implemented DSA hash truncation support (per FIPS 186-3) in the OpenSSL backend. This works around an issue in 1.0.0, 1.0.0a, and 1.0.0b where truncation was not implemented.

2.9.62 0.6 - 2014-09-29

- Added load_pem_private_key() to ease loading private keys, and load_pem_public_key() to support loading public keys.
- Removed the, deprecated in 0.4, support for the salt_length argument to the MGF1 constructor. The salt_length should be passed to PSS instead.
- Fix compilation on OS X Yosemite.
• **Deprecated** `elliptic_curve_private_key_from_numbers` and `elliptic_curve_public_key_from_numbers` in favor of `load_elliptic_curve_private_numbers` and `load_elliptic_curve_public_numbers` on `EllipticCurveBackend`.

• **Added** `EllipticCurvePrivateKeyWithNumbers` and `EllipticCurvePublicKeyWithNumbers` support.

• Work around three GCM related bugs in CommonCrypto and OpenSSL.
  
  – On the CommonCrypto backend adding AAD but not subsequently calling update would return null tag bytes.
  
  – One the CommonCrypto backend a call to update without an empty add AAD call would return null ciphertext bytes.
  
  – On the OpenSSL backend with certain versions adding AAD only would give invalid tag bytes.

• Support loading EC private keys from PEM.

**2.9.63 0.5.4 - 2014-08-20**

• Added several functions to the OpenSSL bindings to support new functionality in pyOpenSSL.

• Fixed a redefined constant causing compilation failure with Solaris 11.2.

**2.9.64 0.5.3 - 2014-08-06**

• Updated Windows wheels to be compiled against OpenSSL 1.0.1i.

**2.9.65 0.5.2 - 2014-07-09**

• Add `TraditionalOpenSSLSerializationBackend support` to `multibackend`.

• Fix compilation error on OS X 10.8 (Mountain Lion).

**2.9.66 0.5.1 - 2014-07-07**

• Add `PKCS8SerializationBackend support` to `multibackend`.

**2.9.67 0.5 - 2014-07-07**

• **BACKWARDS INCOMPATIBLE:** GCM no longer allows truncation of tags by default. Previous versions of `cryptography` allowed tags to be truncated by default. Applications wishing to preserve this behavior (not recommended) can pass the `min_tag_length` argument.

• Windows builds now statically link OpenSSL by default. When installing a wheel on Windows you no longer need to install OpenSSL separately. Windows users can switch between static and dynamic linking with an environment variable. See `Installation` for more details.

• Added `HKDFExpand`.

• Added `CFB8` support for AES and `TripleDES` on commoncrypto and OpenSSL backend.

• Added AES CTR support to the OpenSSL backend when linked against 0.9.8.
• Added PKCS8SerializationBackend and TraditionalOpenSSLSerializationBackend support to the OpenSSL backend.

• Added Elliptic curve cryptography and EllipticCurveBackend.

• Added ECB support for TripleDES on commoncrypto and OpenSSL backend.

• Deprecated the concrete RSAPrivateKey class in favor of backend specific providers of the cryptography.hazmat.primitives.asymmetric.rsa.RSAPrivateKey interface.

• Deprecated the concrete RSAPublicKey in favor of backend specific providers of the cryptography.hazmat.primitives.asymmetric.rsa.RSAPublicKey interface.

• Deprecated the concrete DSAPrivateKey class in favor of backend specific providers of the cryptography.hazmat.primitives.asymmetric.dsa.DSAPrivateKey interface.

• Deprecated the concrete DSAPublicKey class in favor of backend specific providers of the cryptography.hazmat.primitives.asymmetric.dsa.DSAPublicKey interface.

• Deprecated the concrete DSAParameters class in favor of backend specific providers of the cryptography.hazmat.primitives.asymmetric.dsa.DSAParameters interface.

• Deprecated encrypt_rsa, decrypt_rsa, create_rsa_signature_ctx and create_rsa_verification_ctx on RSABackend.

• Deprecated create_dsa_signature_ctx and create_dsa_verification_ctx on DSABackend.

2.9.68 0.4 - 2014-05-03

• Deprecated salt_length on MGF1 and added it to PSS. It will be removed from MGF1 in two releases per our API stability policy.

• Added SEED support.

• Added CMAC.

• Added decryption support to RSAPrivateKey and encryption support to RSAPublicKey.

• Added signature support to DSAPrivateKey and verification support to DSAPublicKey.

2.9.69 0.3 - 2014-03-27

• Added HOTP.

• Added TOTP.

• Added IDEA support.

• Added signature support to RSAPrivateKey and verification support to RSAPublicKey.

• Moved test vectors to the new cryptography_vectors package.

2.9.70 0.2.2 - 2014-03-03

• Removed a constant definition that was causing compilation problems with specific versions of OpenSSL.
2.9.71 0.2.1 - 2014-02-22

- Fix a bug where importing cryptography from multiple paths could cause initialization to fail.

2.9.72 0.2 - 2014-02-20

- Added commoncrypto.
- Added initial commoncrypto.
- Removed register_cipher_adapter method from CipherBackend.
- Added support for the OpenSSL backend under Windows.
- Improved thread-safety for the OpenSSL backend.
- Fixed compilation on systems where OpenSSL's ec.h header is not available, such as CentOS.
- Added PBKDF2HMAC.
- Added HKDF.
- Added multibackend.
- Set default random for the OpenSSL backend to the OS random engine.
- Added CAST5 (CAST-128) support.

2.9.73 0.1 - 2014-01-08

- Initial release.

2.10 Frequently asked questions

2.10.1 cryptography failed to install!

If you are having issues installing cryptography the first troubleshooting step is to upgrade pip and then try to install again. For most users this will take the form of pip install -U pip, but on Windows you should do python -m pip install -U pip. If you are still seeing errors after upgrading and trying pip install cryptography again, please see the Installation documentation.

2.10.2 How does cryptography compare to NaCl (Networking and Cryptography Library)?

While cryptography and NaCl both share the goal of making cryptography easier, and safer, to use for developers, cryptography is designed to be a general purpose library, interoperable with existing systems, while NaCl features a collection of hand selected algorithms.

cryptography’s recipes layer has similar goals to NaCl.

If you prefer NaCl’s design, we highly recommend PyNaCl, which is also maintained by the PyCA team.
2.10.3 Why use cryptography?

If you’ve done cryptographic work in Python before you have likely encountered other libraries in Python such as M2Crypto, PyCrypto, or PyOpenSSL. In building cryptography we wanted to address a few issues we observed in the legacy libraries:

- Extremely error prone APIs and insecure defaults.
- Use of poor implementations of algorithms (i.e. ones with known side-channel attacks).
- Lack of maintenance.
- Lack of high level APIs.
- Lack of PyPy and Python 3 support.
- Absence of algorithms such as AES-GCM and HKDF.

2.10.4 Compiling cryptography on macOS produces a fatal error: 'openssl/aes.h' file not found error

This happens because macOS 10.11 no longer includes a copy of OpenSSL. cryptography now provides wheels which include a statically linked copy of OpenSSL. You’re seeing this error because your copy of pip is too old to find our wheel files. Upgrade your copy of pip with pip install -U pip and then try install cryptography again.

If you are using PyPy, we do not currently ship cryptography wheels for PyPy. You will need to install your own copy of OpenSSL – we recommend using Homebrew.

2.10.5 cryptography raised an InternalError and I’m not sure what to do?

Frequently InternalError is raised when there are errors on the OpenSSL error stack that were placed there by other libraries that are also using OpenSSL. Try removing the other libraries and see if the problem persists. If you have no other libraries using OpenSSL in your process, or they do not appear to be at fault, it’s possible that this is a bug in cryptography. Please file an issue with instructions on how to reproduce it.

2.10.6 error: -Werror=sign-conversion: No option -Wsign-conversion during installation

The compiler you are using is too old and not supported by cryptography. Please upgrade to a more recent version. If you are running OpenBSD 6.1 or earlier the default compiler is extremely old. Use pkg_add to install a newer gcc and then install cryptography using CC=/path/to/newer/gcc pip install cryptography.

2.10.7 Installing cryptography fails with Invalid environment marker: python_version < '3'

Your pip and/or setuptools are outdated. Please upgrade to the latest versions with pip install -U pip setuptools (or on Windows python -m pip install -U pip setuptools).
2.10.8 Installing cryptography with OpenSSL 0.9.8 or 1.0.0 fails

The OpenSSL project has dropped support for the 0.9.8 and 1.0.0 release series. Since they are no longer receiving security patches from upstream, cryptography is also dropping support for them. To fix this issue you should upgrade to a newer version of OpenSSL (1.0.2 or later). This may require you to upgrade to a newer operating system.

2.10.9 Why are there no wheels for Python 3.5+ on Linux or macOS?

Our Python3 wheels, for macOS and Linux, are abi3 wheels. This means they support multiple versions of Python. The Python 3.4 abi3 wheel can be used with any version of Python greater than or equal to 3.4. Recent versions of pip will automatically install abi3 wheels.

2.10.10 ImportError: idna is not installed

cryptography deprecated passing U-label strings to various X.509 constructors in version 2.1 and in version 2.5 moved the idna dependency to a setuptools extra. If you see this exception you should upgrade your software so that it no longer depends on this deprecated feature. If that is not yet possible you can also install cryptography with pip install cryptography[idna] to automatically install the missing dependency. This workaround will be available until the feature is fully removed.

2.10.11 Why can’t I import my PEM file?

PEM is a format (defined by several RFCs, but originally RFC 1421) for encoding keys, certificates and other cryptographic data into a regular form. The data is encoded as base64 and wrapped with a header and footer.

If you are having trouble importing PEM files, make sure your file fits the following rules:

• has a one-line header like this: -----BEGIN [FILE TYPE]----- (where [FILE TYPE] is CERTIFICATE, PUBLIC KEY, PRIVATE KEY, etc.)

• has a one-line footer like this: -----END [FILE TYPE]------

• all lines, except for the final one, must consist of exactly 64 characters.

For example, this is a PEM file for a RSA Public Key:

```
-----BEGIN PUBLIC KEY-----
MIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCqKCAQE7Z5AzKEH2Ko98L65OwQgQcV
9DSXKADv0ziI5hT1KG6Bex5seE9pUecUxNu4uXo2jzAUGyRweRl/DLU8SoN8+
Wd6Ywik4ZGvnV7j0zz8hQ5jRySxy4dmE1FtIRHGLkHgq1206z4AzrmKEZgxxOk
Lj9Y9c7W+iXj8KzwNNyavvjb5Yzq6V60RhpynTkpMh2+zRLgIK9sROEPQeYfK
2zj2CnGBmg5cm2PuOsGDt/1/Fdh1aO34i1GXwCuPfikSAg61PJ0batftkSG
v0X0heUaV0j1HSN1BWMatT4IR9+ijfKJHeqOqvHQBaCu7Ja4kXzw6GZ3M2j/Ja3A
2QIDAQAB
-----END PUBLIC KEY-----
```

2.11 Development

As an open source project, cryptography welcomes contributions of all forms. The sections below will help you get started.

File bugs and feature requests on our issue tracker on GitHub. If it is a bug check out what to put in your bug report.
2.11.1 Getting started

Development dependencies

Working on cryptography requires the installation of a small number of development dependencies in addition to the dependencies for Installation. These are listed in dev-requirements.txt and they can be installed in a virtualenv using pip. Before you install them, follow the build instructions in Installation (be sure to stop before actually installing cryptography). Once you’ve done that, install the development dependencies, and then install cryptography in editable mode. For example:

```
# Create a virtualenv and activate it
# Set up your cryptography build environment
$ pip install --requirement dev-requirements.txt
$ pip install --editable .
```

Make sure that `pip install --requirement ...` has installed the Python package vectors/ and packages on tests/. If it didn’t, you may install them manually by using pip on each directory.

You will also need to install enchant using your system’s package manager to check spelling in the documentation.

---

**Note:** There is an upstream bug in enchant that prevents its installation on Windows with 64-bit Python. See this Github issue for more information. The easiest workaround is to use 32-bit Python for cryptography development, even on 64-bit Windows.

You are now ready to run the tests and build the documentation.

**OpenSSL on macOS**

You must have installed OpenSSL via Homebrew or MacPorts and must set CFLAGS and LDFLAGS environment variables before installing the dev-requirements.txt otherwise pip will fail with include errors.

For example, with Homebrew:

```
$ env LDFLAGS="-L$(brew --prefix openssl@1.1)/lib" \
  CFLAGS="-I$(brew --prefix openssl@1.1)/include" \
  pip install --requirement ./dev-requirements.txt
```

Alternatively for a static build you can specify CRYPTOGRAPHY_SUPPRESS_LINK_FLAGS=1 and ensure LDFLAGS points to the absolute path for the OpenSSL libraries before calling pip.

---

**Tip:** You will also need to set these values when Building documentation.

**Running tests**

cryptography unit tests are found in the tests/ directory and are designed to be run using pytest. pytest will discover the tests automatically, so all you have to do is:

```
$ pytest
...
62746 passed in 220.43 seconds
```
This runs the tests with the default Python interpreter.

You can also verify that the tests pass on other supported Python interpreters. For this we use tox, which will automatically create a virtualenv for each supported Python version and run the tests. For example:

```bash
$ tox
...
py27: commands succeeded
ERROR: pypy: InterpreterNotFound: pypy
py34: commands succeeded
docs: commands succeeded
pep8: commands succeeded
```

You may not have all the required Python versions installed, in which case you will see one or more InterpreterNotFound errors.

**Building documentation**

cryptography documentation is stored in the docs/ directory. It is written in reStructured Text and rendered using Sphinx.

Use tox to build the documentation. For example:

```bash
$ tox -e docs
...
docs: commands succeeded
congratulations :)
```

The HTML documentation index can now be found at docs/_build/html/index.html.

## 2.11.2 Submitting patches

- Always make a new branch for your work.
- Patches should be small to facilitate easier review. Studies have shown that review quality falls off as patch size grows. Sometimes this will result in many small PRs to land a single large feature.
- Larger changes should be discussed on our mailing list before submission.
- New features and significant bug fixes should be documented in the Changelog.
- You must have legal permission to distribute any code you contribute to cryptography, and it must be available under both the BSD and Apache Software License Version 2.0 licenses.

If you believe you’ve identified a security issue in cryptography, please follow the directions on the security page.

**Code**

When in doubt, refer to PEP 8 for Python code. You can check if your code meets our automated requirements by running flake8 against it. If you’ve installed the development requirements this will automatically use our configuration. You can also run the tox job with `tox -e pep8`.

Write comments as complete sentences.

Class names which contains acronyms or initialisms should always be capitalized. A class should be named HTTPClient, not HttpClient.

Every code file must start with the boilerplate licensing notice:
Additionally, every Python code file must contain

```python
from __future__ import absolute_import, division, print_function
```

### API considerations

Most projects’ APIs are designed with a philosophy of “make easy things easy, and make hard things possible”. One of the perils of writing cryptographic code is that secure code looks just like insecure code, and its results are almost always indistinguishable. As a result, cryptography has, as a design philosophy: “make it hard to do insecure things”. Here are a few strategies for API design that should be both followed, and should inspire other API choices:

If it is necessary to compare a user provided value with a computed value (for example, verifying a signature), there should be an API provided that performs the verification in a secure way (for example, using a constant time comparison), rather than requiring the user to perform the comparison themselves.

If it is incorrect to ignore the result of a method, it should raise an exception, and not return a boolean `True/False` flag. For example, a method to verify a signature should raise `InvalidSignature`, and not return whether the signature was valid.

```python
# This is bad.
def verify(sig):
    # ...
    return is_valid

# Good!
def verify(sig):
    # ...
    if not is_valid:
        raise InvalidSignature
```

Every recipe should include a version or algorithmic marker of some sort in its output in order to allow transparent upgrading of the algorithms in use, as the algorithms or parameters needed to achieve a given security margin evolve.

APIs at the Primitives layer should always take an explicit backend, APIs at the recipes layer should automatically use the `default_backend()`, but optionally allow specifying a different backend.

### C bindings

More information on C bindings can be found in the dedicated section of the documentation.

### Tests

All code changes must be accompanied by unit tests with 100% code coverage (as measured by the combined metrics across our build matrix).

When implementing a new primitive or recipe cryptography requires that you provide a set of test vectors. See Test vectors for more details.
Documentation

All features should be documented with prose in the docs section. To ensure it builds and passes doc8 style checks you can run tox -e docs.

Because of the inherent challenges in implementing correct cryptographic systems, we want to make our documentation point people in the right directions as much as possible. To that end:

- When documenting a generic interface, use a strong algorithm in examples. (e.g. when showing a hashing example, don’t use MD5)
- When giving prescriptive advice, always provide references and supporting material.
- When there is real disagreement between cryptographic experts, represent both sides of the argument and describe the trade-offs clearly.

When documenting a new module in the hazmat package, its documentation should begin with the “Hazardous Materials” warning:

````
hazmat::
```

Always prefer terminology that is most broadly accepted. For example:

- When referring to class instances use “an instance of Foo” instead of “a Foo provider”.

When referring to a hypothetical individual (such as “a person receiving an encrypted message”) use gender neutral pronouns (they/them/their).

Docstrings are typically only used when writing abstract classes, but should be written like this if required:

```python
def some_function(some_arg):
    
    Does some things.

    :param some_arg: Some argument.
    
```

So, specifically:

- Always use three double quotes.
- Put the three double quotes on their own line.
- No blank line at the end.
- Use Sphinx parameter/attribute documentation syntax.

2.11.3 Reviewing and merging patches

Everyone is encouraged to review open pull requests. We only ask that you try and think carefully, ask questions and are excellent to one another. Code review is our opportunity to share knowledge, design ideas and make friends.

When reviewing a patch try to keep each of these concepts in mind:

**Intent**

- What is the change being proposed?
- Do we want this feature or is the bug they’re fixing really a bug?
Architecture

- Is the proposed change being made in the correct place? Is it a fix in a backend when it should be in the primitives?

Implementation

- Does the change do what the author claims?
- Are there sufficient tests?
- Has it been documented?
- Will this change introduce new bugs?

Grammar and style

These are small things that are not caught by the automated style checkers.

- Does a variable need a better name?
- Should this be a keyword argument?

Merge requirements

Because cryptography is so complex, and the implications of getting it wrong so devastating, cryptography has a strict merge policy for committers:

- Patches must never be pushed directly to master, all changes (even the most trivial typo fixes!) must be submitted as a pull request.
- A committer may never merge their own pull request, a second party must merge their changes. If multiple people work on a pull request, it must be merged by someone who did not work on it.
- A patch that breaks tests, or introduces regressions by changing or removing existing tests should not be merged. Tests must always be passing on master.
- If somehow the tests get into a failing state on master (such as by a backwards incompatible release of a dependency) no pull requests may be merged until this is rectified.
- All merged patches must have 100% test coverage.

The purpose of these policies is to minimize the chances we merge a change that jeopardizes our users’ security.

2.11.4 Test vectors

Testing the correctness of the primitives implemented in each cryptography backend requires trusted test vectors. Where possible these vectors are obtained from official sources such as NIST or IETF RFCs. When this is not possible cryptography has chosen to create a set of custom vectors using an official vector file as input to verify consistency between implemented backends.

Vectors are kept in the cryptography_vectors package rather than within our main test suite.
Sources

Project Wycheproof

We run vectors from Project Wycheproof – a collection of known edge-cases for various cryptographic algorithms. These are not included in the repository (or `cryptography_vectors` package), but rather cloned from Git in our continuous integration environments.

We have ensured all test vectors are used as of commit `c313761979d74b0417230edd0f87d0cfab2b46b`.

Asymmetric ciphers

- RSA FIPS 186-2 and PKCS1 v1.5 vulnerability test vectors from NIST CAVP.
- FIPS 186-2 and FIPS 186-3 DSA test vectors from NIST CAVP.
- FIPS 186-2 and FIPS 186-3 ECDSA test vectors from NIST CAVP.
- DH and ECDH and ECDH+KDF(17.4) test vectors from NIST CAVP.
- Ed25519 test vectors from the Ed25519 website.
- OpenSSL PEM RSA serialization vectors from the OpenSSL example key and GnuTLS key parsing tests.
- OpenSSL PEM DSA serialization vectors from the GnuTLS example keys.
- PKCS #8 PEM serialization vectors from
  - GnuTLS: enc-rsa-pkcs8.pem, enc2-rsa-pkcs8.pem, unenc-rsa-pkcs8.pem, pkcs12_s2k.pem.c. The encoding error in unenc-rsa-pkcs8.pem was fixed, and the contents of enc-rsa-pkcs8.pem was re-encrypted to include it. The contents of enc2-rsa-pkcs8.pem was re-encrypted using a stronger PKCS#8 cipher.
  - Botan’s ECC private keys.
- asymmetric/public/PKCS1/dsa.pub.pem is a PKCS1 DSA public key from the Ruby test suite.
- X25519 and X448 test vectors from RFC 7748.
- RSA OAEP with custom label from the BoringSSL evp tests.
- Ed448 test vectors from RFC 8032.

Custom asymmetric vectors

SECP256K1 vector creation

This page documents the code that was used to generate the SECP256K1 elliptic curve test vectors as well as code used to verify them against another implementation.

Creation

The vectors are generated using a pure Python ecdsa implementation. The test messages and combinations of algorithms are derived from the NIST vector data.
from __future__ import absolute_import, print_function

import hashlib
import os
from binascii import hexlify
from collections import defaultdict
from ecdsa import SECP256k1, SigningKey
from ecdsa.util import sigdecode_der, sigencode_der

from cryptography_vectors import open_vector_file
from tests.utils import (load_fips_ecdsa_signing_vectors, load_vectors_from_file)

HASHLIB_HASH_TYPES = {
    "SHA-1": hashlib.sha1,
    "SHA-224": hashlib.sha224,
    "SHA-256": hashlib.sha256,
    "SHA-384": hashlib.sha384,
    "SHA-512": hashlib.sha512,
}

class TruncatedHash(object):
    def __init__(self, hasher):
        self.hasher = hasher

    def __call__(self, data):
        self.hasher.update(data)
        return self

    def digest(self):
        return self.hasher.digest()[:256 // 8]

def build_vectors(fips_vectors):
    vectors = defaultdict(list)
    for vector in fips_vectors:
        vectors[vector['digest_algorithm']].append(vector['message'])

    for digest_algorithm, messages in vectors.items():
        if digest_algorithm not in HASHLIB_HASH_TYPES:
            continue

        yield ""
        yield f"('[K-256, {0}]'.format(digest_algorithm)
        yield ""

        for message in messages:
            hash_func = TruncatedHash(HASHLIB_HASH_TYPES[digest_algorithm]())

            # Sign the message using warner/ecdsa
            secret_key = SigningKey.generate(curve=SECP256k1)
            public_key = secret_key.get_verifying_key()
signature = secret_key.sign(message, hashfunc=hash_func,
    sigencode=sigencode_der)

r, s = sigdecode_der(signature, None)

yield "Msg = {0}".format(hexlify(message))
yield "d = {0:x}".format(secret_key.privkey.secret_multiplier)
yield "Qx = {0:x}".format(public_key.pubkey.point.x())
yield "Qy = {0:x}".format(public_key.pubkey.point.y())
yield "R = {0:x}".format(r)
yield "S = {0:x}".format(s)
yield ""

def write_file(lines, dest):
    for line in lines:
        print(line)
        print(line, file=dest)

source_path = os.path.join("asymmetric", "ECDSA", "FIPS_186-3", "SigGen.txt")
dest_path = os.path.join("asymmetric", "ECDSA", "SECP256K1", "SigGen.txt")

fips_vectors = load_vectors_from_file(
    source_path,
    load_fips_ecdsa_signing_vectors
)

with open_vector_file(dest_path, "w") as dest_file:
    write_file(
        build_vectors(fips_vectors),
        dest_file
    )

Download link: generate_secp256k1.py

Verification

cryptography was modified to support the SECP256K1 curve. Then the following python script was run to
generate the vector files.

```python
from __future__ import absolute_import, print_function
import os

from cryptography.hazmat.backends import default_backend
from cryptography.hazmat.primitives import hashes
from cryptography.hazmat.primitives.asymmetric import ec
from cryptography.hazmat.primitives.asymmetric.utils import encode_dss_signature
from tests.utils import load_fips_ecdsa_signing_vectors, load_vectors_from_file
```
Cryptography Documentation, Release 2.8.dev1

CRYPTOGRAPHY_HASH_TYPES = {
    "SHA-1": hashes.SHA1,
    "SHA-224": hashes.SHA224,
    "SHA-256": hashes.SHA256,
    "SHA-384": hashes.SHA384,
    "SHA-512": hashes.SHA512,
}

def verify_one_vector(vector):
    digest_algorithm = vector['digest_algorithm']
    message = vector['message']
    x = vector['x']
    y = vector['y']
    signature = encode_dss_signature(vector['r'], vector['s'])

    numbers = ec.EllipticCurvePublicNumbers(
        x, y,
        ec.SECP256K1()
    )

    key = numbers.public_key(default_backend())

    verifier = key.verifier(
        signature,
        ec.ECDSA(CRYPTOGRAPHY_HASH_TYPES[digest_algorithm]()
    )
    verifier.update(message)
    return verifier.verify()

def verify_vectors(vectors):
    for vector in vectors:
        assert verify_one_vector(vector)

vector_path = os.path.join("asymmetric", "ECDSA", "SECP256K1", "SigGen.txt")

secp256k1_vectors = load_vectors_from_file(
    vector_path,
    load_fips_ecdsa_signing_vectors
)

verify_vectors(secp256k1_vectors)

Download link: verify_secp256k1.py

RSA OAEP SHA2 vector creation

This page documents the code that was used to generate the RSA OAEP SHA2 test vectors as well as code used to verify them against another implementation.
Cryptography Documentation, Release 2.8.dev1

Creation

cryptography was modified to allow the use of SHA2 in OAEP encryption. Then the following python script was run to generate the vector files.

```python
# This file is dual licensed under the terms of the Apache License, Version
# 2.0, and the BSD License. See the LICENSE file in the root of this repository
# for complete details.

from __future__ import absolute_import, division, print_function

import binascii
import itertools
import os

from cryptography.hazmat.backends.openssl.backend import backend
from cryptography.hazmat.primitives import hashes
from cryptography.hazmat.primitives.asymmetric import padding, rsa

from tests.utils import load_pkcs1_vectors, load_vectors_from_file

def build_vectors(mgf1alg, hashalg, filename):
    vectors = load_vectors_from_file(filename, load_pkcs1_vectors)
    output = []
    for vector in vectors:
        # RSA keys for this must be long enough to accommodate the length of
        # the underlying hash function. This means we can't use the keys from
        # the sha1 test vectors for sha512 tests because 1024-bit keys are too
        # small. Instead we parse the vectors for the test cases, then
        # generate our own 2048-bit keys for each.
        private, _ = vector
        skey = rsa.generate_private_key(65537, 2048, backend)
        pn = skey.private_numbers()
        examples = private.get("examples")
        output.append(b"# =============================================")
        output.append(b"# Example")
        output.append(b"# Public key")
        output.append(b"# Modulus:" + format(pn.public_numbers.n, "x"))
        output.append(b"# Exponent:" + format(pn.public_numbers.e, "x"))
        output.append(b"# Private key")
        output.append(b"# Modulus:" + format(pn.public_numbers.n, "x"))
        output.append(b"# Public exponent:" + format(pn.public_numbers.e, "x"))
        output.append(b"# Exponent:" + format(pn.d, "x"))
        output.append(b"# Prime 1:" + format(pn.p, "x"))
        output.append(b"# Prime 2:" + format(pn.q, "x"))
        output.append(b"# Prime exponent 1:" + format(pn.dmp1, "x"))
        output.append(b"# Prime exponent 2:" + format(pn.dmp2, "x"))
```

(continues on next page)
output.append(format(pn.dmq1, "x"))
output.append(b"# Coefficient:")
pkey = skey.public_key()
vectorkey = rsa.RSAPrivateNumbers(
p=private["p"],
q=private["q"],
d=private["private_exponent"],
dmpl=private["dmpl"],
dmq1=private["dmq1"],
iqmp=private["iqmp"],
public_numbers=rsa.RSAPublicNumbers(
e=private["public_exponent"],
n=private["modulus"]
)).private_key(backend)
count = 1

for example in examples:
    message = vectorkey.decrypt(
        binascii.unhexlify(example["encryption"]),
        padding.OAEP(
            mgf=padding.MGF1(algorithm=hashes.SHA1()),
            algorithm=hashes.SHA1(),
            label=None
        )
    )
    assert message == binascii.unhexlify(example["message"])
ct = pkey.encrypt(
    message,
    padding.OAEP(
        mgf=padding.MGF1(algorithm=mgf1alg),
        algorithm=hashalg,
        label=None
    )
)
output.append(b"# OAEP Example {0} alg={1} mgf1={2}".format(
    count, hashalg.name, mgf1alg.name
    )
)
count += 1
output.append(b"# Message:")
output.append(example["message"])
output.append(b"# Encryption:")
output.append(b"\n".join(output))

return b\n
def write_file(data, filename):
    with open(filename, "w") as f:
        f.write(data)

aepp_path = os.path.join("asymmetric", "RSA", "pkcs-1v2-1d2-vec", "oaep-vec.txt"
hashalgs = [
    hashes.SHA1(),
    hashes.SHA224(),
    hashes.SHA256(),
    hashes.SHA384(),
    hashes.SHA512(),
]
for hashtuple in itertools.product(hashalgs, hashalgs):
    if (isinstance(hashtuple[0], hashes.SHA1) and
        isinstance(hashtuple[1], hashes.SHA1)):
        continue
    write_file(
        build_vectors(hashtuple[0], hashtuple[1], oaep_path),
        "oaep-{0}-{1}.txt".format(hashtuple[0].name, hashtuple[1].name)
    )

Download link: generate_rsa_oaep_sha2.py

Verification

A Java 8 program was written using Bouncy Castle to load and verify the test vectors.

import java.io.BufferedReader;
import java.io.FileReader;
import java.io.IOException;
import java.math.BigInteger;
import java.security.AlgorithmParameters;
import java.security.GeneralSecurityException;
import java.security.KeyFactory;
import java.security.PrivateKey;
import java.security.Security;
import java.security.spec.AlgorithmParameterSpec;
import java.security.spec.MGF1ParameterSpec;
import java.security.spec.RSAPrivateKeySpec;
import java.util.Arrays;
import javax.crypto.Cipher;
import javax.crypto.spec.OAEPParameterSpec;
import javax.crypto.spec.PSource;
import javax.xml.bind.DatatypeConverter;
import org.bouncycastle.jce.provider.BouncyCastleProvider;

class TestVectorData {
    public BigInteger pub_key_modulus;
    public BigInteger pub_key_exponent;
    public BigInteger priv_key_public_exponent;
    public BigInteger priv_key_modulus;
    public BigInteger priv_key_exponent;
    public BigInteger priv_key_prime_1;
    public BigInteger priv_key_prime_2;
}
public BigInteger priv_key_prime_exponent_1;
public BigInteger priv_key_prime_exponent_2;
public BigInteger priv_key_coefficient;
public byte[] plaintext;
public byte[] ciphertext;
}

class TestVectorLoader {
    private static final String FILE_HEADER = "# RSA OAEP SHA2 vectors built";
    private static final String EXAMPLE_HEADER = "# =====";
    private static final String EXAMPLE = "# Example";
    private static final String PUBLIC_KEY = "# Public key";
    private static final String PUB_MODULUS = "# Modulus:";
    private static final String PUB_EXPONENT = "# Exponent:";
    private static final String PRIVATE_KEY = "# Private key";
    private static final String PRIV_MODULUS = "# Modulus:";
    private static final String PRIV_PUBLIC_EXPONENT = "# Public exponent:";
    private static final String PRIV_EXPONENT = "# Exponent:";
    private static final String PRIV_PRIME_1 = "# Prime 1:";
    private static final String PRIV_PRIME_2 = "# Prime 2:";
    private static final String PRIV_PRIME_EXPONENT_1 = "# Prime exponent 1:";
    private static final String PRIV_PRIME_EXPONENT_2 = "# Prime exponent 2:";
    private static final String PRIV_COEFFICIENT = "# Coefficient:";
    private static final String OAEP_EXAMPLE_HEADER = "# OAEP Example";
    private static final String MESSAGE = "# Message:";
    private static final String ENCRYPTION = "# Encryption:";
    private BufferedReader m_reader = null;
    private FileReader m_file_reader = null;
    private TestVectorData m_data = null;

    TestVectorLoader() {
    }

    protected void finalize() {
        close();
    }

    public void open(String path) throws IOException {
        close();
        m_file_reader = new FileReader(path);
        m_reader = new BufferedReader(m_file_reader);
        m_data = new TestVectorData();
    }

    public void close() {
        try {
            if (m_reader != null) {
                m_reader.close();
                m_reader = null;
            }
            if (m_file_reader != null) {
                m_file_reader.close();
                m_file_reader = null;
            }
        } finally {
            m_data = null;
        }
    }
}
public TestVectorData loadNextTest() throws IOException {
    if (m_file_reader == null || m_reader == null || m_data == null) {
        throw new IOException("A test vector file must be opened first");
    }

    String line = m_reader.readLine();
    if (line == null) {
        // end of file
        return null;
    }

    if (line.startsWith(FILE_HEADER)) {
        // start of file
        skipFileHeader(m_reader);
        line = m_reader.readLine();
    }

    if (line.startsWith(OAEP_EXAMPLE_HEADER)) {
        // Next example, keep existing keys and load next message
        loadMessage(m_reader, m_data);
        return m_data;
    }

    // otherwise it's a new example
    if (!line.startsWith(EXAMPLE_HEADER)) {
        throw new IOException("Test Header Missing");
    }

    startNewTest(m_reader);
    m_data = new TestVectorData();

    line = m_reader.readLine();
    if (!line.startsWith(PUBLIC_KEY))
        throw new IOException("Public Key Missing");

    loadPublicKey(m_reader, m_data);

    line = m_reader.readLine();
    if (!line.startsWith(PRIVATE_KEY))
        throw new IOException("Private Key Missing");

    loadPrivateKey(m_reader, m_data);

    line = m_reader.readLine();
    if (!line.startsWith(OAEP_EXAMPLE_HEADER))
        throw new IOException("Message Missing");

    loadMessage(m_reader, m_data);

    return m_data;
}

private byte[] unhexlify(String line) {
    byte[] bytes = DatatypeConverter.parseHexBinary(line);
}
private BigInteger readBigInteger(BufferedReader br) throws IOException {
    return new BigInteger(br.readLine(), 16);
}

private void skipFileHeader(BufferedReader br) throws IOException {
    br.readLine(); // # # Derived from the NIST OAEP SHA1 vectors
    br.readLine(); // # # Verified against the Bouncy Castle OAEP SHA2 implementation
    br.readLine(); // #
}

private void startNewTest(BufferedReader br) throws IOException {
    String line = br.readLine();
    if (!line.startsWith(EXAMPLE))
        throw new IOException("Example Header Missing");
}

private void loadPublicKey(BufferedReader br, TestVectorData data) throws IOException {
    String line = br.readLine();
    if (!line.startsWith(PUB_MODULUS))
        throw new IOException("Public Key Modulus Missing");
    data.pub_key_modulus = readBigInteger(br);
    line = br.readLine();
    if (!line.startsWith(PUB_EXPONENT))
        throw new IOException("Public Key Exponent Missing");
    data.pub_key_exponent = readBigInteger(br);
}

private void loadPrivateKey(BufferedReader br, TestVectorData data) throws IOException {
    String line = br.readLine();
    if (!line.startsWith(PRIV_MODULUS))
        throw new IOException("Private Key Modulus Missing");
    data.priv_key_modulus = readBigInteger(br);
    line = br.readLine();
    if (!line.startsWith(PRIV_PUBLIC_EXPONENT))
        throw new IOException("Private Key Public Exponent Missing");
    data.priv_key_public_exponent = readBigInteger(br);
    line = br.readLine();
    if (!line.startsWith(PRIV_EXPONENT))
        throw new IOException("Private Key Exponent Missing");
    data.priv_key_exponent = readBigInteger(br);
    line = br.readLine();
    if (!line.startsWith(PRIV_PRIME_1))
        throw new IOException("Private Key Prime 1 Missing");
    data.priv_key_prime_1 = readBigInteger(br);
    line = br.readLine();
    if (!line.startsWith(PRIV_PRIME_2))
throw new IOException("Private Key Prime 2 Missing");
data.priv_key_prime_2 = readBigInteger(br);

line = br.readLine();
if (!line.startsWith(PRIV_PRIME_EXPONENT_1))
    throw new IOException("Private Key Prime Exponent 1 Missing");
data.priv_key_prime_exponent_1 = readBigInteger(br);

line = br.readLine();
if (!line.startsWith(PRIV_PRIME_EXPONENT_2))
    throw new IOException("Private Key Prime Exponent 2 Missing");
data.priv_key_prime_exponent_2 = readBigInteger(br);

line = br.readLine();
if (!line.startsWith(PRIV_COEFFICIENT))
    throw new IOException("Private Key Coefficient Missing");
data.priv_key_coefficient = readBigInteger(br);
}

private void loadMessage(BufferedReader br, TestVectorData data) throws IOException {
    String line = br.readLine();
    if (!line.startsWith(MESSAGE))
        throw new IOException("Plaintext Missing");
data.plaintext = unhexlify(br.readLine());

line = br.readLine();
if (!line.startsWith(ENCRYPTION))
    throw new IOException("Ciphertext Missing");
data.ciphertext = unhexlify(br.readLine());
}

public class VerifyRSAOAEPSHA2 {

    public enum SHAHash {
        SHA1, SHA224, SHA256, SHA384, SHA512
    }

    private SHAHash m_mgf1_hash;
    private SHAHash m_alg_hash;
    private Cipher m_cipher;
    private PrivateKey m_private_key;
    private AlgorithmParameters m_algo_param;

    VerifyRSAOAEPSHA2(SHAHash mgf1_hash, SHAHash alg_hash, TestVectorData test_data) throws Exception {
        m_mgf1_hash = mgf1_hash;
        m_alg_hash = alg_hash;

        MGF1ParameterSpec mgf1_spec = getMGF1ParameterSpec(m_mgf1_hash);
        AlgorithmParameterSpec algo_param_spec = getAlgorithmParameterSpec(m_alg_hash, mgf1_spec);

        m_algo_param = AlgorithmParameters.getInstance("OAEP");
    }
}
m_algo_param.init(algo_param_spec);

m_private_key = loadPrivateKey(test_data);

m_cipher = getCipher(m_alg_hash);
}

private Cipher getCipher(SHAHash alg_hash) throws GeneralSecurityException {
    Cipher cipher = null;

    switch (alg_hash) {
    case SHA1:
        cipher = Cipher.getInstance("RSA/ECB/OAEPwithSHA1andMGF1Padding", "BC");
        break;
    case SHA224:
        cipher = Cipher.getInstance("RSA/ECB/OAEPwithSHA-224andMGF1Padding", "BC");
        break;
    case SHA256:
        cipher = Cipher.getInstance("RSA/ECB/OAEPwithSHA-256andMGF1Padding", "BC");
        break;
    case SHA384:
        cipher = Cipher.getInstance("RSA/ECB/OAEPwithSHA-384andMGF1Padding", "BC");
        break;
    case SHA512:
        cipher = Cipher.getInstance("RSA/ECB/OAEPwithSHA-512andMGF1Padding", "BC");
        break;
    }

    return cipher;
}

private MGF1ParameterSpec getMGF1ParameterSpec(SHAHash mgf1_hash) {
    MGF1ParameterSpec mgf1 = null;

    switch (mgf1_hash) {
    case SHA1:
        mgf1 = MGF1ParameterSpec.SHA1;
        break;
    case SHA224:
        mgf1 = MGF1ParameterSpec.SHA224;
        break;
    case SHA256:
        mgf1 = MGF1ParameterSpec.SHA256;
        break;
    case SHA384:
        mgf1 = MGF1ParameterSpec.SHA384;
        break;
    }

    return mgf1;
}
private AlgorithmParameterSpec getAlgorithmParameterSpec(SHAHash alg_hash,
MGF1ParameterSpec mgf1_spec) {
    OAEPParameterSpec oaep_spec = null;
    switch (alg_hash) {
        case SHA1:
            oaep_spec = new OAEPParameterSpec("SHA1", "MGF1", mgf1_spec, PSource.
PSpecified.DEFAULT);
            break;
        case SHA224:
            oaep_spec = new OAEPParameterSpec("SHA-224", "MGF1", mgf1_spec, PSource.
PSpecified.DEFAULT);
            break;
        case SHA256:
            oaep_spec = new OAEPParameterSpec("SHA-256", "MGF1", mgf1_spec, PSource.
PSpecified.DEFAULT);
            break;
        case SHA384:
            oaep_spec = new OAEPParameterSpec("SHA-384", "MGF1", mgf1_spec, PSource.
PSpecified.DEFAULT);
            break;
        case SHA512:
            oaep_spec = new OAEPParameterSpec("SHA-512", "MGF1", mgf1_spec, PSource.
PSpecified.DEFAULT);
            break;
    }
    return oaep_spec;
}

private PrivateKey loadPrivateKey(TestVectorData test_data) throws Exception {
    KeyFactory kf = KeyFactory.getInstance("RSA");
    RSAPrivateKeySpec keySpec = new RSAPrivateKeySpec(test_data.priv_key_modulus,
    test_data.priv_key_exponent);
    return kf.generatePrivate(keySpec);
}

public void testDecrypt(byte[] plaintext, byte[] ciphertext) throws Exception {
    (continues on next page)
System.out.println("Verifying OAEP with mgf1_hash: " + m_mgf1_hash + " alg_hash: " + m_alg_hash + " - " + ciphertext.length + " bytes ciphertext - " + plaintext.length + " bytes plaintext");

m_cipher.init(Cipher.DECRYPT_MODE, m_private_key, m_algo_param);
byte[] java_plaintext = m_cipher.doFinal(ciphertext);
if (Arrays.equals(java_plaintext, plaintext) == false) {
    throw new Exception("Verification failure - plaintext does not match after decryption.");
}

public static void main(String[] args) {
    Security.addProvider(new BouncyCastleProvider());
    // assume current directory if no path given on command line
    String vector_path = "/vectors/cryptography_vectors/asymmetric/RSA/oaep-custom";

    if (args.length > 0) {
        vector_path = args[0];
    }

    System.out.println("Vector file path: " + vector_path);

    try {
        // loop over each combination of hash loading the vector file
        // to verify for each
        for (SHAHash mgf1_hash : SHAHash.values()) {
            for (SHAHash alg_hash : SHAHash.values()) {
                if (mgf1_hash.name().toLowerCase().equals("sha1") &&
                    alg_hash.name().toLowerCase().equals("sha1")) {
                    continue;
                }
                String filename = "oaep-" + mgf1_hash.name().toLowerCase() + "-" + alg_hash.name().toLowerCase() + ".txt";

                System.out.println("Loading " + filename + "...");
                TestVectorLoader loader = new TestVectorLoader();
                loader.open(vector_path + filename);
                TestVectorData test_data;

                // load each test in the file and verify
                while ((test_data = loader.loadNextTest()) != null) {
                    VerifyRSAOAEPSHA2 verify = new VerifyRSAOAEPSHA2(mgf1_hash,
                        alg_hash, test_data);
                    verify.testDecrypt(test_data.plaintext, test_data.ciphertext);
                }
                System.out.println("Verifying " + filename + " completed successfully.");
            }
        }
    }
System.out.println("All verification completed successfully");
}

Download link: VerifyRSAOAEPSHA2.java

Using the Verifier

Download and install the Java 8 SDK. Initial verification was performed using jdk-8u77-macosx-x64.dmg. Download the latest Bouncy Castle JAR. Initial verification was performed using bcprov-jdk15on-154.jar. Set the -classpath to include the Bouncy Castle jar and the path to VerifyRSAOAEPSHA2.java and compile the program.

$ javac -classpath ~/Downloads/bcprov-jdk15on-154.jar:./ VerifyRSAOAEPSHA2.java

Finally, run the program with the path to the SHA-2 vectors:

$ java -classpath ~/Downloads/bcprov-jdk15on-154.jar:./ VerifyRSAOAEPSHA2

- asymmetric/PEM_Serialization/ec_private_key.pem and asymmetric/DER_Serialization/ec_private_key.der - Contains an Elliptic Curve key generated by OpenSSL from the curve secp256r1.
- asymmetric/PEM_Serialization/ec_private_key_encrypted.pem and asymmetric/DER_Serialization/ec_private_key_encrypted.der - Contains the same Elliptic Curve key as ec_private_key.pem, except that it is encrypted with AES-128 with the password "123456".
- asymmetric/PEM_Serialization/ec_public_key.pem and asymmetric/DER_Serialization/ec_public_key.der - Contains the public key corresponding to ec_private_key.pem, generated using OpenSSL.
- asymmetric/PEM_Serialization/rsa_private_key.pem - Contains an RSA 2048 bit key generated using OpenSSL, protected by the secret "123456" with DES3 encryption.
- asymmetric/PEM_Serialization/rsa_public_key.pem and asymmetric/DER_Serialization/rsa_public_key.der - Contains an RSA 2048 bit public generated using OpenSSL from rsa_private_key.pem.
- asymmetric/PEM_Serialization/dsaparam.pem - Contains 2048-bit DSA parameters generated using OpenSSL; contains no keys.
- asymmetric/PEM_Serialization/dsa_private_key.pem - Contains a DSA 2048 bit key generated using OpenSSL from the parameters in dsaparam.pem, protected by the secret “123456” with DES3 encryption.
- asymmetric/PEM_Serialization/dsa_public_key.pem and asymmetric/DER_Serialization/dsa_public_key.der - Contains a DSA 2048 bit key generated using OpenSSL from dsa_private_key.pem.
• asymmetric/PKCS8/unenc-dsa-pkcs8.pem and asymmetric/DER_Serialization/unenc-dsa-pkcs8.der - Contains a DSA 1024 bit key generated using OpenSSL.

• asymmetric/PKCS8/unenc-dsa-pkcs8.pub.pem and asymmetric/DER_Serialization/unenc-dsa-pkcs8.pub.der - Contains a DSA 2048 bit public key generated using OpenSSL from unenc-dsa-pkcs8.pem.

• DER conversions of the GnuTLS example keys for DSA as well as the OpenSSL example key for RSA.

• asymmetric/public/PKCS1/rsa.pub.pem and asymmetric/public/PKCS1/rsa.pub.der are PKCS1 conversions of the public key from asymmetric/PKCS8/unenc-rsa-pkcs8.pem using PEM and DER encoding.

• asymmetric/EC/compressed_points.txt - Contains compressed public points generated using OpenSSL.

• asymmetric/X448/x448-pkcs8-enc.pem and asymmetric/X448/x448-pkcs8-enc.der contain an X448 key encrypted with AES 256 CBC with the password password.

• asymmetric/X448/x448-pkcs8.pem and asymmetric/X448/x448-pkcs8.der contain an unencrypted X448 key.

• asymmetric/X448/x448-pub.pem and asymmetric/X448/x448-pub.der contain an X448 public key.

• asymmetric/Ed25519/ed25519-pkcs8-enc.pem and asymmetric/Ed25519/ed25519-pkcs8-enc.der contain an Ed25519 key encrypted with AES 256 CBC with the password password.


• asymmetric/Ed25519/ed25519-pub.pem and asymmetric/Ed25519/ed25519-pub.der contain an Ed25519 public key.

• asymmetric/X25519/x25519-pkcs8-enc.pem and asymmetric/X25519/x25519-pkcs8-enc.der contain an X25519 key encrypted with AES 256 CBC with the password password.

• asymmetric/X25519/x25519-pkcs8.pem and asymmetric/X25519/x25519-pkcs8.der contain an unencrypted X25519 key.

• asymmetric/X25519/x25519-pub.pem and asymmetric/X25519/x25519-pub.der contain an X25519 public key.

• asymmetric/Ed448/ed448-pkcs8-enc.pem and asymmetric/Ed448/ed448-pkcs8-enc.der contain an Ed448 key encrypted with AES 256 CBC with the password password.

• asymmetric/Ed448/ed448-pkcs8.pem and asymmetric/Ed448/ed448-pkcs8.der contain an unencrypted Ed448 key.

• asymmetric/Ed448/ed448-pub.pem and asymmetric/Ed448/ed448-pub.der contain an Ed448 public key.
Key exchange

- `vectors/cryptography_vectors/asymmetric/DH/rfc3526.txt` contains several standardized Diffie-Hellman groups from RFC 3526.
- `vectors/cryptography_vectors/asymmetric/DH/vec.txt` contains Diffie-Hellman examples from `botan`.
- `vectors/cryptography_vectors/asymmetric/DH/bad_exchange.txt` contains Diffie-Hellman vector pairs that were generated using OpenSSL `DH_generate_parameters_ex` and `DH_generate_key`.
- `vectors/cryptography_vectors/asymmetric/DH/dhp.pem`, `vectors/cryptography_vectors/asymmetric/DH/dhkey.pem` and `vectors/cryptography_vectors/asymmetric/DH/dhpub.pem` contains Diffie-Hellman parameters and key respectively. The keys were generated using OpenSSL following DHKE guide. `vectors/cryptography_vectors/asymmetric/DH/dhkey.txt` contains all parameter in text. `vectors/cryptography_vectors/asymmetric/DH/dhkey.der` and `vectors/cryptography_vectors/asymmetric/DH/dhpublish.der` contains are the above parameters and keys in DER format.
- `vectors/cryptography_vectors/asymmetric/DH/dhp_rfc5114_2.pem`, `vectors/cryptography_vectors/asymmetric/DH/dhkey_rfc5114_2.pem` and `vectors/cryptography_vectors/asymmetric/DH/dhpub_rfc5114_2.pem` contains Diffie-Hellman parameters and key respectively. When creating the parameters we added the `-pkeyopt dh_rfc5114:2` option to use RFC 5114 2048 bit DH parameters with 224 bit subgroup. `vectors/cryptography_vectors/asymmetric/DH/dhkey_rfc5114_2.txt` contains all parameter in text. `vectors/cryptography_vectors/asymmetric/DH/dhp_rfc5114_2.der`, `vectors/cryptography_vectors/asymmetric/DH/dhkey_rfc5114_2.der` and `vectors/cryptography_vectors/asymmetric/DH/dhpublish_rfc5114_2.der` contains are the above parameters and keys in DER format.
- `vectors/cryptography_vectors/asymmetric/ECDH/brainpool.txt` contains Brainpool vectors from RFC 7027.

X.509

- PKITS test suite from NIST PKI Testing.
- `v1_cert.pem` from the OpenSSL source tree (`testx509.pem`).
- `ecdsa_root.pem` - DigiCert Global Root G3, a secp384r1 ECDSA root certificate.
- `verisign-md2-root.pem` - A legacy Verisign public root signed using the MD2 algorithm. This is a PEM conversion of the root data in the NSS source tree.
- `cryptography.io.pem` - A leaf certificate issued by RapidSSL for the cryptography website.
- `rapidssl_sha256_ca_g3.pem` - The intermediate CA that issued the `cryptography.io.pem` certificate.
- `cryptography.io.precert.pem` - A pre-certificate with the CT poison extension for the cryptography website.
- `cryptography-scts.io.pem` - A leaf certificate issued by Let’s Encrypt for the cryptography website which contains signed certificate timestamps.
• wildcard_san.pem - A leaf certificate issued by a public CA for langui.sh that contains wildcard entries in the SAN extension.

• san_edipartname.der - A DSA certificate from a Mozilla bug containing a SAN extension with an ediPartyName general name.

• san_x400address.der - A DSA certificate from a Mozilla bug containing a SAN extension with an x400Address general name.

• department-of-state-root.pem - The intermediary CA for the Department of State, issued by the United States Federal Government’s Common Policy CA. Notably has a critical policy constraints extensions.

• e-trust.ru.der - A certificate from a Russian CA signed using the GOST cipher and containing numerous unusual encodings such as NUMERICSTRING in the subject DN.

• alternate-rsa-shal-oid.pem - A certificate from an unknown signature OID Mozilla bug that uses an alternate signature OID for RSA with SHA1.

• badssl-sct.pem - A certificate with the certificate transparency signed certificate timestamp extension.

• bigoid.pem - A certificate with a rather long OID in the Certificate Policies extension. We need to make sure we can parse long OIDs.

• wosign-bc-invalid.pem - A certificate issued by WoSign that contains a basic constraints extension with CA set to false and a path length of zero in violation of RFC 5280.

• tls-feature-ocsp-staple.pem - A certificate issued by Let’s Encrypt that contains a TLS Feature extension with the status_request feature (commonly known as OCSP Must-Staple).

• unique-identifier.pem - A certificate containing a distinguished name with an x500UniqueIdentifier.

• utf8-dnsname.pem - A certificate containing non-ASCII characters in the DNS name entries of the SAN extension.

• badasn1time.pem - A certificate containing an incorrectly specified UTCTime in its validity->not_after.

• letsencryptx3.pem - A subordinate certificate used by Let’s Encrypt to issue end entity certificates.

Custom X.509 Vectors

• invalid_version.pem - Contains an RSA 2048 bit certificate with the X.509 version field set to 0x7.

• post2000utctime pem - Contains an RSA 2048 bit certificate with the notBefore and notAfter fields encoded as post-2000 UTCTime.

• dsa_selfsigned_ca.pem - Contains a DSA self-signed CA certificate generated using OpenSSL.

• ec_no_named_curve.pem - Contains an ECDSA certificate that does not have an embedded OID defining the curve.

• all_supported_names.pem - An RSA 2048 bit certificate generated using OpenSSL that contains a subject and issuer that have two of each supported attribute type from RFC 5280.

• unsupported_subject_name.pem - An RSA 2048 bit self-signed CA certificate generated using OpenSSL that contains the unsupported “initials” name.

• utf8_common_name.pem - An RSA 2048 bit self-signed CA certificate generated using OpenSSL that contains a UTF8String common name with the value “We heart UTF8™”.

• two_basic_constraints.pem - An RSA 2048 bit self-signed certificate containing two basic constraints extensions.
• basic_constraints_not_critical.pem - An RSA 2048 bit self-signed certificate containing a basic constraints extension that is not marked as critical.

• bc_path_length_zero.pem - An RSA 2048 bit self-signed certificate containing a basic constraints extension with a path length of zero.

• unsupported_extension.pem - An RSA 2048 bit self-signed certificate containing an unsupported extension type. The OID was encoded as “1.2.3.4” with an extnValue of “value”.

• unsupported_extension_2.pem - A secp256r1 certificate containing two unsupported extensions. The OIDs are 1.3.6.1.4.1.41482.2 with an extnValue of 1.3.6.1.4.1.41482.1.2 and 1.3.6.1.4.1.45724.2.1.1 with an extnValue of \x03\x02\x040

• unsupported_extension_critical.pem - An RSA 2048 bit self-signed certificate containing an unsupported extension type marked critical. The OID was encoded as “1.2.3.4” with an extnValue of “value”.

• san_email_dns_ip_dirname_uri.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with the following general names: rfc822Name, dNSName, iPAddress, directoryName, and uniformResourceIdentifier.

• san_empty_hostname.pem - An RSA 2048 bit self-signed certificate containing a subject alternative extension with an empty dNSName general name.

• san_other_name.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with the otherName general name.

• san_registered_id.pem - An RSA 1024 bit certificate containing a subject alternative name extension with the registeredID general name.

• all_key_usages.pem - An RSA 2048 bit self-signed certificate containing a key usage extension with all nine purposes set to true.

• extended_key_usage.pem - An RSA 2048 bit self-signed certificate containing an extended key usage extension with eight usages.

• san_idna_names.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with rfc822Name, dNSName, and uniformResourceIdentifier general names with IDNA (RFC 5895) encoding.

• sanWildcard_idna.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with a dNSName general name with a wildcard IDNA (RFC 5895) domain.

• san_idna2003_dnsname.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with an IDNA 2003 (RFC 3490) dNSName.

• san_rfc822_names.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with various rfc822Name values.

• san_rfc822_idna.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with an IDNA rfc822Name.

• san_uri_with_port.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with various uniformResourceIdentifier values.

• san_ipaddr.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with an iPAddress value.

• san_dirname.pem - An RSA 2048 bit self-signed certificate containing a subject alternative name extension with a directoryName value.

• inhibit_any_policy_5.pem - An RSA 2048 bit self-signed certificate containing an inhibit any policy extension with the value 5.
- inhibit_any_policy_negative.pem - An RSA 2048 bit self-signed certificate containing an inhibit any policy extension with the value -1.
- authority_key_identifier.pem - An RSA 2048 bit self-signed certificate containing an authority key identifier extension with key identifier, authority certificate issuer, and authority certificate serial number fields.
- authority_key_identifier_no_keyid.pem - An RSA 2048 bit self-signed certificate containing an authority key identifier extension with authority certificate issuer and authority certificate serial number fields.
- aia_ocsp_ca_issuers.pem - An RSA 2048 bit self-signed certificate containing an authority information access extension with two OCSP and one CA issuers entry.
- aia_ocsp.pem - An RSA 2048 bit self-signed certificate containing an authority information access extension with an OCSP entry.
- aia_ca_issuers.pem - An RSA 2048 bit self-signed certificate containing an authority information access extension with a CA issuers entry.
- cdp_empty_hostname.pem - An RSA 2048 bit self-signed certificate containing a CRL distribution point extension with fullName URI without a hostname.
- cdp_fullname_reasons_crlIssuer.pem - An RSA 1024 bit certificate containing a CRL distribution points extension with fullName, cRLIssuer, and reasons data.
- cdp_crlIssuer.pem - An RSA 1024 bit certificate containing a CRL distribution points extension with cRLIssuer data.
- cdp_all_reasons.pem - An RSA 1024 bit certificate containing a CRL distribution points extension with all reasons bits set.
- cdp_reason_aaCompromise.pem - An RSA 1024 bit certificate containing a CRL distribution points extension with the AACompromise reasons bit set.
- nc_permitted_excluded.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with both permitted and excluded elements. Contains IPv4 and IPv6 addresses with network mask as well as dNSName with a leading period.
- nc_permitted_excluded_2.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with both permitted and excluded elements. Unlike nc_permitted_excluded.pem, the general names do not contain any name constraints specific values.
- nc_permitted.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with permitted elements.
- nc_permitted_2.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with permitted elements that do not contain any name constraints specific values.
- nc_excluded.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with excluded elements.
- nc_invalid_ip_netmask.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with a permitted element that has an IPv6 IP and an invalid network mask.
- nc_single_ip_netmask.pem - An RSA 2048 bit self-signed certificate containing a name constraints extension with a permitted element that has two IPs with /32 and /128 network masks.
- cp_userNotice_with_notice_reference.pem - An RSA 2048 bit self-signed certificate containing a certificate policies extension with a notice reference in the user notice.
- cp_userNotice_with_explicit_text.pem - An RSA 2048 bit self-signed certificate containing a certificate policies extension with explicit text and no notice reference.
- cp_cpsURI.pem - An RSA 2048 bit self-signed certificate containing a certificate policies extension with a CPS URI and no user notice.
• cp_user_notice_no_explicit_text.pem - An RSA 2048 bit self-signed certificate containing a certificate policies extension with a user notice with no explicit text.

• cp_invalid.pem - An RSA 2048 bit self-signed certificate containing a certificate policies extension with invalid data.

• ian_uri.pem - An RSA 2048 bit certificate containing an issuer alternative name extension with a URI general name.

• ocsp_nocheck.pem - An RSA 2048 bit self-signed certificate containing an OCSPNoCheck extension.

• pc_inhibit Require.pem - An RSA 2048 bit self-signed certificate containing a policy constraints extension with both inhibit policy mapping and require explicit policy elements.

• pc_inhibit.pem - An RSA 2048 bit self-signed certificate containing a policy constraints extension with an inhibit policy mapping element.

• pc_require.pem - An RSA 2048 bit self-signed certificate containing a policy constraints extension with a require explicit policy element.

• unsupported_subject_public_key_info.pem - A certificate whose public key is an unknown OID (1.3.6.1.4.1.8432.1.1.2).

• policy_constraints_explicit.pem - A self-signed certificate containing a policyConstraints extension with a requireExplicitPolicy value.

• freshestcrl.pem - A self-signed certificate containing a freshestCRL extension.

• ca/ca.pem - A self-signed certificate with basicConstraints set to true. Its private key is ca/ca_key.pem. This certificate is encoded in several of the PKCS12 custom vectors.

• negative_serial.pem - A certificate with a serial number that is a negative number.

• rsa_pss.pem - A certificate with an RSA PSS signature.

**Custom X.509 Request Vectors**

• dsa_sha1.pem and dsa_sha1.der - Contain a certificate request using 1024-bit DSA parameters and SHA1 generated using OpenSSL.

• rsa_md4.pem and rsa_md4.der - Contain a certificate request using 2048 bit RSA and MD4 generated using OpenSSL.

• rsa_sha1.pem and rsa_sha1.der - Contain a certificate request using 2048 bit RSA and SHA1 generated using OpenSSL.

• rsa_sha256.pem and rsa_sha256.der - Contain a certificate request using 2048 bit RSA and SHA256 generated using OpenSSL.

• ec_sha256.pem and ec_sha256.der - Contain a certificate request using EC (secp384r1) and SHA256 generated using OpenSSL.

• san_rsa_shal.pem and san_rsa_shal.der - Contain a certificate request using RSA and SHA1 with a subject alternative name extension generated using OpenSSL.

• two_basic_constraints.pem - A certificate signing request for an RSA 2048 bit key containing two basic constraints extensions.

• unsupported_extension.pem - A certificate signing request for an RSA 2048 bit key containing containing an unsupported extension type. The OID was encoded as “1.2.3.4” with an extnValue of “value”.
• unsupported_extension_critical.pem - A certificate signing request for an RSA 2048 bit key containing an unsupported extension type marked critical. The OID was encoded as “1.2.3.4” with an extnValue of “value”.

• basic_constraints.pem - A certificate signing request for an RSA 2048 bit key containing a basic constraints extension marked as critical.

• invalid_signature.pem - A certificate signing request for an RSA 1024 bit key containing an invalid signature with correct padding.

**Custom X.509 Certificate Revocation List Vectors**

• crl_all_reasons.pem - Contains a CRL with 12 revoked certificates, whose serials match their list position. It includes one revocation without any entry extensions, 10 revocations with every supported reason code and one revocation with an unsupported, non-critical entry extension with the OID value set to “1.2.3.4”.

• crl_dup_entry_ext.pem - Contains a CRL with one revocation which has a duplicate entry extension.

• crl_md2_unknown_crit_entry_ext.pem - Contains a CRL with one revocation which contains an unsupported critical entry extension with the OID value set to “1.2.3.4”. The CRL uses an unsupported MD2 signature algorithm.

• crl_unsupported_reason.pem - Contains a CRL with one revocation which has an unsupported reason code.

• crl_inval_cert_issuer_entry_ext.pem - Contains a CRL with one revocation which has one entry extension for certificate issuer with an empty value.

• crl_empty.pem - Contains a CRL with no revoked certificates.

• crl_ian_aia_aki.pem - Contains a CRL with IssuerAlternativeName, AuthorityInformationAccess, AuthorityKeyIdentifier and CRLNumber extensions.

• valid_signature.pem - Contains a CRL with the public key which was used to generate it.

• invalid_signature.pem - Contains a CRL with the last signature byte incremented by 1 to produce an invalid signature, and the public key which was used to generate it.

• crl_delta_crl_indicator.pem - Contains a CRL with the deltaCRLIndicator extension.

• crl_idp_fullname_only.pem - Contains a CRL with an IssuingDistributionPoints extension with only a fullname for the distribution point.

• crl_idp_only_ca.pem - Contains a CRL with an IssuingDistributionPoints extension that is only valid for CA certificate revocation.

• crl_idp_fullname_only_aa.pem - Contains a CRL with an IssuingDistributionPoints extension that sets a fullname and is only valid for attribute certificate revocation.

• crl_idp_fullname_only_user.pem - Contains a CRL with an IssuingDistributionPoints extension that sets a fullname and is only valid for user certificate revocation.

• crl_idp_fullname_indirect_crl.pem - Contains a CRL with an IssuingDistributionPoints extension that sets a fullname and the indirect CRL flag.

• crl_idp_reasons_only.pem - Contains a CRL with an IssuingDistributionPoints extension that is only valid for revocations with the keyCompromise reason.

• crl_idp_relative_user_all_reasons.pem - Contains a CRL with an IssuingDistributionPoints extension that sets all revocation reasons as allowed.
• `crl_idp_relativename_only.pem` - Contains a CRL with an `IssuingDistributionPoints` extension with only a `relativename` for the distribution point.

### X.509 OCSP Test Vectors

- `x509/ocsp/resp-sha256.der` - An OCSP response for `cryptography.io` with a SHA256 signature.
- `x509/ocsp/resp-unauthorized.der` - An OCSP response with an unauthorized status.
- `x509/ocsp/resp-revoked.der` - An OCSP response for `revoked.badssl.com` with a revoked status.
- `x509/ocsp/resp-delegate-unknown-cert.der` - An OCSP response for an unknown cert from AC Camerafirma. This response also contains a delegate certificate.
- `x509/ocsp/resp-responder-key-hash.der` - An OCSP response from the DigiCert OCSP responder that uses a key hash for the responder ID.
- `x509/ocsp/resp-revoked-reason.der` - An OCSP response from the QuoVadis OCSP responder that contains a revoked certificate with a revocation reason.
- `x509/ocsp/resp-revoked-no-next-update.der` - An OCSP response that contains a revoked certificate and no `nextUpdate` value.
- `x509/ocsp/resp-invalid-signature-oid.der` - An OCSP response that was modified to contain an MD2 signature algorithm object identifier.

### Custom X.509 OCSP Test Vectors

- `x509/ocsp/req-sha1.der` - An OCSP request containing a single request and using SHA1 as the hash algorithm.
- `x509/ocsp/req-multi-sha1.der` - An OCSP request containing multiple requests.
- `x509/ocsp/req-invalid-hash-alg.der` - An OCSP request containing an invalid hash algorithm OID.
- `x509/ocsp/req-ext-nonce.der` - An OCSP request containing a nonce extension.

### Custom PKCS12 Test Vectors

- `pkcs12/cert-key-aes256cbc.p12` - A PKCS12 file containing a cert (`x509/custom/ca/ca.pem`) and key (`x509/custom/ca/ca_key.pem`) both encrypted with AES 256 CBC with the password `cryptography`.
- `pkcs12/cert-none-key-none.p12` - A PKCS12 file containing a cert (`x509/custom/ca/ca.pem`) and key (`x509/custom/ca/ca_key.pem`) with no encryption. The password (used for integrity checking only) is `cryptography`.
- `pkcs12/cert-rc2-key-3des.p12` - A PKCS12 file containing a cert (`x509/custom/ca/ca.pem`) encrypted with RC2 and key (`x509/custom/ca/ca_key.pem`) encrypted via 3DES with the password `cryptography`.
- `pkcs12/no-password.p12` - A PKCS12 file containing a cert (`x509/custom/ca/ca.pem`) and key (`x509/custom/ca/ca_key.pem`) with no encryption and no password.
- `pkcs12/no-cert-key-aes256cbc.p12` - A PKCS12 file containing a key (`x509/custom/ca/ca_key.pem`) encrypted via AES 256 CBC with the password `cryptography` and no certificate.
• pkcs12/cert-aes256cbc-no-key.p12 - A PKCS12 file containing a cert (x509/custom/ca/ca.pem) encrypted via AES 256 CBC with the password cryptography and no private key.

Hashes

• MD5 from RFC 1321.
• RIPEMD160 from the RIPEMD website.
• SHA1 from NIST CAVP.
• SHA2 (224, 256, 384, 512, 512/224, 512/256) from NIST CAVP.
• SHA3 (224, 256, 384, 512) from NIST CAVP.
• SHAKE (128, 256) from NIST CAVP.
• Blake2s and Blake2b from OpenSSL test/evptests.txt.

HMAC

• HMAC-MD5 from RFC 2202.
• HMAC-SHA1 from RFC 2202.
• HMAC-RIPEMD160 from RFC 2286.
• HMAC-SHA2 (224, 256, 384, 512) from RFC 4231.

Key derivation functions

• HKDF (SHA1, SHA256) from RFC 5869.
• PBKDF2 (HMAC-SHA1) from RFC 6070.
• scrypt from the draft RFC.
• X9.63 KDF from NIST CAVP.
• SP 800-108 Counter Mode KDF (HMAC-SHA1, HMAC-SHA224, HMAC-SHA256, HMAC-SHA384, HMAC-SHA512) from NIST CAVP.

Key wrapping

• AES key wrap (AESKW) and 3DES key wrap test vectors from NIST CAVP.
• AES key wrap with padding vectors from Botan’s key wrap vectors.

Recipes

• Fernet from its specification repository.
Symmetric ciphers

- AES (CBC, CFB, ECB, GCM, OFB, CCM) from NIST CAVP.
- AES CTR from RFC 3686.
- 3DES (CBC, CFB, ECB, OFB) from NIST CAVP.
- ARC4 (KEY-LENGTH: 40, 56, 64, 80, 128, 192, 256) from RFC 6229.
- ARC4 (KEY-LENGTH: 160) generated by this project. See: ARC4 vector creation
- Blowfish (CBC, CFB, ECB, OFB) from Bruce Schneier’s vectors.
- Camellia (ECB) from NTT’s Camellia page as linked by CRYPTREC.
- Camellia (CBC, CFB, OFB) from OpenSSL’s test vectors.
- CAST5 (ECB) from RFC 2144.
- CAST5 (CBC, CFB, OFB) generated by this project. See: CAST5 vector creation
- ChaCha20 from RFC 7539.
- ChaCha20Poly1305 from RFC 7539, OpenSSL's evpciph.txt, and the BoringSSL ChaCha20Poly1305 tests.
- IDEA (ECB) from the NESSIE IDEA vectors created by NESSIE.
- IDEA (CBC, CFB, OFB) generated by this project. See: IDEA vector creation
- SEED (ECB) from RFC 4269.
- SEED (CBC) from RFC 4196.
- SEED (CFB, OFB) generated by this project. See: SEED vector creation

Two factor authentication

- HOTP from RFC 4226
- TOTP from RFC 6238 (Note that an errata for the test vectors in RFC 6238 exists)

CMAC

- AES-128, AES-192, AES-256, 3DES from NIST SP-800-38B

Poly1305

- Test vectors from RFC 7539.

Creating test vectors

When official vectors are unavailable cryptography may choose to build its own using existing vectors as source material.
### Created Vectors

#### ARC4 vector creation

This page documents the code that was used to generate the ARC4 test vectors for key lengths not available in RFC 6229. All the vectors were generated using OpenSSL and verified with Go.

#### Creation

cryptography was modified to support ARC4 key lengths not listed in RFC 6229. Then the following Python script was run to generate the vector files.

```python
# This file is dual licensed under the terms of the Apache License, Version 2.0, and the BSD License. See the LICENSE file in the root of this repository for complete details.

from __future__ import absolute_import, division, print_function

import binascii

from cryptography.hazmat.backends import default_backend
from cryptography.hazmat.primitives import ciphers
from cryptography.hazmat.primitives.ciphers import algorithms

_RFC6229_KEY_MATERIALS = [
    (True,
     8 * '012030405060708090a0b0c0d0e0f10112131415161718191a1b1c1d1e1f20'),
    (False,
     8 * '1ada31d5cf688221c109163908ebe51debb46227c6cc8b37641910833222772a')
]

_RFC6229_OFFSETS = [
    0,
    16,
    240,
    256,
    496,
    512,
    752,
    768,
    1008,
    1024,
    1520,
    1536,
    2032,
    2048,
    3056,
    3072,
    4080,
    4096
]
```

(continues on next page)
_SIZES_TO_GENERATE = [
    160
]

def _key_for_size(size, keyinfo):
    msb, key = keyinfo
    if msb:
        return key[:size // 4]
    else:
        return key[-size // 4:]

def _build_vectors():
    count = 0
    output = []
    key = None
    plaintext = binascii.unhexlify(32 * '0')
    for size in _SIZES_TO_GENERATE:
        for keyinfo in _RFC6229_KEY_MATERIALS:
            key = _key_for_size(size, keyinfo)
            cipher = ciphers.Cipher(
                algorithms.ARC4(binascii.unhexlify(key)),
                None,
                default_backend())
            encryptor = cipher.encryptor()
            current_offset = 0
            for offset in _RFC6229_OFFSETS:
                if offset % 16 != 0:
                    raise ValueError("Offset {} is not evenly divisible by 16".format(offset))
                while current_offset < offset:
                    encryptor.update(plaintext)
                    current_offset += len(plaintext)
                output.append("\nCOUNT = {}").format(count))
                count += 1
                output.append("KEY = {}").format(key))
                output.append("OFFSET = {}").format(offset))
                output.append("PLAINTEXT = {}").format(  
                    binascii.hexlify(plaintext)))
                output.append("CIPHERTEXT = {}").format(  
                    binascii.hexlify(encryptor.update(plaintext)))
                current_offset += len(plaintext)
                assert not encryptor.finalize()
            return "\n".join(output)

def _write_file(data, filename):
    with open(filename, 'w') as f:
        f.write(data)

if __name__ == '__main__':
    _write_file(_build_vectors(), 'arc4.txt')

Download link: generate_arc4.py
The following Go code was used to verify the vectors.

```go
package main

import {
    "bufio"
    "bytes"
    "crypto/rc4"
    "encoding/hex"
    "fmt"
    "os"
    "strconv"
    "strings"
}

func unhexlify(s string) []byte {
    bytes, err := hex.DecodeString(s)
    if err != nil {
        panic(err)
    }
    return bytes
}

type vectorArgs struct {
    count string
    offset uint64
    key string
    plaintext string
    ciphertext string
}

type vectorVerifier interface {
    validate(count string, offset uint64, key, plaintext, expectedCiphertext []byte)
}

type arc4Verifier struct{
}

func (o arc4Verifier) validate(count string, offset uint64, key, plaintext, expectedCiphertext []byte) {
    if offset%16 != 0 || len(plaintext) != 16 || len(expectedCiphertext) != 16 {
        panic(fmt.Errorf("Unexpected input value encountered: offset=%v; len(plaintext)=%v; len(expectedCiphertext)=%v", offset, len(plaintext), len(expectedCiphertext)))
    }
    stream, err := rc4.NewCipher(key)
    if err != nil {
        panic(err)
    }

    var currentOffset uint64 = 0
    ciphertext := make([]byte, len(plaintext))
    for currentOffset <= offset {
        // (continues on next page)
    }
}
```

(continues on next page)
stream.XORKeyStream(ciphertext, plaintext)
currentOffset += uint64(len(plaintext))
}
if !bytes.Equal(ciphertext, expectedCiphertext) {
    panic(fmt.Errorf("vector mismatch @ COUNT = %s:
    %s != %s
", count,
    hex.EncodeToString(expectedCiphertext),
    hex.EncodeToString(ciphertext)))
}
func validateVectors(verifier vectorVerifier, filename string) {
    vectors, err := os.Open(filename)
    if err != nil {
        panic(err)
    }
    defer vectors.Close()
    var segments []string
    var vector *vectorArgs
    scanner := bufio.NewScanner(vectors)
    for scanner.Scan() {
        segments = strings.Split(scanner.Text(), " = ")
        switch {
        case strings.ToUpper(segments[0]) == "COUNT":
            if vector != nil {
                verifier.validate(vector.count,
                vector.offset,
                unhexlify(vector.key),
                unhexlify(vector.plaintext),
                unhexlify(vector.ciphertext))
            }
            vector = &vectorArgs{count: segments[1]}
        case strings.ToUpper(segments[0]) == "OFFSET":
            vector.offset, err = strconv.ParseUint(segments[1], 10, 64)
            if err != nil {
                panic(err)
            }
        case strings.ToUpper(segments[0]) == "KEY":
            vector.key = segments[1]
        case strings.ToUpper(segments[0]) == "PLAINTEXT":
            vector.plaintext = segments[1]
        case strings.ToUpper(segments[0]) == "CIPHERTEXT":
            vector.ciphertext = segments[1]
        }
        if vector != nil {
            verifier.validate(vector.count,
            vector.offset,
            unhexlify(vector.key),
            unhexlify(vector.plaintext),
            unhexlify(vector.ciphertext))
        }
    }
func main() {
    validateVectors(arc4Verifier{}, "vectors/cryptography_vectors/ciphers/ARC4/arc4.txt")
    fmt.Println("ARC4 OK.")
}

Download link: verify_arc4.go

CAST5 vector creation

This page documents the code that was used to generate the CAST5 CBC, CFB, OFB, and CTR test vectors as well as
the code used to verify them against another implementation. The CBC, CFB, and OFB vectors were generated using
OpenSSL and the CTR vectors were generated using Apple’s CommonCrypto. All the generated vectors were verified
with Go.

Creation

cryptography was modified to support CAST5 in CBC, CFB, and OFB modes. Then the following Python script
was run to generate the vector files.

```python
# This file is dual licensed under the terms of the Apache License, Version
# 2.0, and the BSD License. See the LICENSE file in the root of this repository
# for complete details.

from __future__ import absolute_import, division, print_function
import binascii
from cryptography.hazmat.backends import default_backend
from cryptography.hazmat.primitives.ciphers import algorithms, base, modes

def encrypt(mode, key, iv, plaintext):
    cipher = base.Cipher(
        algorithms.CAST5(binascii.unhexlify(key)),
        mode(binascii.unhexlify(iv)),
        default_backend()
    )
    encryptor = cipher.encryptor()
    ct = encryptor.update(binascii.unhexlify(plaintext))
    ct += encryptor.finalize()
    return binascii.hexlify(ct)

def build_vectors(mode, filename):
    vector_file = open(filename, "r")

    count = 0
    output = []
    key = None
    iv = None
    plaintext = None
    for line in vector_file:
```
line = line.strip()
if line.startswith("KEY"):
    if count != 0:
        output.append("CIPHERTEXT = " + encrypt(mode, key, iv, plaintext))
    output.append("\nCOUNT = ".format(count))
    count += 1
    name, key = line.split(" = ")
    output.append("KEY = " + key)
elif line.startswith("IV"):
    name, iv = line.split(" = ")
    iv = iv[0:16]
    output.append("IV = " + iv)
elif line.startswith("PLAINTEXT"):
    name, plaintext = line.split(" = ")
    output.append("PLAINTEXT = " + plaintext)
output.append("CIPHERTEXT = " + encrypt(mode, key, iv, plaintext))
return "\n".join(output)

def write_file(data, filename):
    with open(filename, "w") as f:
        f.write(data)

cbc_path = "tests/hazmat/primitives/vectors/ciphers/AES/CBC/CBCMMT128.rsp"
cbc_path = "tests/hazmat/primitives/vectors/ciphers/AES/OFB/OFBMMT128.rsp"
cfb_path = "tests/hazmat/primitives/vectors/ciphers/AES/CFB/CFB128MMT128.rsp"
ctr_path = "tests/hazmat/primitives/vectors/ciphers/AES/CTR/aes-128-ctr.txt"
write_file(build_vectors(modes.CBC, cbc_path), "cast5-cbc.txt")
write_file(build_vectors(modes.OFB, ofb_path), "cast5-ofb.txt")
write_file(build_vectors(modes.CFB, cfb_path), "cast5-cfb.txt")
write_file(build_vectors(modes.CTR, ctr_path), "cast5-ctr.txt")

Download link: generate_cast5.py

Verification

The following Go code was used to verify the vectors.

```go
package main

import {
    "bufio"
    "bytes"
    "golang.org/x/crypto/cast5"
    "crypto/cipher"
    "encoding/hex"
    "fmt"
    "os"
    "strings"
}
```
func unhexlify(s string) []byte {
    bytes, err := hex.DecodeString(s)
    if err != nil {
        panic(err)
    }
    return bytes
}

type vectorArgs struct {
    count   string
    key     string
    iv      string
    plaintext string
    ciphertext string
}

type vectorVerifier interface {
    validate(count string, key, iv, plaintext, expectedCiphertext []byte)
}

type ofbVerifier struct {
}

func (o ofbVerifier) validate(count string, key, iv, plaintext, expectedCiphertext []byte) {
    block, err := cast5.NewCipher(key)
    if err != nil {
        panic(err)
    }
    ciphertext := make([]byte, len(plaintext))
    stream := cipher.NewOFB(block, iv)
    stream.XORKeyStream(ciphertext, plaintext)
    if !bytes.Equal(ciphertext, expectedCiphertext) {
        panic(fmt.Errorf("vector mismatch @ COUNT = %s:\n %s != %s\n", count,
                           hex.EncodeToString(expectedCiphertext),
                           hex.EncodeToString(ciphertext)))
    }
}

type cbcVerifier struct {

}

func (o cbcVerifier) validate(count string, key, iv, plaintext, expectedCiphertext []byte) {
    block, err := cast5.NewCipher(key)
    if err != nil {
        panic(err)
    }
    ciphertext := make([]byte, len(plaintext))
    mode := cipher.NewCBCEncrypter(block, iv)
    mode.CryptBlocks(ciphertext, plaintext)
    if !bytes.Equal(ciphertext, expectedCiphertext) {
        panic(fmt.Errorf("vector mismatch @ COUNT = %s:\n %s != %s\n", count,
                           hex.EncodeToString(expectedCiphertext),
                           hex.EncodeToString(ciphertext)))
    }
}
type cfbVerifier struct{}

func (o cfbVerifier) validate(count string, key, iv, plaintext, expectedCiphertext →[]byte) {
    block, err := cast5.NewCipher(key)
    if err != nil {
        panic(err)
    }

    ciphertext := make([]byte, len(plaintext))
    stream := cipher.NewCFBEncrypter(block, iv)
    stream.XORKeyStream(ciphertext, plaintext)

    if !bytes.Equal(ciphertext, expectedCiphertext) {
        panic(fmt.Errorf("vector mismatch @ COUNT = %s: \n %s != %s\n", count, hex.EncodeToString(expectedCiphertext), hex.EncodeToString(ciphertext)))
    }
}

type ctrVerifier struct{}

func (o ctrVerifier) validate(count string, key, iv, plaintext, expectedCiphertext →[]byte) {
    block, err := cast5.NewCipher(key)
    if err != nil {
        panic(err)
    }

    ciphertext := make([]byte, len(plaintext))
    stream := cipher.NewCTR(block, iv)
    stream.XORKeyStream(ciphertext, plaintext)

    if !bytes.Equal(ciphertext, expectedCiphertext) {
        panic(fmt.Errorf("vector mismatch @ COUNT = %s: \n %s != %s\n", count, hex.EncodeToString(expectedCiphertext), hex.EncodeToString(ciphertext)))
    }
}

func validateVectors(verifier vectorVerifier, filename string) {
    vectors, err := os.Open(filename)
    if err != nil {
        panic(err)
    }
    defer vectors.Close()

    var segments []string

    var vector *vectorArgs

scanner := bufio.NewScanner(vectors)
for scanner.Scan() {
    segments = strings.Split(scanner.Text(), " = ")
    switch {
        case strings.ToUpper(segments[0]) == "COUNT":
            if vector != nil {
                verifier.validate(vector.count,
                                 unhexlify(vector.key),
                                 unhexlify(vector.iv),
                                 unhexlify(vector.plaintext),
                                 unhexlify(vector.ciphertext))
            }
            vector = &vectorArgs{count: segments[1]}
        case strings.ToUpper(segments[0]) == "IV":
            vector.iv = segments[1][:16]
        case strings.ToUpper(segments[0]) == "KEY":
            vector.key = segments[1]
        case strings.ToUpper(segments[0]) == "PLAINTEXT":
            vector.plaintext = segments[1]
        case strings.ToUpper(segments[0]) == "CIPHERTEXT":
            vector.ciphertext = segments[1]
    }
}

func main() {
    validateVectors(ofbVerifier{},
                    "vectors/cryptography_vectors/ciphers/CAST5/cast5-ofb.txt")
    fmt.Println("OFB OK.")
    validateVectors(cfbVerifier{},
                    "vectors/cryptography_vectors/ciphers/CAST5/cast5-cfb.txt")
    fmt.Println("CFB OK.")
    validateVectors(cbcVerifier{},
                    "vectors/cryptography_vectors/ciphers/CAST5/cast5-cbc.txt")
    fmt.Println("CBC OK.")
    validateVectors(ctrVerifier{},
                    "vectors/cryptography_vectors/ciphers/CAST5/cast5-ctr.txt")
    fmt.Println("CTR OK.")
}

Download link: verify_cast5.go

IDEA vector creation

This page documents the code that was used to generate the IDEA CBC, CFB, and OFB test vectors as well as the code used to verify them against another implementation. The vectors were generated using OpenSSL and verified with Botan.

Creation

cryptography was modified to support IDEA in CBC, CFB, and OFB modes. Then the following python script was run to generate the vector files.
import binascii

from cryptography.hazmat.backends.openssl.backend import backend
from cryptography.hazmat.primitives.ciphers import algorithms, base, modes

def encrypt(mode, key, iv, plaintext):
    cipher = base.Cipher(
        algorithms.IDEA(binascii.unhexlify(key)),
        mode(binascii.unhexlify(iv)),
        backend
    )
    encryptor = cipher.encryptor()
    ct = encryptor.update(binascii.unhexlify(plaintext))
    ct += encryptor.finalize()
    return binascii.hexlify(ct)

def build_vectors(mode, filename):
    with open(filename, "r") as f:
        vector_file = f.read().splitlines()
        count = 0
        output = []
        key = None
        iv = None
        plaintext = None
        for line in vector_file:
            line = line.strip()
            if line.startswith("KEY"):
                if count != 0:
                    output.append("CIPHERTEXT = {0}").format(encrypt(mode, key, iv, plaintext))
                    output.append("\nCOUNT = {0}".format(count))
                    count += 1
                name, key = line.split("=")
                output.append("KEY = {0}".format(key))
            elif line.startswith("IV"):
                name, iv = line.split("=")
                iv = iv[0:16]
                output.append("IV = {0}".format(iv))
            elif line.startswith("PLAINTEXT"):
                name, plaintext = line.split("=")
                output.append("PLAINTEXT = {0}".format(plaintext))
            output.append("CIPHERTEXT = {0}".format(encrypt(mode, key, iv, plaintext)))
        return "\n".join(output)

def write_file(data, filename):
    with open(filename, "w") as f:
        f.write(data)

CBC_PATH = "tests/hazmat/primitives/vectors/ciphers/AES/CBC/CBCM@128.rsp"
write_file(build_vectors(modes.CBC, CBC_PATH), "idea-cbc.txt")
Cryptography Documentation, Release 2.8.dev1

(continued from previous page)

```
OFB_PATH = "tests/hazmat/primitives/vectors/ciphers/AES/OFB/OFBMMT128.rsp"
write_file(build_vectors(modes.OFB, OFB_PATH), "idea-ofb.txt")
CFB_PATH = "tests/hazmat/primitives/vectors/ciphers/AES/CFB/CFB128MMT128.rsp"
write_file(build_vectors(modes.CFB, CFB_PATH), "idea-cfb.txt")
```

Download link: generate_idea.py

Verification

The following Python code was used to verify the vectors using the Botan project’s Python bindings.

```
import binascii
import botan
from tests.utils import load_nist_vectors

BLOCK_SIZE = 64

def encrypt(mode, key, iv, plaintext):
    encryptor = botan.Cipher("IDEA/{0}/NoPadding".format(mode), "encrypt",
        binascii.unhexlify(key))

    cipher_text = encryptor.cipher(binascii.unhexlify(plaintext),
        binascii.unhexlify(iv))
    return binascii.hexlify(cipher_text)

def verify_vectors(mode, filename):
    with open(filename, "r") as f:
        vector_file = f.read().splitlines()

    vectors = load_nist_vectors(vector_file)
    for vector in vectors:
        ct = encrypt(
            mode,
            vector["key"],
            vector["iv"],
            vector["plaintext"]
        )
        assert ct == vector["ciphertext"]

cbc_path = "tests/hazmat/primitives/vectors/ciphers/IDEA/idea-cbc.txt"
verify_vectors("CBC", cbc_path)
ofb_path = "tests/hazmat/primitives/vectors/ciphers/IDEA/idea-ofb.txt"
verify_vectors("OFB", ofb_path)
cfb_path = "tests/hazmat/primitives/vectors/ciphers/IDEA/idea-cfb.txt"
verify_vectors("CFB", cfb_path)
```

Download link: verify_idea.py

2.11. Development 229
SEED vector creation

This page documents the code that was used to generate the SEED CFB and OFB test vectors as well as the code used to verify them against another implementation. The vectors were generated using OpenSSL and verified with Botan.

Creation

cryptography was modified to support SEED in CFB and OFB modes. Then the following python script was run to generate the vector files.

```python
import binascii

from cryptography.hazmat.backends.openssl.backend import backend
from cryptography.hazmat.primitives.ciphers import algorithms, base, modes

def encrypt(mode, key, iv, plaintext):
    cipher = base.Cipher(
        algorithms.SEED(binascii.unhexlify(key)),
        mode(binascii.unhexlify(iv)),
        backend
    )
    encryptor = cipher.encryptor()
    ct = encryptor.update(binascii.unhexlify(plaintext))
    ct += encryptor.finalize()
    return binascii.hexlify(ct)

def build_vectors(mode, filename):
    with open(filename, "r") as f:
        vector_file = f.read().splitlines()
        count = 0
        output = []
        key = None
        iv = None
        plaintext = None

        for line in vector_file:
            line = line.strip()
            if line.startswith("KEY"):
                if count != 0:
                    output.append("CIPHERTEXT = \"{0}\".format(encrypt(mode, key, iv, plaintext))
                output.append("\nCOUNT = {0}\".format(count))
                count += 1
                name, key = line.split(" = ")
                output.append("KEY = \"{0}\".format(key))
            elif line.startswith("IV"):
                name, iv = line.split(" = ")
                output.append("IV = \"{0}\".format(iv))
            elif line.startswith("PLAINTEXT"):
                name, plaintext = line.split(" = ")
                output.append("PLAINTEXT = \"{0}\".format(plaintext))
            output.append("CIPHERTEXT = \"{0}\".format(encrypt(mode, key, iv, plaintext)))
```

(continues on next page)
return "\n".join(output)

def write_file(data, filename):
    with open(filename, "w") as f:
        f.write(data)

OFB_PATH = "vectors/cryptography_vectors/ciphers/AES/OFB/OFBMMT128.rsp"
write_file(build_vectors(modes.OFB, OFB_PATH), "seed-ofb.txt")
CFB_PATH = "vectors/cryptography_vectors/ciphers/AES/CFB/CFB128MMT128.rsp"
write_file(build_vectors(modes.CFB, CFB_PATH), "seed-cfb.txt")

Download link: generate_seed.py

Verification

The following Python code was used to verify the vectors using the Botan project’s Python bindings.

```python
import binascii
import botan
from tests.utils import load_nist_vectors

def encrypt(mode, key, iv, plaintext):
    encryptor = botan.Cipher("SEED/0/NoPadding".format(mode), "encrypt",
                           binascii.unhexlify(key))
    cipher_text = encryptor.cipher(binascii.unhexlify(plaintext),
                                  binascii.unhexlify(iv))
    return binascii.hexlify(cipher_text)

def verify_vectors(mode, filename):
    with open(filename, "r") as f:
        vector_file = f.read().splitlines()

    vectors = load_nist_vectors(vector_file)
    for vector in vectors:
        ct = encrypt(
                    mode,
                    vector["key"],
                    vector["iv"],
                    vector["plaintext"]
                   )
        assert ct == vector["ciphertext"]

ofb_path = "vectors/cryptography_vectors/ciphers/SEED/seed-ofb.txt"
verify_vectors("OFB", ofb_path)
cfb_path = "vectors/cryptography_vectors/ciphers/SEED/seed-cfb.txt"
verify_vectors("CFB", cfb_path)

Download link: verify_seed.py

2.11. Development
HKDF vector creation

This page documents the code that was used to generate a longer HKDF test vector (1200 bytes) than is available in RFC 5869. All the vectors were generated using OpenSSL and verified with Go.

Creation

The following Python script was run to generate the vector files.

```python
# This file is dual licensed under the terms of the Apache License, Version 2.0, and the BSD License. See the LICENSE file in the root of this repository for complete details.

from __future__ import absolute_import, division, print_function

def _build_vectors():
    output = []
    output.append("COUNT = 0")
    output.append("Hash = SHA-256")
    output.append("IKM = " + binascii.hexlify(IKM).decode("ascii"))
    output.append("salt = ")
    output.append("info = ")
    output.append("L = {}".format(L))
    output.append("OKM = " + binascii.hexlify(OKM).decode("ascii"))
    return \
        \
        \
        \
        
    def _write_file(data, filename):
        with open(filename, 'w') as f:
            f.write(data)

    if __name__ == '__main__':
        _write_file(_build_vectors(), 'hkdf.txt')
```

Download link: generate_hkdf.py

Verification

The following Go code was used to verify the vectors.
package main

import {
    "bufio"
    "bytes"
    "crypto/sha256"
    "encoding/hex"
    "fmt"
    "golang.org/x/crypto/hkdf"
    "io"
    "os"
    "strconv"
    "strings"
}

func unhexlify(s string) []byte {
    bytes, err := hex.DecodeString(s)
    if err != nil {
        panic(err)
    }
    return bytes
}

func verifier(l uint64, ikm, okm []byte) bool {
    hash := sha256.New
    hkdf := hkdf.New(hash, ikm, nil, nil)
    okmComputed := make([]byte, l)
    io.ReadFull(hkdf, okmComputed)
    return bytes.Equal(okmComputed, okm)
}

func validateVectors(filename string) bool {
    vectors, err := os.Open(filename)
    if err != nil {
        panic(err)
    }
    defer vectors.Close()

    var segments []string
    var l uint64
    var ikm, okm string

    scanner := bufio.NewScanner(vectors)
    for scanner.Scan() {
        segments = strings.Split(scanner.Text(), " = ")
        switch {
            case strings.ToUpper(segments[0]) == "L":
                l, err = strconv.ParseUint(segments[1], 10, 64)
                if err != nil {
                    panic(err)
                }
            case strings.ToUpper(segments[0]) == "IKM":
                ikm = segments[1]
            case strings.ToUpper(segments[0]) == "OKM":
                okm = segments[1]
        }
    }
}
return verifier(l, unhexlify(ikm), unhexlify(okm))
}

func main() {
    if validateVectors("vectors/cryptography_vectors/KDF/hkdf-generated.txt") {
        fmt.Println("HKDF OK.")
    } else {
        fmt.Println("HKDF failed.")
        os.Exit(1)
    }
}

Download link: verify_hkdf.go

If official test vectors appear in the future the custom generated vectors should be discarded.

Any vectors generated by this method must also be prefixed with the following header format (substituting the correct information):

```plaintext
# CAST5 CBC vectors built for https://github.com/pyca/cryptography
# Derived from the AESVS MMT test data for CBC
# Verified against the CommonCrypto and Go crypto packages
# Key Length : 128
```

### 2.11.5 C bindings

C bindings are bindings to C libraries, using cffi whenever possible.

Bindings live in `cryptography.hazmat.bindings`.

When modifying the bindings you will need to recompile the C extensions to test the changes. This can be accomplished with `pip install -e .` in the project root. If you do not do this a `RuntimeError` will be raised.

**Style guide**

Don’t name parameters:

```go
/* Good */
long f(long);
/* Bad */
long f(long x);
```

...unless they’re inside a struct:

```go
struct my_struct {
    char *name;
    int number;
    ...
};
```

Include `void` if the function takes no arguments:
Wrap lines at 80 characters like so:

```c
/* Pretend this went to 80 characters */
long f(long, long,
    int *)
```

Include a space after commas between parameters:

```c
/* Good */
long f(int, char *)
/* Bad */
long f(int, char *)
```

Use C-style /* */ comments instead of C++-style //:

```c
// Bad
/* Good */
```

Values set by `#define` should be assigned the appropriate type. If you see this:

```c
#define SOME_INTEGER_LITERAL 0x0;
#define SOME_UNSIGNED_INTEGER_LITERAL 0x0001U;
#define SOME_STRING_LITERAL "hello";
```

...it should be added to the bindings like so:

```c
static const int SOME_INTEGER_LITERAL;
static const unsigned int SOME_UNSIGNED_INTEGER_LITERAL;
static const char *const SOME_STRING_LITERAL;
```

**Adding constant, types, functions...**

You can create bindings for any name that exists in some version of the library you're binding against. However, the project also has to keep supporting older versions of the library. In order to achieve this, binding modules have a `CUSTOMIZATIONS` constant, and there is a `CONDITIONAL_NAMES` constants in `src/cryptography/hazmat/bindings/openssl/_conditional.py`.

Let's say you want to enable quantum transmogrification. The upstream library implements this as the following API:

```c
static const int QM_TRANSMOGRIFICATION_ALIGNMENT_LEFT;
static const int QM_TRANSMOGRIFICATION_ALIGNMENT_RIGHT;
typedef ... QM_TRANSMOGRIFICATION_CTX;
int QM_transmogrify(QM_TRANSMOGRIFICATION_CTX *, int);
```

To start, create a new constant that defines if the actual library has the feature you want, and add it to `TYPES`:

```c
static const long Cryptography_HAS_QUANTUM_TRANSMOGRIFICATION;
```

This should start with `Cryptography_` since we’re adding it in this library. This prevents namespace collisions. Then, define the actual features (constants, types, functions...) you want to expose. If it’s a constant, just add it to `TYPES`:
static const int QM_TRANSMOGRIFICATION_ALIGNMENT_LEFT;
static const int QM_TRANSMOGRIFICATION_ALIGNMENT_RIGHT;

If it’s a struct, add it to TYPES as well. The following is an opaque struct:

typedef ... QM_TRANSMOGRIFICATION_CTX;

... but you can also make some or all items in the struct accessible:

typedef struct {
   /* Fundamental constant k for your particular universe */
   BIGNUM *k;
   ...
} QM_TRANSMOGRIFICATION_CTX;

For functions just add the signature to FUNCTIONS:

int QM_transmogrify(QM_TRANSMOGRIFICATION_CTX *, int);

Then, we define the CUSTOMIZATIONS entry. To do that, we have to come up with a C preprocessor expression that decides whether or not a feature exists in the library. For example:

#ifdef QM_transmogrify

Then, we set the flag that signifies the feature exists:

static const long Cryptography_HAS_QUANTUM_TRANSMOGRIFICATION = 1;

Otherwise, we set that flag to 0:

#else
static const long Cryptography_HAS_QUANTUM_TRANSMOGRIFICATION = 0;

Then, in that #else block, we define the names that aren’t available as dummy values. For an integer constant, use 0:

static const int QM_TRANSMOGRIFICATION_ALIGNMENT_LEFT = 0;
static const int QM_TRANSMOGRIFICATION_ALIGNMENT_RIGHT = 0;

For a function, it’s a bit trickier. You have to define a function pointer of the appropriate type to be NULL:

int (*QM_transmogrify)(QM_TRANSMOGRIFICATION_CTX *, int) = NULL;

(To do that, copy the signature, put a * in front of the function name and wrap it in parentheses, and then put = NULL at the end).

Note how types don’t need to be conditionally defined, as long as all the necessarily type definitions are in place.

Finally, add an entry to CONDITIONAL_NAMES with all of the things you want to conditionally export:

def cryptography_has_quantum_transmogrification():
    return [
        "QM_TRANSMOGRIFICATION_ALIGNMENT_LEFT",
        "QM_TRANSMOGRIFICATION_ALIGNMENT_RIGHT",
        "QM_transmogrify",
    ]

(continues on next page)
Caveats

Sometimes, a set of loosely related features are added in the same version, and it’s impractical to create `#ifdef` statements for each one. In that case, it may make sense to either check for a particular version. For example, to check for OpenSSL 1.1.0 or newer:

```
#if CRYPTOGRAPHY_OPENSSL_110_OR_GREATER
```

Sometimes, the version of a library on a particular platform will have features that you thought it wouldn’t, based on its version. Occasionally, packagers appear to ship arbitrary VCS checkouts. As a result, sometimes you may have to add separate `#ifdef` statements for particular features. This kind of issue is typically only caught by running the tests on a wide variety of systems, which is the job of our continuous integration infrastructure.

2.12 Security

We take the security of cryptography seriously. The following are a set of policies we have adopted to ensure that security issues are addressed in a timely fashion.

2.12.1 Infrastructure

In addition to cryptography’s code, we’re also concerned with the security of the infrastructure we run (primarily cryptography.io). If you discover a security vulnerability in our infrastructure, we ask you to report it using the same procedure.

2.12.2 What is a security issue?

Anytime it’s possible to write code using cryptography’s public API which does not provide the guarantees that a reasonable developer would expect it to based on our documentation.

That’s a bit academic, but basically it means the scope of what we consider a vulnerability is broad, and we do not require a proof of concept or even a specific exploit, merely a reasonable threat model under which cryptography could be attacked.

To give a few examples of things we would consider security issues:

- If a recipe, such as Fernet, made it easy for a user to bypass confidentiality or integrity with the public API (e.g. if the API let a user reuse nonces).
- If, under any circumstances, we used a CSPRNG which wasn’t fork-safe.
- If cryptography used an API in an underlying C library and failed to handle error conditions safely.

Examples of things we wouldn’t consider security issues:
Offering ECB mode for symmetric encryption in the Hazmat layer. Though ECB is critically weak, it is documented as being weak in our documentation.

Using a variable time comparison somewhere, if it’s not possible to articulate any particular program in which this would result in problematic information disclosure.

In general, if you’re unsure, we request that you to default to treating things as security issues and handling them sensitively, the worst thing that can happen is that we’ll ask you to file a public issue.

2.12.3 Reporting a security issue

We ask that you do not report security issues to our normal GitHub issue tracker.

If you believe you’ve identified a security issue with cryptography, please report it to alex.gaynor@gmail.com. Messages may be optionally encrypted with PGP using key fingerprint F7FC 698F AAE2 D2EF BECD E98E D1B3 ADC0 E023 8CA6 (this public key is available from most commonly-used key servers).

Once you’ve submitted an issue via email, you should receive an acknowledgment within 48 hours, and depending on the action to be taken, you may receive further follow-up emails.

2.12.4 Supported Versions

At any given time, we will provide security support for the master branch as well as the most recent release.

2.12.5 New releases for OpenSSL updates

As of versions 0.5, 1.0.1, and 2.0.0, cryptography statically links OpenSSL on Windows, macOS, and Linux respectively, to ease installation. Due to this, cryptography will release a new version whenever OpenSSL has a security or bug fix release to avoid shipping insecure software.

Like all our other releases, this will be announced on the mailing list and we strongly recommend that you upgrade as soon as possible.

2.12.6 Disclosure Process

When we become aware of a security bug in cryptography, we will endeavor to fix it and issue a release as quickly as possible. We will generally issue a new release for any security issue.

The steps for issuing a security release are described in our Doing a release documentation.

2.13 Known security limitations

2.13.1 Lack of secure memory wiping

Memory wiping is used to protect secret data or key material from attackers with access to uninitialized memory. This can be either because the attacker has some kind of local user access or because of how other software uses uninitialized memory.

Python exposes no API for us to implement this reliably and as such almost all software in Python is potentially vulnerable to this attack. The CERT secure coding guidelines assesses this issue as “Severity: medium, Likelihood: unlikely, Remediation Cost: expensive to repair” and we do not consider this a high risk for most users.
2.14 API stability

From its first release, cryptography will have a strong API stability policy.

2.14.1 What does this policy cover?

This policy includes any API or behavior that is documented in this documentation.

2.14.2 What does “stable” mean?

• Public APIs will not be removed or renamed without providing a compatibility alias.
• The behavior of existing APIs will not change.

2.14.3 What doesn’t this policy cover?

• We may add new features, things like the result of \texttt{dir(obj)} or the contents of \texttt{obj.__dict__} may change.
• Objects are not guaranteed to be pickleable, and pickled objects from one version of cryptography may not be loadable in future versions.
• Development versions of cryptography. Before a feature is in a release, it is not covered by this policy and may change.

Security

One exception to our API stability policy is for security. We will violate this policy as necessary in order to resolve a security issue or harden cryptography against a possible attack.

2.14.4 Versioning

This project uses a custom versioning scheme as described below.

Given a version cryptography X.Y.Z,

• X.Y is a decimal number that is incremented for potentially-backwards-incompatible releases.
  – This increases like a standard decimal. In other words, 0.9 is the ninth release, and 1.0 is the tenth (not 0.10). The dividing decimal point can effectively be ignored.
• Z is an integer that is incremented for backward-compatible releases.

Deprecation

From time to time we will want to change the behavior of an API or remove it entirely. In that case, here’s how the process will work:

• In cryptography X.Y the feature exists.
• In cryptography X.Y + 0.1 using that feature will emit a UserWarning.
• In cryptography X.Y + 0.2 using that feature will emit a UserWarning.
• In cryptography X.Y + 0.3 the feature will be removed or changed.

In short, code that runs without warnings will always continue to work for a period of two releases.

From time to time, we may decide to deprecate an API that is particularly widely used. In these cases, we may decide to provide an extended deprecation period, at our discretion.

2.15 Doing a release

Doing a release of cryptography requires a few steps.

2.15.1 Security Releases

In addition to the other steps described below, for a release which fixes a security vulnerability, you should also include the following steps:

• Request a CVE from MITRE. Once you have received the CVE, it should be included in the Changelog. Ideally you should request the CVE before starting the release process so that the CVE is available at the time of the release.

• Ensure that the Changelog entry credits whoever reported the issue.

• The release should be announced on the oss-security mailing list, in addition to the regular announcement lists.

2.15.2 Verifying OpenSSL version

The release process creates wheels bundling OpenSSL for Windows, macOS, and Linux. Check that the Windows and macOS Azure Pipelines builders have the latest version of OpenSSL installed and verify that the latest version is present in both the pyca/cryptography-manylinux1 and pyca/cryptography-manylinux2010 docker containers. If anything is out of date follow the instructions for upgrading OpenSSL.

2.15.3 Upgrading OpenSSL

Use the upgrading OpenSSL issue template.

2.15.4 Bumping the version number

The next step in doing a release is bumping the version number in the software.

• Update the version number in src/cryptography/__about__.py.

• Update the version number in vectors/cryptography_vectors/__about__.py.

• Set the release date in the Changelog.

• Do a commit indicating this.

• Send a pull request with this.

• Wait for it to be merged.
2.15.5 Performing the release

The commit that merged the version number bump is now the official release commit for this release. You will need to have gpg installed and a gpg key in order to do a release. Once this has happened:

- Run `python release.py {version}`.

The release should now be available on PyPI and a tag should be available in the repository.

2.15.6 Verifying the release

You should verify that `pip install cryptography` works correctly:

```python
>>> import cryptography
>>> cryptography.__version__
'...
>>> import cryptography_vectors
>>> cryptography_vectors.__version__
'...
```

Verify that this is the version you just released.

For the Windows wheels check the builds for the `cryptography-wheel-builder` job and verify that the final output for each build shows it loaded and linked the expected OpenSSL version.

2.15.7 Post-release tasks

- Update the version number to the next major (e.g. 0.5.dev1) in `src/cryptography/__about__.py` and `vectors/cryptography_vectors/__about__.py`.
- Close the milestone for the previous release on GitHub.
- Add new Changelog entry with next version and note that it is under active development.
- Send a pull request with these items.
- Check for any outstanding code undergoing a deprecation cycle by looking in `cryptography.utils` for `DeprecatedIn**` definitions. If any exist open a ticket to increment them for the next release.
- Send an email to the mailing list and python-announce announcing the release.

2.16 Community

You can find cryptography all over the web:

- Mailing list
- Source code
- Issue tracker
- Documentation
- IRC: #cryptography-dev on irc.freenode.net

Wherever we interact, we adhere to the Python Community Code of Conduct.


1.7 Glossary

A-label  The ASCII compatible encoded (ACE) representation of an internationalized (unicode) domain name. A-labels begin with the prefix xn--. To create an A-label from a unicode domain string use a library like idna.

classification  The process of verifying that a message was created by a specific individual (or program). Like encryption, authentication can be either symmetric or asymmetric. Authentication is necessary for effective encryption.

bits A bit is binary value – a value that has only two possible states. Typically binary values are represented visually as 0 or 1, but remember that their actual value is not a printable character. A byte on modern computers is 8 bits and represents 256 possible values. In cryptographic applications when you see something say it requires a 128 bit key, you can calculate the number of bytes by dividing by 8. 128 divided by 8 is 16, so a 128 bit key is a 16 byte key.

ciphertext  The encoded data, it’s not user readable. Potential attackers are able to see this.

ciphertext indistinguishability This is a property of encryption systems whereby two encrypted messages aren’t distinguishable without knowing the encryption key. This is considered a basic, necessary property for a working encryption system.

decryption  The process of converting ciphertext to plaintext.

encryption  The process of converting plaintext to ciphertext.

key A secret data is encoded with a function using this key. Sometimes multiple keys are used. These must be kept secret, if a key is exposed to an attacker, any data encrypted with it will be exposed.

nonce A nonce is a number used once. Nonces are used in many cryptographic protocols. Generally, a nonce does not have to be secret or unpredictable, but it must be unique. A nonce is often a random or pseudo-random number (see Random number generation). Since a nonce does not have to be unpredictable, it can also take a form of a counter.

opaque key An opaque key is a type of key that allows you to perform cryptographic operations such as encryption, decryption, signing, and verification, but does not allow access to the key itself. Typically an opaque key is loaded from a hardware security module (HSM).

plaintext  User-readable data you care about.

private key  This is one of two keys involved in public-key cryptography. It can be used to decrypt messages which were encrypted with the corresponding public key, as well as to create signatures, which can be verified with the corresponding public key. These must be kept secret, if they are exposed, all encrypted messages are compromised, and an attacker will be able to forge signatures.

public key  This is one of two keys involved in public-key cryptography. It can be used to encrypt messages for someone possessing the corresponding private key and to verify signatures created with the corresponding private key. This can be distributed publicly, hence the name.

public-key cryptography

asymmetric cryptography  Cryptographic operations where encryption and decryption use different keys. There are separate encryption and decryption keys. Typically encryption is performed using a public key, and it can then be decrypted using a private key. Asymmetric cryptography can also be used to create signatures, which can be generated with a private key and verified with a public key.

symmetric cryptography  Cryptographic operations where encryption and decryption use the same key.

text  This type corresponds to unicode on Python 2 and str on Python 3. This is equivalent to six.text_type.
**U-label** The presentational unicode form of an internationalized domain name. U-labels use unicode characters outside the ASCII range and are encoded as A-labels when stored in certificates.

**Note:** cryptography has not been subjected to an external audit of its code or documentation. If you’re interested in discussing an audit please get in touch.
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