1 Crypto User's Guide

The Crypto application provides functions for computation of message digests, and functions for encryption and decryption.

This product includes software developed by the OpenSSL Project for use in the OpenSSL Toolkit (http://www.openssl.org/).

This product includes cryptographic software written by Eric Young (eay@cryptsoft.com).

This product includes software written by Tim Hudson (tjh@cryptsoft.com).

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1.1 Licenses

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1.2 FIPS mode

This chapter describes FIPS mode support in the crypto application.
1.2 FIPS mode

1.2.1 Background

OpenSSL can be built to provide FIPS 140-2 validated cryptographic services. It is not the OpenSSL application that is validated, but a special software component called the OpenSSL FIPS Object Module. However applications do not use this Object Module directly, but through the regular API of the OpenSSL library.

The crypto application supports using OpenSSL in FIPS mode. In this scenario only the validated algorithms provided by the Object Module are accessible, other algorithms usually available in OpenSSL (like md5) or implemented in the Erlang code (like SRP) are disabled.

1.2.2 Enabling FIPS mode

- Build or install the FIPS Object Module and a FIPS enabled OpenSSL library.

You should read and precisely follow the instructions of the Security Policy and User Guide.

**Warning:**

It is very easy to build a working OpenSSL FIPS Object Module and library from the source. However it **does not** qualify as FIPS 140-2 validated if the numerous restrictions in the Security Policy are not properly followed.

- Configure and build Erlang/OTP with FIPS support:

```
$ cd $ERL_TOP
$ ./otp_build configure --enable-fips ...
  checking for FIPS_mode_set... yes ...
$ make
```

If `FIPS_mode_set` returns `no` the OpenSSL library is not FIPS enabled and crypto won't support FIPS mode either.

- Set the `fips_mode` configuration setting of the crypto application to `true` **before loading the crypto module**.

  The best place is in the `sys.config` system configuration file of the release.

- Start and use the crypto application as usual. However take care to avoid the non-FIPS validated algorithms, they will all throw exception `not_supported`.

Entering and leaving FIPS mode on a node already running crypto is not supported. The reason is that OpenSSL is designed to prevent an application requesting FIPS mode to end up accidentally running in non-FIPS mode. If entering FIPS mode fails (e.g. the Object Module is not found or is compromised) any subsequent use of the OpenSSL API would terminate the emulator.

An on-the-fly FIPS mode change would thus have to be performed in a critical section protected from any concurrently running crypto operations. Furthermore in case of failure all crypto calls would have to be disabled from the Erlang or nif code. This would be too much effort put into this not too important feature.

1.2.3 Incompatibilities with regular builds

The Erlang API of the crypto application is identical regardless of building with or without FIPS support. However the nif code internally uses a different OpenSSL API.

This means that the context (an opaque type) returned from streaming crypto functions (`hash_`(init|update|final), `hmac_`(init|update|final) and `stream_`(init|encrypt|decrypt)) is different and incompatible with regular builds when compiling crypto with FIPS support.
1.2.4 Common caveats

In FIPS mode non-validated algorithms are disabled. This may cause some unexpected problems in application relying on crypto.

**Warning:**

Do not try to work around these problems by using alternative implementations of the missing algorithms! An application can only claim to be using a FIPS 140-2 validated cryptographic module if it uses it exclusively for every cryptographic operation.

Restrictions on key sizes

Although public key algorithms are supported in FIPS mode they can only be used with secure key sizes. The Security Policy requires the following minimum values:

- **RSA**: 1024 bit
- **DSS**: 1024 bit
- **EC algorithms**: 160 bit

Restrictions on elliptic curves

The Erlang API allows using arbitrary curve parameters, but in FIPS mode only those allowed by the Security Policy shall be used.

Avoid md5 for hashing

Md5 is a popular choice as a hash function, but it is not secure enough to be validated. Try to use sha instead wherever possible.

For exceptional, non-cryptographic use cases one may consider switching to `erlang:md5/1` as well.

Certificates and encrypted keys

As md5 is not available in FIPS mode it is only possible to use certificates that were signed using sha hashing. When validating an entire certificate chain all certificates (including the root CA’s) must comply with this rule.

For similar dependency on the md5 and des algorithms most encrypted private keys in PEM format do not work either. However, the PBES2 encryption scheme allows the use of stronger FIPS verified algorithms which is a viable alternative.

SNMP v3 limitations

It is only possible to use `usmHMACSHAAuthProtocol` and `usmAesCfb128Protocol` for authentication and privacy respectively in FIPS mode. The snmp application however won't restrict selecting disabled protocols in any way, and using them would result in run time crashes.

TLS 1.2 is required

All SSL and TLS versions prior to TLS 1.2 use a combination of md5 and sha1 hashes in the handshake for various purposes:

- Authenticating the integrity of the handshake messages.
- In the exchange of DH parameters in cipher suites providing non-anonymous PFS (perfect forward secrecy).
- In the PRF (pseud-random function) to generate keying materials in cipher suites not using PFS.
OpenSSL handles these corner cases in FIPS mode, however the Erlang crypto and ssl applications are not prepared for them and therefore you are limited to TLS 1.2 in FIPS mode.

On the other hand it worth mentioning that at least all cipher suites that would rely on non-validated algorithms are automatically disabled in FIPS mode.

**Note:**
Certificates using weak (md5) digests may also cause problems in TLS. Although TLS 1.2 has an extension for specifying which type of signatures are accepted, and in FIPS mode the ssl application will use it properly, most TLS implementations ignore this extension and simply send whatever certificates they were configured with.

## 1.3 Engine Load

This chapter describes the support for loading encryption engines in the crypto application.

### 1.3.1 Background

OpenSSL exposes an Engine API, which makes it possible to plug in alternative implementations for some or all of the cryptographic operations implemented by OpenSSL. When configured appropriately, OpenSSL calls the engine's implementation of these operations instead of its own.

Typically, OpenSSL engines provide a hardware implementation of specific cryptographic operations. The hardware implementation usually offers improved performance over its software-based counterpart, which is known as cryptographic acceleration.

**Note:**
The file name requirement on the engine dynamic library can differ between SSL versions.

### 1.3.2 Use Cases

**Dynamically load an engine from default directory**

If the engine is located in the OpenSSL/LibreSSL installation engines directory.

```erlang
1> {ok, Engine} = crypto:engine_load({"otp_test_engine"}, [], []). {ok, #Ref}
```

**Load an engine with the dynamic engine**

Load an engine with the help of the dynamic engine by giving the path to the library.

```erlang
2> {ok, Engine} = crypto:engine_load({"dynamic"}, [{"SO_PATH"}, 
    
```

```erlang
"/some/path/otp_test_engine.so"}, 
    
```

```erlang
{"ID"}, 
```

```erlang
{"MD5"}], 
```

```erlang
{"LOAD"}], 
```

```erlang
[)]. {ok, #Ref}
```

**Load an engine and replace some methods**

Load an engine with the help of the dynamic engine and just replace some engine methods.
1.4 Engine Stored Keys

This chapter describes the support in the crypto application for using public and private keys stored in encryption engines.

1.4.1 Background

OpenSSL exposes an Engine API, which makes it possible to plug in alternative implementations for some of the cryptographic operations implemented by OpenSSL. See the chapter Engine Load for details and how to load an Engine.

An engine could among other tasks provide a storage for private or public keys. Such a storage could be made safer than the normal file system. Those techniques are not described in this User's Guide. Here we concentrate on how to use private or public keys stored in such an engine.

The storage engine must call ENGINE_set_load_privkey_function and ENGINE_set_load_pubkey_function. See the OpenSSL cryptolib's manpages.

OTP/Crypto requires that the user provides two or three items of information about the key. The application used by the user is usually on a higher level, for example in SSL. If using the crypto application directly, it is required that:

- an Engine is loaded, see the chapter on Engine Load or the Reference Manual
- a reference to a key in the Engine is available. This should be an Erlang string or binary and depends on the Engine loaded
1.5 Algorithm Details

- An Erlang map is constructed with the Engine reference, the key reference and possibly a key passphrase if needed by the Engine. See the Reference Manual for details of the map.

1.4.2 Use Cases

Sign with an engine stored private key

This example shows how to construct a key reference that is used in a sign operation. The actual key is stored in the engine that is loaded at prompt 1.

```
1> ok, EngineRef = crypto:engine_load(....).
...
ok, #Ref<0.2399045421.3028942852.173962>}
2> PrivKey = #{engine => EngineRef,
    key_id => "id of the private key in Engine"}.
...
3> Signature = crypto:sign(rsa, sha, "The message"), PrivKey).
<<65,6,125,254,54,233,84,77,83,63,168,28,169,214,121,76,
  207,177,124,183,156,189,169,243,36,79,125,230,231,...>>
```

Verify with an engine stored public key

Here the signature and message in the last example is verified using the public key. The public key is stored in an engine, only to exemplify that it is possible. The public key could of course be handled openly as usual.

```
4> PublicKey = #{engine => EngineRef,
    key_id => "id of the public key in Engine"}.
...
5> crypto:verify(rsa, sha, "The message"), Signature, PublicKey).
true
6>
```

Using a password protected private key

The same example as the first sign example, except that a password protects the key down in the Engine.

```
6> PrivKeyPwd = #{engine => EngineRef,
    key_id => "id of the pwd protected private key in Engine",
    password => "password"}.
...
7> crypto:sign(rsa, sha, "The message"), PrivKeyPwd).
<<140,80,168,101,234,211,146,183,231,190,169,82,85,163,
  175,106,77,241,141,128,72,149,181,181,194,154,175,76,
  223,...>>
8>
```

1.5 Algorithm Details

This chapter describes details of algorithms in the crypto application.

The tables only documents the supported cryptos and key lengths. The user should not draw any conclusion on security from the supplied tables.

1.5.1 Ciphers

A cipher in the new api is categorized as either cipher_no_iv(), cipher_jiv() or cipher_aead(). The letters IV are short for Initialization Vector and AEAD is an abbreviation of Authenticated Encryption with Associated Data.

Due to irregular naming conventions, some cipher names in the old api are substituted by new names in the new api. For a list of retired names, see Retired cipher names.
To dynamically check availability, check that the name in the Cipher and Mode column is present in the list returned by crypto:supports(ciphers).

**Ciphers without an IV - cipher_no_iv()**

To be used with:
- crypto_one_time/4
- crypto_init/3

The ciphers are:

<table>
<thead>
<tr>
<th>Cipher and Mode</th>
<th>Key length [bytes]</th>
<th>Block size [bytes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_128_ecb</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>aes_192_ecb</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>aes_256_ecb</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>blowfish_ecb</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>des_ecb</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>rc4</td>
<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.1: Ciphers without IV

**Ciphers with an IV - cipher_iv()**

To be used with:
- crypto_one_time/5
- crypto_init/4
- crypto_dyn_iv_init/3

The ciphers are:

<table>
<thead>
<tr>
<th>Cipher and Mode</th>
<th>Key length [bytes]</th>
<th>IV length [bytes]</th>
<th>Block size [bytes]</th>
<th>Limited to OpenSSL versions</th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_128_cbc</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>aes_192_cbc</td>
<td>24</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>aes_256_cbc</td>
<td>32</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>aes_128_cfb8</td>
<td>16</td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>aes_192_cfb8</td>
<td>24</td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>aes_256_cfb8</td>
<td>32</td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
1.5 Algorithm Details

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_128_cfb128</td>
<td>16</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aes_192_cfb128</td>
<td>24</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aes_256_cfb128</td>
<td>32</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aes_128_ctr</td>
<td>16</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aes_192_ctr</td>
<td>24</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aes_256_ctr</td>
<td>32</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>blowfish_cbc</td>
<td>16</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>blowfish_cfb64</td>
<td>16</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>blowfish_ofb64</td>
<td>16</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chacha20</td>
<td>32</td>
<td>16</td>
<td>1</td>
<td></td>
<td></td>
<td>#1.1.0d</td>
</tr>
<tr>
<td>des_cbc</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>des_ede3_cbc</td>
<td>24</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>des_cfb</td>
<td>8</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>des_ede3_cfb</td>
<td>24</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rc2_cbc</td>
<td>16</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2: Ciphers with IV

Ciphers with AEAD - cipher_aead()

To be used with:
- crypto_one_time_aead/6
- crypto_one_time_aead/7

The ciphers are:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_128_ccm</td>
<td>16</td>
<td>7-13</td>
<td>any</td>
<td>even 4-16 default: 12</td>
<td>any</td>
<td>#1.0.1</td>
</tr>
<tr>
<td>aes_192_ccm</td>
<td>24</td>
<td>7-13</td>
<td>any</td>
<td>even 4-16 default: 12</td>
<td>any</td>
<td>#1.0.1</td>
</tr>
<tr>
<td>aes_256_ccm</td>
<td>32</td>
<td>7-13</td>
<td>any</td>
<td>even 4-16 default: 12</td>
<td>any</td>
<td>#1.0.1</td>
</tr>
</tbody>
</table>
### 1.5 Algorithm Details

#### AEAD ciphers

<table>
<thead>
<tr>
<th>Cipher and Mode</th>
<th>Key length [bytes]</th>
<th>Max Mac Length (= default length) [bytes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_128_gcm</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>aes_192_gcm</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>aes_256_gcm</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>chacha20_poly1305</td>
<td>1-16</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 5.3: AEAD ciphers

#### 1.5.2 Message Authentication Codes (MACs)

To be used in mac/4 and related functions.

**CMAC**

CMAC with the following ciphers are available with OpenSSL 1.0.1 or later if not disabled by configuration.

To dynamically check availability, check that the name `cmac` is present in the list returned by `crypto:supports(macs)`.

Also check that the name in the `Cipher and Mode` column is present in the list returned by `crypto:supports(ciphers)`.

<table>
<thead>
<tr>
<th>Cipher and Mode</th>
<th>Key length [bytes]</th>
<th>Max Mac Length (= default length) [bytes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_128_cbc</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>aes_192_cbc</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>aes_256_cbc</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>aes_128_ecb</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>aes_192_ecb</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>aes_256_ecb</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>blowfish_cbc</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>blowfish_ecb</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>des_cbc</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>des_ecb</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>des_ede3_cbc</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>rc2_cbc</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 5.4: CMAC cipher key lengths
1.5  Algorithm Details

HMAC
Available in all OpenSSL compatible with Erlang CRYPTO if not disabled by configuration.
To dynamically check availability, check that the name hmac is present in the list returned by crypto:supports(macs) and that the hash name is present in the list returned by crypto:supports(hashs).

<table>
<thead>
<tr>
<th>Hash</th>
<th>Max Mac Length (= default length) [bytes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>sha</td>
<td>20</td>
</tr>
<tr>
<td>sha224</td>
<td>28</td>
</tr>
<tr>
<td>sha256</td>
<td>32</td>
</tr>
<tr>
<td>sha384</td>
<td>48</td>
</tr>
<tr>
<td>sha512</td>
<td>64</td>
</tr>
<tr>
<td>sha3_224</td>
<td>28</td>
</tr>
<tr>
<td>sha3_256</td>
<td>32</td>
</tr>
<tr>
<td>sha3_384</td>
<td>48</td>
</tr>
<tr>
<td>sha3_512</td>
<td>64</td>
</tr>
<tr>
<td>blake2b</td>
<td>64</td>
</tr>
<tr>
<td>blake2s</td>
<td>32</td>
</tr>
<tr>
<td>md4</td>
<td>16</td>
</tr>
<tr>
<td>md5</td>
<td>16</td>
</tr>
<tr>
<td>ripemd160</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 5.5: HMAC output sizes

POLY1305
POLY1305 is available with OpenSSL 1.1.1 or later if not disabled by configuration.
To dynamically check availability, check that the name poly1305 is present in the list returned by crypto:supports(macs).
The poly1305 mac wants an 32 bytes key and produces a 16 byte MAC by default.

1.5.3 Hash
To dynamically check availability, check that the wanted name in the Names column is present in the list returned by crypto:supports(hashs).
1.5 Algorithm Details

<table>
<thead>
<tr>
<th>Type</th>
<th>Names</th>
<th>Limited to OpenSSL versions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHA1</td>
<td>sha</td>
<td></td>
</tr>
<tr>
<td>SHA2</td>
<td>sha224, sha256, sha384, sha512</td>
<td></td>
</tr>
<tr>
<td>SHA3</td>
<td>sha3_224, sha3_256, sha3_384, sha3_512</td>
<td>#1.1.1</td>
</tr>
<tr>
<td>MD4</td>
<td>md4</td>
<td></td>
</tr>
<tr>
<td>MD5</td>
<td>md5</td>
<td></td>
</tr>
<tr>
<td>RIPEMD</td>
<td>ripemd160</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.6:

1.5.4 Public Key Cryptography

RSA

RSA is available with all OpenSSL versions compatible with Erlang CRYPTO if not disabled by configuration. To dynamically check availability, check that the atom rsa is present in the list returned by crypto:supports(public_keys).

**Warning:**

The RSA options are experimental.
The exact set of options and their syntax may be changed without prior notice.

<table>
<thead>
<tr>
<th>Option</th>
<th>sign/verify</th>
<th>public encrypt private decrypt</th>
<th>private encrypt public decrypt</th>
</tr>
</thead>
<tbody>
<tr>
<td>{rsa_padding,rsa_x931_padding}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{rsa_padding,rsa_pkcs1_padding}</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>{rsa_padding,rsa_pkcs1_oaep_padding}</td>
<td></td>
<td>x (2)</td>
<td>x (2)</td>
</tr>
<tr>
<td>{rsa_pss_saltlen, -2..}</td>
<td></td>
<td>x (2)</td>
<td></td>
</tr>
<tr>
<td>{rsa_mgf1_md, atom()}</td>
<td></td>
<td>x (2)</td>
<td></td>
</tr>
<tr>
<td>{rsa_oaep_label, binary()}</td>
<td></td>
<td>x (2)</td>
<td></td>
</tr>
<tr>
<td>{rsa_oaep_md, atom()}</td>
<td></td>
<td>x (2)</td>
<td></td>
</tr>
<tr>
<td>{rsa_padding,rsa_no_padding}</td>
<td></td>
<td>x (2)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.7:
1.6 New and Old API

Notes:
• (1) OpenSSL # 1.0.0
• (2) OpenSSL # 1.0.1
• (3) OpenSSL # 1.1.0

DSS
DSS is available with OpenSSL versions compatible with Erlang CRYPTO if not disabled by configuration. To
dynamically check availability, check that the atom dss is present in the list returned by crypto:supports(public_keys).

ECDSA
ECDSA is available with OpenSSL 0.9.8o or later if not disabled by configuration. To dynamically check availability,
check that the atom ecdsa is present in the list returned by crypto:supports(public_keys). If the atom ec_gf2m also
is present, the characteristic two field curves are available.
The actual supported named curves could be checked by examining the list returned by crypto:supports(curves).

EdDSA
EdDSA is available with OpenSSL 1.1.1 or later if not disabled by configuration. To dynamically check availability,
check that the atom eddsa is present in the list returned by crypto:supports(public_keys).
Support for the curves ed25519 and ed448 is implemented. The actual supported named curves could be checked by
examining the list with the list returned by crypto:supports(curves).

Diffie-Hellman
Diffie-Hellman computations are available with OpenSSL versions compatible with Erlang CRYPTO if not disabled
by configuration. To dynamically check availability, check that the atom dh is present in the list returned by
crypto:supports(public_keys).

Elliptic Curve Diffie-Hellman
Elliptic Curve Diffie-Hellman is available with OpenSSL 0.9.8o or later if not disabled by configuration. To
dynamically check availability, check that the atom ecdh is present in the list returned by
crypto:supports(public_keys).
The Edward curves x25519 and x448 are supported with OpenSSL 1.1.1 or later if not disabled by configuration.
The actual supported named curves could be checked by examining the list returned by crypto:supports(curves).

1.6 New and Old API
This chapter describes the new api to encryption and decryption.

1.6.1 Background
The CRYPTO app has evolved during its lifetime. Since also the OpenSSL cryptolib has changed the API several
times, there are parts of the CRYPTO app that uses a very old one internally and other parts that uses the latest one.
The internal definitions of e.g cipher names was a bit hard to maintain.
It turned out that using the old api in the new way (more about that later), and still keep it backwards compatible, was
not possible. Specially as more precision in the error messages is desired it could not be combined with the old standard.
Therefore the old api (see next section) is kept for now but internally implemented with new primitives.
1.6.2 The old API

The old functions - deprecated from 23.0 and removed from OTP 24.0 - are for chippers:

- block_encrypt/3
- block_encrypt/4
- block_decrypt/3
- block_decrypt/4
- stream_init/2
- stream_init/3
- stream_encrypt/2
- stream_decrypt/2
- next_iv/2
- next_iv/3

for lists of supported algorithms:

- supports/0

and for MACs (Message Authentication Codes):

- cmac/3
- cmac/4
- hmac/3
- hmac/4
- hmac_init/2
- hmac_update/2
- hmac_final/1
- hmac_final_n/2
- poly1305/2

1.6.3 The new API

Encryption and decryption

The new functions for encrypting or decrypting one single binary are:

- crypto_one_time/4
- crypto_one_time/5
- crypto_one_time_aead/6
- crypto_one_time_aead/7

In those functions the internal crypto state is first created and initialized with the cipher type, the key and possibly other data. Then the single binary is encrypted or decrypted, the crypto state is de-allocated and the result of the crypto operation is returned.

The crypto_one_time_aead functions are for the ciphers of mode ccm or gcm, and for the cipher chacha20-poly1305.

For repeated encryption or decryption of a text divided in parts, where the internal crypto state is initialized once, and then many binaries are encrypted or decrypted with the same state, the functions are:

- crypto_init/4
- crypto_init/3
1.6 New and Old API

- `crypto_update/2`
- `crypto_final/1`

The `crypto_init` initialises an internal cipher state, and one or more calls of `crypto_update` does the actual encryption or decryption. Note that AEAD ciphers can’t be handled this way due to their nature.

For repeated encryption or decryption of a text divided in parts where the same cipher and same key is used, but a new initialization vector (nonce) should be applied for each part, the functions are:

- `crypto_dyn_iv_init/3`
- `crypto_dyn_iv_update/3`

An example of where those functions are needed, is when handling the TLS protocol.

If padding was not enabled, the call to `crypto_final/1` may be excluded.

For information about available algorithms, use:

- `supports/1`
- `hash_info/1`
- `cipher_info/1`

The `next_iv/2` and `next_iv/3` are not needed since the `crypto_init` and `crypto_update` includes this functionality.

MACs (Message Authentication Codes)

The new functions for calculating a MAC of a single piece of text are:

- `mac/3`
- `mac/4`
- `macN/4`
- `macN/5`

For calculating a MAC of a text divided in parts use:

- `mac_init/2`
- `mac_init/3`
- `mac_update/2`
- `mac_final/1`
- `mac_finalN/2`

1.6.4 Examples of the new api

Examples of `crypto_init/4` and `crypto_update/2`

The functions `crypto_init/4` and `crypto_update/2` are intended to be used for encrypting or decrypting a sequence of blocks. First one call of `crypto_init/4` initialises the crypto context. One or more calls `crypto_update/2` does the actual encryption or decryption for each block.

This example shows first the encryption of two blocks and then decryptions of the cipher text, but divided into three blocks just to show that it is possible to divide the plain text and cipher text differently for some ciphers:
1.6 New and Old API

```
1> crypto:start().
ok
2> Key = <<1:128>>.
<<0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1>>
3> IV = <<0:128>>.
<<0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0>>
4> StateEnc = crypto:crypto_init(aes_128_ctr, Key, IV, true). % encrypt -> true
   #Ref<0.3768901617.112860993.124047>
5> crypto:crypto_update(StateEnc, <<"First bytes">>).
   <<67,44,216,166,25,130,203,5,66,6,162>>
6> crypto:crypto_update(StateEnc, <<"Second bytes">>).
   <<16,79,94,115,234,197,94,253,16,144,151,41,16,79,94,115,234,197,94,253,16,144,151,41>>
7> StateDec = crypto:crypto_init(aes_128_ctr, Key, IV, false). % decrypt -> false
   #Ref<0.3768901617.112860994.124255>
8> crypto:crypto_update(StateDec, <<67,44,216,166,25,130,203>>).
   "First bytes"
   "Second bytes"
10> crypto:crypto_update(StateDec, <<41>>).
   "s"
```

Note that the internal data that the `StateEnc` and `StateDec` references are destructively updated by the calls to `crypto_update/2`. This is to gain time in the calls of the nifs interfacing the cryptolib. In a loop where the state is saved in the loop's state, it also saves one update of the loop state per crypto operation.

For example, a simple server receiving text parts to encrypt and send the result back to the one who sent them (the Requester):

```
encode(Crypto, Key, IV) ->
    crypto_loop(crypto:crypto_init(Crypto, Key, IV, true)).

crypto_loop(State) ->
    receive
        {Text, Requester} ->
            Requester ! crypto:crypto_update(State, Text),
            loop(State)
    end.
```

**Example of crypto_one_time/5**

The same example as in the previous section, but now with one call to `crypto_one_time/5`:

```
1> Key = <<1:128>>.
<<0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1>>
2> IV = <<0:128>>.
<<0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0>>
3> Txt = ["First bytes", "Second bytes"].
4> crypto:crypto_one_time(aes_128_ctr, Key, IV, Txt, true).
```

The `"First bytes", "Second bytes"` could of course have been one single binary: `"First bytesSecond bytes"`.

**Example of crypto_one_time_aead/6**

The same example as in the previous section, but now with one call to `crypto_one_time_aead/6`:
1.6 New and Old API

The [["First bytes"],["Second bytes"]]

Example of mac_init mac_update and mac_final

and compare the result with a single calculation just for this example:

1.6.5 Retired cipher names

This table lists the retired cipher names in the first column and suggests names to replace them with in the second column.

The new names follow the OpenSSL libcrypto names. The format is ALGORITM_KEYSIZE_MODE.

Examples of algorithms are aes, chacha20 and des. The keysize is the number of bits and examples of the mode are cbc, ctr and gcm. The mode may be followed by a number depending on the mode. An example is the ccm mode which has a variant called ccm8 where the so called tag has a length of eight bits.

The old names had by time lost any common naming convention which the new names now introduces. The new names include the key length which improves the error checking in the lower levels of the crypto application.

<table>
<thead>
<tr>
<th>Instead of:</th>
<th>Use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_cbc128</td>
<td>aes_128_cbc</td>
</tr>
</tbody>
</table>
### New and Old API

<table>
<thead>
<tr>
<th>New API</th>
<th>Old API</th>
</tr>
</thead>
<tbody>
<tr>
<td>aes_cbc256</td>
<td>aes_256_cbc</td>
</tr>
<tr>
<td>aescbc</td>
<td>aes_128_cbc, aes_192_cbc, aes_256_cbc</td>
</tr>
<tr>
<td>aes_ccm</td>
<td>aes_128_ccm, aes_192_ccm, aes_256_ccm</td>
</tr>
<tr>
<td>aes_cfb128</td>
<td>aes_128_cfb128, aes_192_cfb128, aes_256_cfb128</td>
</tr>
<tr>
<td>aes_cfb8</td>
<td>aes_128_cfb8, aes_192_cfb8, aes_256_cfb8</td>
</tr>
<tr>
<td>aes_ctr</td>
<td>aes_128_ctr, aes_192_ctr, aes_256_ctr</td>
</tr>
<tr>
<td>aes_gcm</td>
<td>aes_128_gcm, aes_192_gcm, aes_256_gcm</td>
</tr>
<tr>
<td>des3_cbc</td>
<td>des_ede3_cbc</td>
</tr>
<tr>
<td>des3_cbf</td>
<td>des_ede3_cfb</td>
</tr>
<tr>
<td>des3_cfb</td>
<td>des_ede3_cfb</td>
</tr>
<tr>
<td>des_ede3</td>
<td>des_ede3_cbc</td>
</tr>
<tr>
<td>des_ede3_cbf</td>
<td>des_ede3_cfb</td>
</tr>
</tbody>
</table>

Table 6.1:
2 Reference Manual

The Crypto Application provides functions for computation of message digests, and encryption and decryption functions.

This product includes software developed by the OpenSSL Project for use in the OpenSSL Toolkit (http://www.openssl.org/).

This product includes cryptographic software written by Eric Young (eay@cryptsoft.com).

This product includes software written by Tim Hudson (tjh@cryptsoft.com).

For full OpenSSL and SSLeay license texts, see Licenses.
The purpose of the Crypto application is to provide an Erlang API to cryptographic functions, see crypto(3). Note that the API is on a fairly low level and there are some corresponding API functions available in public_key(3), on a higher abstraction level, that uses the crypto application in its implementation.

**DEPENDENCIES**

The current crypto implementation uses nifs to interface OpenSSLs crypto library and may work with limited functionality with as old versions as OpenSSL 0.9.8c. FIPS mode support requires at least version 1.0.1 and a FIPS capable OpenSSL installation. We recommend using a version that is officially supported by the OpenSSL project. API compatible backends like LibreSSL should also work.

Source releases of OpenSSL can be downloaded from the OpenSSL project home page, or mirror sites listed there.

**CONFIGURATION**

The following configuration parameters are defined for the crypto application. See app(3) for more information about configuration parameters.

- `fips_mode = boolean()`
  
  Specifies whether to run crypto in FIPS mode. This setting will take effect when the nif module is loaded. If FIPS mode is requested but not available at run time the nif module and thus the crypto module will fail to load. This mechanism prevents the accidental use of non-validated algorithms.

- `rand_cache_size = integer()`
  
  Sets the cache size in bytes to use by `crypto:rand_seed_alg(crypto_cache)` and `crypto:rand_seed_alg_s(crypto_cache)`. This parameter is read when a seed function is called, and then kept in generators state object. It has a rather small default value that causes reads of strong random bytes about once per hundred calls for a random value. The set value is rounded up to an integral number of words of the size these seed functions use.

**SEE ALSO**

application(3)
This module provides a set of cryptographic functions.

Hash functions

- SHA1, SHA2
  - Secure Hash Standard [FIPS PUB 180-4]
- SHA3
  - SHA-3 Standard: Permutation-Based Hash and Extendable-Output Functions [FIPS PUB 202]
- Blake2
  - Blake2 — fast secure hashing
- MD5
  - The MD5 Message Digest Algorithm [RFC 1321]
- MD4
  - The MD4 Message Digest Algorithm [RFC 1320]

MACs - Message Authentication Codes

- Hmac functions
  - Keyed-Hashing for Message Authentication [RFC 2104]
- Cmac functions
  - The AES-CMAC Algorithm [RFC 4493]
- POLY1305
  - ChaCha20 and Poly1305 for IETF Protocols [RFC 7539]

Symmetric Ciphers

- DES, 3DES and AES
  - Block Cipher Techniques [NIST]
- Blowfish
- Chacha20
  - ChaCha20 and Poly1305 for IETF Protocols [RFC 7539]
- Chacha20_poly1305
  - ChaCha20 and Poly1305 for IETF Protocols [RFC 7539]

Modes

- ECB, CBC, CFB, OFB and CTR
  - Recommendation for Block Cipher Modes of Operation: Methods and Techniques [NIST SP 800-38A]
- GCM
  - Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC [NIST SP 800-38D]
- CCM
  - Recommendation for Block Cipher Modes of Operation: The CCM Mode for Authentication and Confidentiality [NIST SP 800-38C]
Asymmetric Ciphers - Public Key Techniques

**RSA**
- PKCS #1: RSA Cryptography Specifications [RFC 3447]

**DSS**
- Digital Signature Standard (DSS) [FIPS 186-4]

**ECDSA**
- Elliptic Curve Digital Signature Algorithm [ECDSA]

**SRP**
- The SRP Authentication and Key Exchange System [RFC 2945]

**Note:**
The actual supported algorithms and features depends on their availability in the actual libcrypto used. See the crypto (App) about dependencies.
Enabling FIPS mode will also disable algorithms and features.

The CRYPTO User's Guide has more information on FIPS, Engines and Algorithm Details like key lengths.

**Data Types**

**Ciphers**

\[
\text{cipher()} = \text{cipher\_no\_iv()} | \text{cipher\_iv()} | \text{cipher\_aead()}
\]

\[
\text{cipher\_no\_iv()} =
\begin{align*}
\text{aes\_128\_ecb} & | \text{aes\_192\_ecb} & | \text{aes\_256\_ecb} & | \text{aes\_ecb} & |
\text{blowfish\_ecb} & | \text{des\_ecb} & | \text{rc4}
\end{align*}
\]

\[
\text{cipher\_iv()} =
\begin{align*}
\text{aes\_128\_cbc} & | \text{aes\_192\_cbc} & | \text{aes\_256\_cbc} & | \text{aes\_cbc} & |
\text{aes\_cfb128} & | \text{aes\_192\_cfb128} & | \text{aes\_256\_cfb128} & |
\text{aes\_cfb8} & | \text{aes\_128\_ctr} & | \text{aes\_192\_ctr} & | \text{aes\_256\_ctr} & | \text{aes\_ctr} & |
\text{blowfish\_cbc} & | \text{blowfish\_cfb64} & | \text{blowfish\_ofb64} & | \text{chacha20} & |
\text{des\_ede3\_cbc} & | \text{des\_ede3\_cfb} & | \text{des\_cbc} & | \text{des\_cfb} & | \text{rc2\_cbc}
\end{align*}
\]

\[
\text{cipher\_aead()} =
\begin{align*}
\text{aes\_128\_ccm} & | \text{aes\_192\_ccm} & | \text{aes\_256\_ccm} & | \text{aes\_ccm} & |
\text{aes\_128\_gcm} & | \text{aes\_192\_gcm} & | \text{aes\_256\_gcm} & | \text{aes\_gcm} & |
\text{chacha20\_poly1305}
\end{align*}
\]

Ciphers known by the CRYPTO application.

Note that this list might be reduced if the underlying libcrypto does not support all of them.

\[
\text{crypto\_opts()} = \text{boolean()} | [\text{crypto\_opt()}]
\]

\[
\text{crypto\_opt()} = \{\text{encrypt, boolean()}\} | \{\text{padding, padding()}\}
\]

Selects encryption ({\text{encrypt, true}}) or decryption ({\text{encrypt, false}}).

\[
\text{padding()} = \text{cryptolib\_padding()} | \text{otp\_padding()}
\]

This option handles padding in the last block. If not set, no padding is done and any bytes in the last unfilled block is silently discarded.
crypto

\texttt{cryptolib\_padding()} = none \mid \texttt{pkcs\_padding}

The \texttt{cryptolib\_padding} are paddings that may be present in the underlying cryptolib linked to the Erlang/OTP crypto app.

For OpenSSL, see the \texttt{OpenSSL documentation} and find \texttt{EVP\_CIPHER\_CTX\_set\_padding()} in cryptolib for your linked version.

\texttt{otp\_padding()} = zero \mid random

Erlang/OTP adds a either padding of zeroes or padding with random bytes.

\textbf{Digests and hash}

\texttt{hash\_algorithm()} =
\begin{verbatim}
sha1() | sha2() | sha3() | blake2() | ripemd160 | compatibility\_only\_hash()
\end{verbatim}

\texttt{hmac\_hash\_algorithm()} =
\begin{verbatim}
sha1() | sha2() | sha3() | compatibility\_only\_hash()
\end{verbatim}

\texttt{cmac\_cipher\_algorithm()} =
\begin{verbatim}
aes\_128\_cbc | aes\_192\_cbc | aes\_256\_cbc | aes\_cbc |
aes\_128\_cfb128 | aes\_192\_cfb128 | aes\_256\_cfb128 |
aes\_cfb128 | aes\_128\_cfb8 | aes\_192\_cfb8 | aes\_256\_cfb8 |
aes\_cfb8 | blowfish\_cbc | des\_cbc | des\_ede3\_cbc | rc2\_cbc
\end{verbatim}

\texttt{rsa\_digest\_type()} = sha1() \mid sha2() \mid md5 \mid ripemd160
\texttt{dss\_digest\_type()} = sha1() \mid sha2()
\texttt{ecdsa\_digest\_type()} = sha1() \mid sha2()

\texttt{sha1()} = sha
\texttt{sha2()} = sha224 \mid sha256 \mid sha384 \mid sha512
\texttt{sha3()} = sha3\_224 \mid sha3\_256 \mid sha3\_384 \mid sha3\_512
\texttt{blake2()} = blake2b \mid blake2s
\texttt{compatibility\_only\_hash()} = md5 \mid md4

The \texttt{compatibility\_only\_hash()} algorithms are recommended only for compatibility with existing applications.

\textbf{Elliptic Curves}

\texttt{ec\_named\_curve()} =
\begin{verbatim}
brainpoolP160r1 \mid brainpoolP160t1 \mid brainpoolP192r1 \mid
brainpoolP192t1 \mid brainpoolP224r1 \mid brainpoolP224t1 \mid
brainpoolP256r1 \mid brainpoolP256t1 \mid brainpoolP320r1 \mid
brainpoolP320t1 \mid brainpoolP384r1 \mid brainpoolP384t1 \mid
brainpoolP512r1 \mid brainpoolP512t1 \mid c2pnb163v1 \mid c2pnb163v2 \mid
c2pnb163v3 \mid c2pnb176v1 \mid c2pnb208w1 \mid c2pnb272w1 \mid
c2pnb304w1 \mid c2pnb368w1 \mid c2tnb191v1 \mid c2tnb191v2 \mid
c2tnb191v3 \mid c2tnb239v1 \mid c2tnb239v2 \mid c2tnb239v3 \mid
c2tnb359v1 \mid c2tnb431r1 \mid ipsec3 \mid ipsec4 \mid prime192v1 \mid
prime192v2 \mid prime192v3 \mid prime239v1 \mid prime239v2 \mid
prime239v3 \mid prime256v1 \mid secp112r1 \mid secp112r2 \mid secp128r1 \mid
secp128r2 \mid secp160k1 \mid secp160r1 \mid secp160r2 \mid secp192k1
\end{verbatim}
crypto

secp192r1 | secp224k1 | secp224r1 | secp256k1 | secp256r1 |
secp384r1 | secp521r1 | sect113r1 | sect113r2 | sect131r1 |
sect131r2 | sect163k1 | sect163r1 | sect163r2 | sect193r1 |
sect193r2 | sect233k1 | sect233r1 | sect239k1 | sect283k1 |
sect283r1 | sect409k1 | sect409r1 | sect571k1 | sect571r1 |
wtls1 | wtls10 | wtls11 | wtls12 | wtls3 | wtls4 | wtls5 |
wtls6 | wtls7 | wtls8 | wtls9

edwards_curve_dh() = x25519 | x448
edwards_curve_ed() = ed25519 | ed448

Note that some curves are disabled if FIPS is enabled.

ec_explicit_curve() =
    {Field :: ec_field(),
     Curve :: ec_curve(),
     BasePoint :: binary(),
     Order :: binary(),
     CoFactor :: none | binary()}

ec_field() = ec_prime_field() | ec_characteristic_two_field()
ec_curve() =
    {A :: binary(), B :: binary(), Seed :: none | binary()}

Parametric curve definition.

ec_prime_field() = {prime_field, Prime :: integer()}
ec_characteristic_two_field() =
    {characteristic_two_field,
     M :: integer(),
     Basis :: ec_basis()}
ec_basis() =
    {tpbasis, K :: integer() >= 0} |
    {ppbasis,
     K1 :: integer() >= 0,
     K2 :: integer() >= 0,
     K3 :: integer() >= 0} | onbasis

Curve definition details.

Keys
key_integer() = integer() | binary()
Always binary() when used as return value

Public/Private Keys
rsa_public() = [key_integer()]
rsa_private() = [key_integer()]
rsa_params() =
    {ModulusSizeInBits :: integer(),
     PublicExponent :: key_integer()}

rsa_public() = [E, N]

rsa_private() = [E, N, D] | [E, N, D, P1, P2, E1, E2, C]
Where $E$ is the public exponent, $N$ is public modulus and $D$ is the private exponent. The longer key format contains
redundant information that will make the calculation faster. $P_1$ and $P_2$ are first and second prime factors. $E_1$ and $E_2$
are first and second exponents. $C$ is the CRT coefficient. The terminology is taken from RFC 3447.

dss_public() = [key_integer()]
dss_private() = [key_integer()]

Where $P$, $Q$ and $G$ are the dss parameters and $Y$ is the public key.

dss_public() = [P, Q, G, Y]
dss_private() = [P, Q, G, X]

Where $P$, $Q$ and $G$ are the dss parameters and $X$ is the private key.

dss_public() = key_integer()
dss_private() = key_integer()

dss_public() = [P, Q, G, Y]
dss_private() = [P, Q, G, X]

Where $P$, $Q$ and $G$ are the dss parameters and $Y$ is the public key.

ecdsa_public() = key_integer()
ecdsa_private() = key_integer()
ecdsa_params() = ec_named_curve() | ec_explicit_curve()
eddsa_public() = key_integer()
eddsa_private() = key_integer()
eddsa_params() = edwards_curve_ed()
srp_public() = key_integer()
srp_private() = key_integer()

Where is $A$ or $B$ from SRP design

srp_public() = key_integer()

Where is $a$ or $b$ from SRP design.

srp_gen_params() =
  {user, srp_user_gen_params()} | {host, srp_host_gen_params()}

srp_comp_params() =
  {user, srp_user_comp_params()} | {host, srp_host_comp_params()}

srp_user_gen_params() = [DerivedKey::binary(), Prime::binary(),
Generator::binary(), Version::atom()]
srp_host_gen_params() = [Verifier::binary(), Prime::binary(), Version::atom()]
srp_user_comp_params() = [DerivedKey::binary(), Prime::binary(), Generator::binary(),
Version::atom() | ScramblerArg::list()]
srp_host_comp_params() = [Verifier::binary(), Prime::binary(), Version::atom() | ScramblerArg::list()]

Where Verifier is $v$, Generator is $g$ and Prime is $N$. DerivedKey is $X$, and Scrambler is $u$ (optional will be generated
if not provided) from SRP design. Version = '3' | '6' | '6a'

Public Key Ciphers

pk_encrypt_decrypt_algs() = rsa
Algorithms for public key encrypt/decrypt. Only RSA is supported.

pk_encrypt_decrypt_opts() = [rsa_opt()] | rsa_compat_opts()
rsa_opt() =
  {rsa_padding, rsa_padding()} | {signature_md, atom()} |
{rsa_mgf1_md, sha} | {rsa_oaep_label, binary()} | {rsa_oaep_md, sha}

rsa_padding() =
    rsa_pkcs1_padding | rsa_pkcs1_oaep_padding |
    rsa_sslv23_padding | rsa_x931_padding | rsa_no_padding

Options for public key encrypt/decrypt. Only RSA is supported.

Warning:
The RSA options are experimental.
The exact set of options and their syntax may be changed without prior notice.

rsa_compat_opts() = [{rsa_pad, rsa_padding()}] | rsa_padding()
Those option forms are kept only for compatibility and should not be used in new code.

Public Key Sign and Verify
pk_sign_verify_algs() = rsa | dss | ecdsa | eddsa
Algorithms for sign and verify.

pk_sign_verify_opts() = [rsa_sign_verify_opt()]
rsa_sign_verify_opt() =
    {rsa_padding, rsa_sign_verify_padding()} | {rsa_pss_saltlen, integer()} | {rsa_mgf1_md, sha2()}

rsa_sign_verify_padding() =
    rsa_pkcs1_padding | rsa_pkcs1_pss_padding | rsa_x931_padding | rsa_no_padding

Options for sign and verify.

Warning:
The RSA options are experimental.
The exact set of options and their syntax may be changed without prior notice.

Diffie-Hellman Keys and parameters
dh_public() = key_integer()
dh_private() = key_integer()
dh_params() = [key_integer()]

dh_params() = [P, G] | [P, G, PrivateKeyBitLength]

ecdh_public() = key_integer()
ecdh_private() = key_integer()
ecdh_params() =
    ec_named_curve() | edwards_curve_dh() | ec_explicit_curve()

Types for Engines
eengine_key_ref() =
#{engine := engine_ref(),
  key_id := key_id(),
  password => password(),
  term() => term()}

engine_ref() = term()
The result of a call to engine_load/3.

key_id() = string() | binary()
Identifies the key to be used. The format depends on the loaded engine. It is passed to the
ENGINE_load_(private|public)_key functions in libcrypto.

password() = string() | binary()
The password of the key stored in an engine.

engine_method_type() =
  engine_method_rsa | engine_method_dsa | engine_method_dh |
  engine_method_rand | engine_method_ecdh |
  engine_method_ecdsa | engine_method_ciphers |
  engine_method_digests | engine_method_store |
  engine_method_pkey_meths | engine_method_pkey_asn1_meths |
  engine_method_ec

engine_cmdn() = {unicode:chardata(), unicode:chardata()}
Pre and Post commands for engine_load/3 and /4.

Internal data types
crypto_state()
hash_state()
mac_state()

Contexts with an internal state that should not be manipulated but passed between function calls.

Error types
run_time_error() = any()
The exception error:badarg signifies that one or more arguments are of wrong data type, or are otherwise badly
formed.

The exception error:notsup signifies that the algorithm is known but is not supported by current underlying
libcrypto or explicitly disabled when building that.

For a list of supported algorithms, see supports(ciphers).

descriptive_error() = any()
This is a more developed variant of the older run_time_error().

The exception is:

  {Tag, {C_FileName,LineNumber}, Description}
  Tag = badarg | notsup | error
  C_FileName = string()
  LineNumber = integer()
  Description = string()
It is like the older type an exception of the error class. In addition they contain a descriptive text in English. That text is targeted to a developer. Examples are "Bad key size" or "Cipher id is not an atom".

The exception tags are:

badarg

Signifies that one or more arguments are of wrong data type or are otherwise badly formed.

notsup

Signifies that the algorithm is known but is not supported by current underlying libcrypto or explicitly disabled when building that one.

error

An error condition that should not occur, for example a memory allocation failed or the underlying cryptolib returned an error code, for example "Can't initialize context, step 1". Those text usually needs searching the C-code to be understood.

To catch the exception, use for example:

```erlang
try crypto:crypto_init(Ciph, Key, IV, true)
catch
    error:{Tag, {C_FileName,LineNumber}, Description} ->
     do_something(......)
end
```

Exports

crypto_init(Cipher, Key, FlagOrOptions) ->
    State | descriptive_error()

Types:
    Cipher = cipher_no_iv()
    Key = iodata()
    FlagOrOptions = crypto_opts() | boolean()
    State = crypto_state()

Equivalent to the call crypto_init(Cipher, Key, <<>>, FlagOrOptions). It is intended for ciphers without an IV (nounce).

crypto_init(Cipher, Key, IV, FlagOrOptions) ->
    State | descriptive_error()

Types:
    Cipher = cipher_iv()
    Key = IV = iodata()
    FlagOrOptions = crypto_opts()
    State = crypto_state()

Initializes a series of encryptions or decryptions and creates an internal state with a reference that is returned.

If IV = <<>>, no IV is used. This is intended for ciphers without an IV (nounce). See crypto_init/3.

If IV = undefined, the IV must be added by calls to crypto_dyn_iv_update/3. This is intended for cases where the IV (nounce) need to be changed for each encryption and decryption. See crypto_dyn_iv_init/3.

The actual encryption or decryption is done by crypto_update/2 (or crypto_dyn_iv_update/3 ).
For encryption, set the FlagOrOptions to true or \([\{\text{encrypt, true}\}]\). For decryption, set it to false or \([\{\text{encrypt, false}\}]\).

Padding could be enabled with the option \{padding, Padding\}. The cryptolib_padding enables pkcs_padding or no padding (none). The paddings zero or random fills the last part of the last block with zeroes or random bytes. If the last block is already full, nothing is added.

In decryption, the cryptolib_padding removes such padding, if present. The otp_padding is not removed - it has to be done elsewhere.

If padding is \{padding, none\} or not specified and the total data from all subsequent crypto_updates does not fill the last block fully, that last data is lost. In case of \{padding, none\} there will be an error in this case. If padding is not specified, the bytes of the unfilled block is silently discarded.

The actual padding is performed by crypto_final/1.

For block sizes call cipher_info/1.

See examples in the User's Guide.

\textbf{crypto_update}(State, Data) \rightarrow Result | \textbf{descriptive_error}()  
\textbf{Types:}  
\begin{align*}  
\text{State} &= \text{crypto\_state}() \\
\text{Data} &= \text{iodata}() \\
\text{Result} &= \text{binary}() 
\end{align*}

It does an actual crypto operation on a part of the full text. If the part is less than a number of full blocks, only the full blocks (possibly none) are encrypted or decrypted and the remaining bytes are saved to the next \textbf{crypto_update} operation. The \text{State} should be created with \textbf{crypto_init}/3 or \textbf{crypto_init}/4.

See examples in the User's Guide.

\textbf{crypto_dyn_iv_init}(Cipher, Key, FlagOrOptions) \rightarrow \text{State} | \textbf{descriptive_error}()  
\textbf{Types:}  
\begin{align*}  
\text{Cipher} &= \text{cipher\_iv}() \\
\text{Key} &= \text{iodata}() \\
\text{FlagOrOptions} &= \text{crypto\_opts()} | \text{boolean}() \\
\text{State} &= \text{crypto\_state}() 
\end{align*}

Initializes a series of encryptions or decryptions where the IV is provided later. The actual encryption or decryption is done by \textbf{crypto_dyn_iv_update}/3.

The function is equivalent to \textbf{crypto_init}(Cipher, Key, undefined, FlagOrOptions).

\textbf{crypto_final}(State) \rightarrow \text{FinalResult} | \textbf{descriptive_error}()  
\textbf{Types:}  
\begin{align*}  
\text{State} &= \text{crypto\_state}() \\
\text{FinalResult} &= \text{binary}() 
\end{align*}

Finalizes a series of encryptions or decryptions and delivers the final bytes of the final block. The data returned from this function may be empty if no padding was enabled in \textbf{crypto_init}/3,4 or \textbf{crypto_dyn_iv_init}/3.

\textbf{crypto_get_data}(State) \rightarrow \text{Result}  
\textbf{Types:}

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State = crypto_state()
Result = map()

Returns information about the State in the argument. The information is the form of a map, which currently contains at least:

size
The number of bytes encrypted or decrypted so far.
padding_size
After a call to crypto_final/1 it contains the number of bytes padded. Otherwise 0.
padding_type
The type of the padding as provided in the call of crypto_init/3,4.
encrypt
Is true if encryption is performed. It is false otherwise.

crypto_dyn_iv_update(State, Data, IV) ->
Result | descriptive_error()

Types:
State = crypto_state()
Data = IV = iodata()
Result = binary()

Do an actual crypto operation on a part of the full text and the IV is supplied for each part. The State should be created with crypto_dyn_iv_init/3.

crypto_one_time(Cipher, Key, Data, FlagOrOptions) ->
Result | descriptive_error()

Types:
Cipher = cipher_no_iv()
Key = Data = iodata()
FlagOrOptions = crypto_opts() | boolean()
Result = binary()

As crypto_one_time/5 but for ciphers without IVs.

crypto_one_time(Cipher, Key, IV, Data, FlagOrOptions) ->
Result | descriptive_error()

Types:
Cipher = cipher_iv()
Key = IV = Data = iodata()
FlagOrOptions = crypto_opts() | boolean()
Result = binary()

Do a complete encrypt or decrypt of the full text in the argument Data.
For encryption, set the FlagOrOptions to true. For decryption, set it to false. For setting other options, see crypto_init/4.
See examples in the User's Guide.

crypto_one_time_aead(Cipher, Key, IV, InText, AAD,
EncFlag :: true) ->
crypto

```erlang
Result | descriptive_error()
crypto_one_time_aead(Cipher, Key, IV, InText, AAD, TagOrTagLength, EncFlag) ->
  Result | descriptive_error()

Types:
  Cipher = cipher_aead()
  Key = IV = InText = AAD = iodata()
  TagOrTagLength = EncryptTagLength | DecryptTag
  EncryptTagLength = integer() >= 0
  DecryptTag = iodata()
  EncFlag = boolean()
  Result = EncryptResult | DecryptResult
  EncryptResult = {OutCryptoText, OutTag}
  DecryptResult = OutPlainText | error
  OutCryptoText = OutTag = OutPlainText = binary()
```

Do a complete encrypt or decrypt with an AEAD cipher of the full text.

For encryption, set the `EncryptFlag` to `true` and set the `TagOrTagLength` to the wanted size (in bytes) of the tag, that is, the tag length. If the default length is wanted, the `crypto_aead/6` form may be used.

For decryption, set the `EncryptFlag` to `false` and put the tag to be checked in the argument `TagOrTagLength`.

See examples in the User's Guide.

```erlang
supports(Type) -> Support
Types:
  Type = hashes | ciphers | public_keys | macs | curves | rsa_opts
  Support = Hashs | Ciphers | PKs | Macs | Curves | RSAopts
  Hashs = [sha1() | sha2() | sha3() | blake2() | ripemd160 | compatibility_only_hash()]
  Ciphers = [cipher()]
  PKs = [rsa | dss | ecdsa | dh | ecdh | eddh | ec_gf2m]
  Macs = [hmac | cmac | poly1305]
  Curves = [ec_named_curve() | edwards_curve_dh() | edwards_curve_ed()]
  RSAopts = [rsa_sign_verify_opt() | rsa_opt()]
```

Can be used to determine which crypto algorithms that are supported by the underlying libcrypto library.

See `hash_info/1` and `cipher_info/1` for information about the hash and cipher algorithms.

```erlang
mac(Type :: poly1305, Key, Data) -> Mac | descriptive_error()
Types:
  Mac = {MacTag, Key}
```

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Key = Data = iodata()
Mac = binary()

Short for mac(Type, undefined, Key, Data).

mac(Type, SubType, Key, Data) -> Mac | descriptive_error()

Types:
  Type = hmac | cmac | poly1305
  SubType =
    hmac_hash_algorithm() | cmac_cipher_algorithm() | undefined
  Key = Data = iodata()
  Mac = binary()

Computes a MAC (Message Authentication Code) of type Type from Data.

SubType depends on the MAC Type:
  • For hmac it is a hash algorithm, see Algorithm Details in the User's Guide.
  • For cmac it is a cipher suitable for cmac, see Algorithm Details in the User's Guide.
  • For poly1305 it should be set to undefined or the mac/2 function could be used instead, see Algorithm Details in the User's Guide.

Key is the authentication key with a length according to the Type and SubType. The key length could be found with the hash_info/1 (hmac) for and cipher_info/1 (cmac) functions. For poly1305 the key length is 32 bytes. Note that the cryptographic quality of the key is not checked.

The Mac result will have a default length depending on the Type and SubType. To set a shorter length, use macN/4 or macN/5 instead. The default length is documented in Algorithm Details in the User's Guide.

macN(Type :: poly1305, Key, Data, MacLength) ->
  Mac | descriptive_error()

Types:
  Key = Data = iodata()
  Mac = binary()
  MacLength = integer() >= 1

Short for macN(Type, undefined, Key, Data, MacLength).

macN(Type, SubType, Key, Data, MacLength) ->
  Mac | descriptive_error()

Types:
  Type = hmac | cmac | poly1305
  SubType =
    hmac_hash_algorithm() | cmac_cipher_algorithm() | undefined
  Key = Data = iodata()
  Mac = binary()
  MacLength = integer() >= 1

Computes a MAC (Message Authentication Code) as mac/3 and mac/4 but MacLength will limit the size of the resultant Mac to at most MacLength bytes. Note that if MacLength is greater than the actual number of bytes returned from the underlying hash, the returned hash will have that shorter length instead.

The max MacLength is documented in Algorithm Details in the User's Guide.
crypto

mac_init(Type :: poly1305, Key) -> State | descriptive_error()
Types:
  Key = iodata()
  State = mac_state()
Short for mac_init(Type, undefined, Key).

mac_init(Type, SubType, Key) -> State | descriptive_error()
Types:
  Type = hmac | cmac | poly1305
  SubType =
    hmac_hash_algorithm() | cmac_cipher_algorithm() | undefined
  Key = iodata()
  State = mac_state()
Initializes the context for streaming MAC operations.
Type determines which mac algorithm to use in the MAC operation.
SubType depends on the MAC Type:
  • For hmac it is a hash algorithm, see Algorithm Details in the User's Guide.
  • For cmac it is a cipher suitable for cmac, see Algorithm Details in the User's Guide.
  • For poly1305 it should be set to undefined or the mac/2 function could be used instead, see Algorithm Details in the User's Guide.
Key is the authentication key with a length according to the Type and SubType. The key length could be found with the hash_info/1 (hmac) for and cipher_info/1 (cmac) functions. For poly1305 the key length is 32 bytes. Note that the cryptographic quality of the key is not checked.
The returned State should be used in one or more subsequent calls to mac_update/2. The MAC value is finally returned by calling mac_final/1 or mac_finalN/2.
See examples in the User's Guide.

mac_update(State0, Data) -> State | descriptive_error()
Types:
  Data = iodata()
  State0 = State = mac_state()
Updates the MAC represented by State0 using the given Data which could be of any length.
The State0 is the State value originally from a MAC init function, that is mac_init/2, mac_init/3 or a previous call of mac_update/2. The value State0 is returned unchanged by the function as State.

mac_final(State) -> Mac | descriptive_error()
Types:
  State = mac_state()
  Mac = binary()
Finalizes the MAC operation referenced by State. The Mac result will have a default length depending on the Type and SubType in the mac_init/2,3 call. To set a shorter length, use mac_finalN/2 instead. The default length is documented in Algorithm Details in the User's Guide.
mac_finalN(State, MacLength) -> Mac | descriptive_error()

Types:
  State = mac_state()
  MacLength = integer() >= 1
  Mac = binary()

Finalizes the MAC operation referenced by State.

Mac will be a binary with at most MacLength bytes. Note that if MacLength is greater than the actual number of bytes returned from the underlying hash, the returned hash will have that shorter length instead.

The max MacLength is documented in Algorithm Details in the User's Guide.

bytes_to_integer(Bin :: binary()) -> integer()

Convert binary representation, of an integer, to an Erlang integer.

compute_key(Type, OthersPublicKey, MyPrivateKey, Params) -> SharedSecret

Types:
  Type = dh | ecdh | eddh | srp
  SharedSecret = binary()
  OthersPublicKey = dh_public() | ecdh_public() | srp_public()
  MyPrivateKey =
    dh_private() | ecdh_private() | {srp_public(), srp_private()}
  Params = dh_params() | ecdh_params() | srp_comp_params()

Computes the shared secret from the private key and the other party’s public key. See also public_key:compute_key/2.

exor(Bin1 :: iodata(), Bin2 :: iodata()) -> binary()

Performs bit-wise XOR (exclusive or) on the data supplied.

generate_key(Type, Params) -> {PublicKey, PrivKeyOut}

generate_key(Type, Params, PrivKeyIn) -> {PublicKey, PrivKeyOut}

Types:
  Type = dh | ecdh | eddh | eddsa | rsa | srp
  PublicKey =
    dh_public() | ecdh_public() | rsa_public() | srp_public()
  PrivKeyIn =
    undefined |
    dh_private() |
    ecdh_private() |
    rsa_private() |
    {srp_public(), srp_private()}
  PrivKeyOut =
    dh_private() |
    ecdh_private() |
    rsa_private() |
    {srp_public(), srp_private()}
  Params =

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Generates a public key of type `Type`. See also `public_key:generate_key/1`. May raise exception:

- `error:badarg`: an argument is of wrong type or has an illegal value,
- `error:low_entropy`: the random generator failed due to lack of secure "randomness",
- `error:computation_failed`: the computation fails of another reason than `low_entropy`.

**Note:**

RSA key generation is only available if the runtime was built with dirty scheduler support. Otherwise, attempting to generate an RSA key will raise exception `error:notsup`.

**hash**

```
hash(Type, Data) -> Digest
```

*Types:*

- `Type = hash_algorithm()`
- `Data = iodata()`
- `Digest = binary()`

Computes a message digest of type `Type` from `Data`.

May raise exception `error:notsup` in case the chosen `Type` is not supported by the underlying libcrypto implementation.

**hash_init**

```
hash_init(Type) -> State
```

*Types:*

- `Type = hash_algorithm()`
- `State = hash_state()`

Initializes the context for streaming hash operations. `Type` determines which digest to use. The returned context should be used as argument to `hash_update`.

May raise exception `error:notsup` in case the chosen `Type` is not supported by the underlying libcrypto implementation.

**hash_update**

```
hash_update(State, Data) -> NewState
```

*Types:*

- `State = NewState = hash_state()`
- `Data = iodata()`

Updates the digest represented by `Context` using the given `Data`. `Context` must have been generated using `hash_init` or a previous call to this function. `Data` can be any length. `NewContext` must be passed into the next call to `hash_update` or `hash_final`.

**hash_final**

```
hash_final(State) -> Digest
```

*Types:*

- `State = hash_state()`
- `Digest = binary()`
State = hash_state()
Digest = binary()

Finalizes the hash operation referenced by Context returned from a previous call to hash_update. The size of Digest is determined by the type of hash function used to generate it.

info_fips() -> not_supported | not_enabled | enabled

Provides information about the FIPS operating status of crypto and the underlying libcrypto library. If crypto was built with FIPS support this can be either enabled (when running in FIPS mode) or not_enabled. For other builds this value is always not_supported.

See enable_fips_mode/1 about how to enable FIPS mode.

Warning:

In FIPS mode all non-FIPS compliant algorithms are disabled and raise exception error:notsup. Check supports(ciphers) that in FIPS mode returns the restricted list of available algorithms.

enable_fips_mode(Enable) -> Result
Types:
  Enable = Result = boolean()

Enables (Enable = true) or disables (Enable = false) FIPS mode. Returns true if the operation was successful or false otherwise.

Note that to enable FIPS mode successfully, OTP must be built with the configure option --enable-fips, and the underlying libcrypto must also support FIPS.

See also info_fips/0.

info_lib() -> [{Name, VerNum, VerStr}]
Types:
  Name = binary()
  VerNum = integer()
  VerStr = binary()

Provides the name and version of the libraries used by crypto.

Name is the name of the library. VerNum is the numeric version according to the library's own versioning scheme. VerStr contains a text variant of the version.

> info_lib().
[{{"OpenSSL"},269484095,{{"OpenSSL 1.1.0c 10 Nov 2016"}}}]
hash_info(Type) -> Result | run_time_error()
Types:
  Type = hash_algorithm()
  Result =
    #{size := integer(),
     block_size := integer(),
     type := integer()}
Provides a map with information about block_size, size and possibly other properties of the hash algorithm in question.
For a list of supported hash algorithms, see supports(sha512).

cipher_info(Type) -> Result | run_time_error()
Types:
  Type = cipher()
  Result =
    #{key_length := integer(),
     iv_length := integer(),
     block_size := integer(),
     mode := CipherModes,
     type := undefined | integer(),
     prop_aead := boolean()}
CipherModes =
  undefined | cbc_mode | ccm_mode | cfb_mode | ctr_mode |
  ecb_mode | gcm_mode | ige_mode | ocb_mode | ofb_mode |
  wrap_mode | xts_mode
Provides a map with information about block_size, key_length, iv_length, aead support and possibly other properties of the cipher algorithm in question.

Note:
The ciphers aes_cbc, aes_cfb8, aes_cfb128, aes_ctr, aes_ecb, aes_gcm and aes_ccm has no keylength in the Type as opposed to for example aes_128_ctr. They adapt to the length of the key provided in the encrypt and decrypt function. Therefor it is impossible to return a valid keylength in the map.
Always use a Type with an explicit key length.
For a list of supported cipher algorithms, see supports(ciphers).

mod_pow(N, P, M) -> Result
Types:
  N = P = M = binary() | integer()
  Result = binary() | error
Computes the function N^P mod M.

private_decrypt(Algorithm, CipherText, PrivateKey, Options) ->
  Plaintext
Types:
Algorithm = pk_encrypt_decrypt_algs()
CipherText = binary()
PrivateKey = rsa_private() | engine_key_ref()
Options = pk_encrypt_decrypt_opts()
PlainText = binary()

Decrypts the CipherText, encrypted with public_encrypt/4 (or equivalent function) using the PrivateKey, and returns the plaintext (message digest). This is a low level signature verification operation used for instance by older versions of the SSL protocol. See also public_key:decrypt_private/[2,3]

private_encrypt(Algorithm, PlainText, PrivateKey, Options) ->
    CipherText

Types:
    Algorithm = pk_encrypt_decrypt_algs()
    PlainText = binary()
    PrivateKey = rsa_private() | engine_key_ref()
    Options = pk_encrypt_decrypt_opts()
    CipherText = binary()

Encrypts the PlainText using the PrivateKey and returns the ciphertext. This is a low level signature operation used for instance by older versions of the SSL protocol. See also public_key:encrypt_private/[2,3]

public_decrypt(Algorithm, CipherText, PublicKey, Options) ->
    PlainText

Types:
    Algorithm = pk_encrypt_decrypt_algs()
    CipherText = binary()
    PublicKey = rsa_public() | engine_key_ref()
    Options = pk_encrypt_decrypt_opts()
    PlainText = binary()

Decrypts the CipherText, encrypted with private_encrypt/4 (or equivalent function) using the PrivateKey, and returns the plaintext (message digest). This is a low level signature verification operation used for instance by older versions of the SSL protocol. See also public_key:decrypt_public/[2,3]

public_encrypt(Algorithm, PlainText, PublicKey, Options) ->
    CipherText

Types:
    Algorithm = pk_encrypt_decrypt_algs()
    PlainText = binary()
    PublicKey = rsa_public() | engine_key_ref()
    Options = pk_encrypt_decrypt_opts()
    CipherText = binary()

Encrypts the PlainText (message digest) using the PublicKey and returns the CipherText. This is a low level signature operation used for instance by older versions of the SSL protocol. See also public_key:encrypt_public/[2,3]
crypto

rand_seed(Seed :: binary()) -> ok
Set the seed for PRNG to the given binary. This calls the RAND_seed function from openssl. Only use this if the system you are running on does not have enough “randomness” built in. Normally this is when strong_rand_bytes/1 raises error:low_entropy

rand_uniform(Lo, Hi) -> N
Types:
   Lo, Hi, N = integer()
Generate a random number N, Lo =< N < Hi. Uses the crypto library pseudo-random number generator. Hi must be larger than Lo.

start() -> ok | {error, Reason :: term()}
Equivalent to application:start(crypto).

stop() -> ok | {error, Reason :: term()}
Equivalent to application:stop(crypto).

strong_rand_bytes(N :: integer() >= 0) -> binary()
Generates N bytes randomly uniform 0..255, and returns the result in a binary. Uses a cryptographically secure prng seeded and periodically mixed with operating system provided entropy. By default this is the RAND_bytes method from OpenSSL.
May raise exception error:low_entropy in case the random generator failed due to lack of secure "randomness".

rand_seed() -> rand:state()
Creates state object for random number generation, in order to generate cryptographically strong random numbers (based on OpenSSL's BN_rand_range), and saves it in the process dictionary before returning it as well. See also rand:seed/1 and rand_seed_s/0.

When using the state object from this function the rand functions using it may raise exception error:low_entropy in case the random generator failed due to lack of secure "randomness".

Example

```erlang
{_, _IntegerValue} = crypto:rand_seed(),
{_, _FloatValue} = crypto:rand_uniform(42), % [1; 42]
```

rand_seed_s() -> rand:state()
Creates state object for random number generation, in order to generate cryptographically strongly random numbers (based on OpenSSL's BN_rand_range). See also rand:seed_s/1.

When using the state object from this function the rand functions using it may raise exception error:low_entropy in case the random generator failed due to lack of secure "randomness".
Note:
The state returned from this function cannot be used to get a reproducible random sequence as from the other rand functions, since reproducability does not match cryptographically safe.
The only supported usage is to generate one distinct random sequence from this start state.

```
rand_seed_alg(Alg) -> rand:state()
```

Types:
- Alg = crypto | crypto_cache

Creates state object for random number generation, in order to generate cryptographically strong random numbers, and saves it in the process dictionary before returning it as well. See also rand:seed/1 and rand_seed_alg_s/1.

When using the state object from this function the rand functions using it may raise exception `error:low_entropy` in case the random generator failed due to lack of secure "randomness".

Example

```
_ = crypto:rand_seed_alg(crypto_cache),
_IntegerValue = rand:uniform(42),  % [1; 42]
_FloatValue = rand:uniform().      % [0.0; 1.0]
```

```
rand_seed_alg(Alg, Seed) -> rand:state()
```

Types:
- Alg = crypto_aes

Creates a state object for random number generation, in order to generate cryptographically unpredictable random numbers, and saves it in the process dictionary before returning it as well. See also rand_seed_alg_s/2.

Example

```
_ = crypto:rand_seed_alg(crypto_aes, "my seed"),
_IntegerValue = rand:uniform(42),  % [1; 42]
_FloatValue = rand:uniform().      % [0.0; 1.0]
_ = crypto:rand_seed_alg(crypto_aes, "my seed"),
_IntegerValue = rand:uniform(42),  % Same values
_FloatValue = rand:uniform().      % again
```

```
rand_seed_alg_s(Alg) -> rand:state()
```

Types:
- Alg = crypto | crypto_cache

Creates state object for random number generation, in order to generate cryptographically strongly random numbers. See also rand:seed_s/1.

If Alg is crypto this function behaves exactly like rand_seed_s/0.

If Alg is crypto_cache this function fetches random data with OpenSSL's RAND_bytes and caches it for speed using an internal word size of 56 bits that makes calculations fast on 64 bit machines.

When using the state object from this function the rand functions using it may raise exception `error:low_entropy` in case the random generator failed due to lack of secure "randomness".
The cache size can be changed from its default value using the crypto app's configuration parameter `rand_cache_size`.

When using the state object from this function the rand functions using it may throw exception `low_entropy` in case the random generator failed due to lack of secure "randomness".

**Note:**

The state returned from this function cannot be used to get a reproducible random sequence as from the other rand functions, since reproducability does not match cryptographically safe.

In fact since random data is cached some numbers may get reproduced if you try, but this is unpredictable.

The only supported usage is to generate one distinct random sequence from this start state.

```
rand_seed_alg_s(Alg, Seed) -> rand:state()
```

Types:
```
  Alg = crypto_aes
```

Creates a state object for random number generation, in order to generate cryptographically unpredictable random numbers. See also `rand_seed_alg/1`.

To get a long period the Xoroshiro928 generator from the rand module is used as a counter (with period $2^{928} - 1$) and the generator states are scrambled through AES to create 58-bit pseudo random values.

The result should be statistically completely unpredictable random values, since the scrambling is cryptographically strong and the period is ridiculously long. But the generated numbers are not to be regarded as cryptographically strong since there is no re-keying schedule.

- If you need cryptographically strong random numbers use `rand_seed_alg_s/1` with `Alg := crypto` or `Alg := crypto_cache`.
- If you need to be able to repeat the sequence use this function.
- If you do not need the statistical quality of this function, there are faster algorithms in the rand module.

Thanks to the used generator the state object supports the `rand:jump/0,1` function with distance $2^{512}$.

Numbers are generated in batches and cached for speed reasons. The cache size can be changed from its default value using the crypto app's configuration parameter `rand_cache_size`.

```
ec_curves() -> [EllipticCurve]
```

Types:
```
  EllipticCurve =
    ec_named_curve() | edwards_curve_dh() | edwards_curve_ed()
```

Can be used to determine which named elliptic curves are supported.

```
ec_curve(CurveName) -> ExplicitCurve
```

Types:
```
  CurveName = ec_named_curve()
  ExplicitCurve = ec_explicit_curve()
```

Return the defining parameters of a elliptic curve.
sign(Algorithm, DigestType, Msg, Key) -> Signature
sign(Algorithm, DigestType, Msg, Key, Options) -> Signature

Types:
  Algorithm = pk_sign_verify_algs()
  DigestType =
    rsa_digest_type() |
    dss_digest_type() |
    ecdsa_digest_type() |
    none
  Msg = iodata() | {digest, iodata()}
  Key =
    rsa_private() |
    dss_private() |
    [ecdsa_private() | ecdsa_params()] |
    [eddsa_private() | eddsa_params()] |
    engine_key_ref()
  Options = pk_sign_verify_opts()
  Signature = binary()

Creates a digital signature.
The msg is either the binary "cleartext" data to be signed or it is the hashed value of "cleartext" i.e. the digest (plaintext).
Algorithm dss can only be used together with digest type sha.
See also public_key:sign/3.

verify(Algorithm, DigestType, Msg, Signature, Key) -> Result
verify(Algorithm, DigestType, Msg, Signature, Key, Options) ->
    Result

Types:
  Algorithm = pk_sign_verify_algs()
  DigestType =
    rsa_digest_type() |
    dss_digest_type() |
    ecdsa_digest_type() |
    none
  Msg = iodata() | {digest, iodata()}
  Signature = binary()
  Key =
    rsa_public() |
    dss_public() |
    [ecdsa_public() | ecdsa_params()] |
    [eddsa_public() | eddsa_params()] |
    engine_key_ref()
  Options = pk_sign_verify_opts()
  Result = boolean()

Verifies a digital signature
The msg is either the binary "cleartext" data to be signed or it is the hashed value of "cleartext" i.e. the digest (plaintext).
Algorithm dss can only be used together with digest type sha.
See also public_key:verify/4.

Exports

`privkey_to_pubkey(Type, EnginePrivateKeyRef) -> PublicKey`

Types:
- `Type = rsa | dss`
- `EnginePrivateKeyRef = engine_key_ref()`
- `PublicKey = rsa_public() | dss_public()`

Fetches the corresponding public key from a private key stored in an Engine. The key must be of the type indicated by the Type parameter.

`engine_get_all_methods() -> Result`

Types:
- `Result = [engine_method_type()]`

Returns a list of all possible engine methods.
May raise exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.
See also the chapter Engine Load in the User's Guide.

`engine_load(EngineId, PreCmds, PostCmds) -> Result`

Types:
- `EngineId = unicode:chardata()`
- `PreCmds = PostCmds = [engine_cmnd()]`
- `Result = {ok, Engine :: engine_ref()} | {error, Reason :: term()}`

Loads the OpenSSL engine given by `EngineId` if it is available and then returns `ok` and an engine handle. This function is the same as calling `engine_load/4` with `EngineMethods` set to a list of all the possible methods. An error tuple is returned if the engine can't be loaded.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.
See also the chapter Engine Load in the User's Guide.

`engine_load(EngineId, PreCmds, PostCmds, EngineMethods) -> Result`

Types:
- `EngineId = unicode:chardata()`
- `PreCmds = PostCmds = [engine_cmnd()]`
- `EngineMethods = [engine_method_type()]`
- `Result = {ok, Engine :: engine_ref()} | {error, Reason :: term()}`

Loads the OpenSSL engine given by `EngineId` if it is available and then returns `ok` and an engine handle. An error tuple is returned if the engine can't be loaded.
The function raises an `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.

### engine_unload(Engine) -> Result

**Types:**
- `Engine = engine_ref()`
- `Result = ok | {error, Reason :: term()}

Unloads the OpenSSL engine given by `Engine`. An error tuple is returned if the engine can't be unloaded.

The function raises a `error:badarg` if the parameter is in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.

### engine_by_id(EngineId) -> Result

**Types:**
- `EngineId = unicode:chardata()`
- `Result = {ok, Engine :: engine_ref()} | {error, Reason :: term()}

Get a reference to an already loaded engine with `EngineId`. An error tuple is returned if the engine can't be unloaded.

The function raises a `error:badarg` if the parameter is in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.

### engine_ctrl_cmd_string(Engine, CmdName, CmdArg) -> Result

**Types:**
- `Engine = term()`
- `CmdName = CmdArg = unicode:chardata()`
- `Result = ok | {error, Reason :: term()}

Sends ctrl commands to the OpenSSL engine given by `Engine`. This function is the same as calling `engine_ctrl_cmd_string/4` with `Optional` set to false.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

### engine_ctrl_cmd_string(Engine, CmdName, CmdArg, Optional) -> Result

**Types:**
- `Engine = term()`
- `CmdName = CmdArg = unicode:chardata()`
- `Optional = boolean()`
- `Result = ok | {error, Reason :: term()}

Sends ctrl commands to the OpenSSL engine given by `Engine`. `Optional` is a boolean argument that can relax the semantics of the function. If set to `true` it will only return failure if the ENGINE supported the given command name but failed while executing it, if the ENGINE doesn't support the command name it will simply return success.
without doing anything. In this case we assume the user is only supplying commands specific to the given ENGINE so we set this to false.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

eengine_add(Engine) -> Result
Types:
   Engine = engine_ref()
   Result = ok | {error, Reason :: term()}
Add the engine to OpenSSL's internal list.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

eengine_remove(Engine) -> Result
Types:
   Engine = engine_ref()
   Result = ok | {error, Reason :: term()}
Remove the engine from OpenSSL's internal list.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

eengine_get_id(Engine) -> EngineId
Types:
   Engine = engine_ref()
   EngineId = unicode:chardata()
Return the ID for the engine, or an empty binary if there is no id set.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

eengine_get_name(Engine) -> EngineName
Types:
   Engine = engine_ref()
   EngineName = unicode:chardata()
Return the name (eg a description) for the engine, or an empty binary if there is no name set.

The function raises a `error:badarg` if the parameters are in wrong format. It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.

eengine_list() -> Result
Types:
   Result = [EngineId :: unicode:chardata()]
List the id's of all engines in OpenSSL's internal list.

It may also raise the exception `error:notsup` in case there is no engine support in the underlying OpenSSL implementation.
See also the chapter Engine Load in the User's Guide.

May raise exception error:notsup in case engine functionality is not supported by the underlying OpenSSL implementation.

\[
\begin{align*}
\text{ensure_engine_loaded}(\text{EngineId, LibPath}) \rightarrow \text{Result} \\
\text{Types:} \\
\quad \text{EngineId} = \text{LibPath} = \text{unicode:chardata()} \\
\quad \text{Result} = \\
\quad \{\text{ok, Engine :: engine_ref()}\} \mid \{\text{error, Reason :: term()}\}
\end{align*}
\]

Loads the OpenSSL engine given by EngineId and the path to the dynamic library implementing the engine. This function is the same as calling ensure_engine_loaded/3 with EngineMethods set to a list of all the possible methods. An error tuple is returned if the engine can't be loaded.

The function raises a error:badarg if the parameters are in wrong format. It may also raise the exception error:notsup in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.

\[
\begin{align*}
\text{ensure_engine_loaded}(\text{EngineId, LibPath, EngineMethods}) \rightarrow \text{Result} \\
\text{Types:} \\
\quad \text{EngineId} = \text{LibPath} = \text{unicode:chardata()} \\
\quad \text{EngineMethods} = [\text{engine_method_type()}] \\
\quad \text{Result} = \\
\quad \{\text{ok, Engine :: engine_ref()}\} \mid \{\text{error, Reason :: term()}\}
\end{align*}
\]

Loads the OpenSSL engine given by EngineId and the path to the dynamic library implementing the engine. This function differs from the normal engine_load in that sense it also add the engine id to the internal list in OpenSSL. Then in the following calls to the function it just fetch the reference to the engine instead of loading it again. An error tuple is returned if the engine can't be loaded.

The function raises a error:badarg if the parameters are in wrong format. It may also raise the exception error:notsup in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.

\[
\begin{align*}
\text{ensure_engine_unloaded}(\text{Engine}) \rightarrow \text{Result} \\
\text{Types:} \\
\quad \text{Engine} = \text{engine_ref()} \\
\quad \text{Result} = \text{ok} \mid \{\text{error, Reason :: term()}\}
\end{align*}
\]

Unloads an engine loaded with the ensure_engine_loaded function. It both removes the label from the OpenSSL internal engine list and unloads the engine. This function is the same as calling ensure_engine_unloaded/2 with EngineMethods set to a list of all the possible methods. An error tuple is returned if the engine can't be unloaded.

The function raises a error:badarg if the parameters are in wrong format. It may also raise the exception error:notsup in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.

\[
\begin{align*}
\text{ensure_engine_unloaded}(\text{Engine, EngineMethods}) \rightarrow \text{Result} \\
\text{Types:}
\end{align*}
\]
Engine = engine_ref()
EngineMethods = [engine_method_type()]
Result = ok | {error, Reason :: term()}

Unloads an engine loaded with the ensure_engine_loaded function. It both removes the label from the OpenSSL internal engine list and unloads the engine. An error tuple is returned if the engine can't be unloaded.

The function raises a error:badarg if the parameters are in wrong format. It may also raise the exception error:notsup in case there is no engine support in the underlying OpenSSL implementation.

See also the chapter Engine Load in the User's Guide.