Nettle Manual

For the Nettle Library version 3.4

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This manual is for the Nettle library (version 3.4), a low-level cryptographic library.

Originally written 2001 by Niels Möller, updated 2017.

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1 Introduction

Nettle is a cryptographic library that is designed to fit easily in more or less any context: In crypto toolkits for object-oriented languages (C++, Python, Pike, ...), in applications like LSH or GNUPG, or even in kernel space. In most contexts, you need more than the basic cryptographic algorithms, you also need some way to keep track of available algorithms, their properties and variants. You often have some algorithm selection process, often dictated by a protocol you want to implement.

And as the requirements of applications differ in subtle and not so subtle ways, an API that fits one application well can be a pain to use in a different context. And that is why there are so many different cryptographic libraries around.

Nettle tries to avoid this problem by doing one thing, the low-level crypto stuff, and providing a *simple* but general interface to it. In particular, Nettle doesn't do algorithm selection. It doesn't do memory allocation. It doesn't do any I/O.

The idea is that one can build several application and context specific interfaces on top of Nettle, and share the code, test cases, benchmarks, documentation, etc. Examples are the Nettle module for the Pike language, and LSH, which both use an object-oriented abstraction on top of the library.

This manual explains how to use the Nettle library. It also tries to provide some background on the cryptography, and advice on how to best put it to use.

2 Copyright

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This manual is in the public domain. You may freely copy it in whole or in part, e.g., into documentation of programs that build on Nettle. Attribution, as well as contribution of improvements to the text, is of course appreciated, but it is not required.

A list of the supported algorithms, their origins, and exceptions to the above licensing:

AES The implementation of the AES cipher (also known as rijndael) is written by Rafael Sevilla. Assembler for x86 by Rafael Sevilla and Niels Möller, Sparc assembler by Niels Möller.

ARCFOUR
The implementation of the ARCFOUR (also known as RC4) cipher is written by Niels Möller.

ARCTWO
The implementation of the ARCTWO (also known as RC2) cipher is written by Nikos Mavroyanopoulos and modified by Werner Koch and Simon Josefsson.

BLOWFISH
The implementation of the BLOWFISH cipher is written by Werner Koch, copyright owned by the Free Software Foundation. Also hacked by Simon Josefsson and Niels Möller.

CAMELLIA
The C implementation is by Nippon Telegraph and Telephone Corporation (NTT), heavily modified by Niels Möller. Assembler for x86 and x86_64 by Niels Möller.

CAST128 The implementation of the CAST128 cipher is written by Steve Reid. Released into the public domain.

CHACHA Implemented by Joachim Strömbergson, based on the implementation of SALSA20 (see below). Assembly for x86_64 by Niels Möller.

DES The implementation of the DES cipher is written by Dana L. How, and released under the LGPL, version 2 or later.

GOSTHASH94
The C implementation of the GOST94 message digest is written by Aleksey Kravchenko and was ported from the rhash library by Nikos Mavrogiannopoulos. It is released under the MIT license.

MD2 The implementation of MD2 is written by Andrew Kuchling, and hacked some by Andreas Sigfridsson and Niels Möller. Python Cryptography Toolkit license (essentially public domain).

MD4 This is almost the same code as for MD5 below, with modifications by Marcus Comstedt. Released into the public domain.

MD5 The implementation of the MD5 message digest is written by Colin Plumb. It has been hacked some more by Andrew Kuchling and Niels Möller. Released into the public domain.

PBKDF2 The C implementation of PBKDF2 is based on earlier work for Shishi and GnuTLS by Simon Josefsson.

RIPEMD160
The implementation of RIPEMD160 message digest is based on the code in libgcrypt, copyright owned by the Free Software Foundation. Ported to Nettle by Andres Mejia.

SALSA20 The C implementation of SALSA20 is based on D. J. Bernstein's reference implementation (in the public domain), adapted to Nettle by Simon Josefsson, and heavily modified by Niels Möller. Assembly for x86_64 and ARM by Niels Möller.

SERPENT
The implementation of the SERPENT cipher is based on the code in libgcrypt, copyright owned by the Free Software Foundation. Adapted to Nettle by Simon Josefsson and heavily modified by Niels Möller. Assembly for x86_64 by Niels Möller.

POLY1305
Based on the implementation by Andrew M. (floodyberry), modified by Nikos Mavrogiannopoulos and Niels Möller. Assembly for x86_64 by Niels Möller.

SHA1 The C implementation of the SHA1 message digest is written by Peter Gutmann, and hacked some more by Andrew Kuchling and Niels Möller. Released into the public domain. Assembler for x86, x86_64 and ARM by Niels Möller, released under the LGPL.

SHA2 Written by Niels Möller, using Peter Gutmann's SHA1 code as a model.

SHA3 Written by Niels Möller.

TWOFISH
The implementation of the TWOFISH cipher is written by Ruud de Rooij.

UMAC Written by Niels Möller.

CMAC Written by Nikos Mavrogiannopoulos, Niels Möller, Jeremy Allison, Michael Adam and Stefan Metzmacher.

RSA Written by Niels Möller. Uses the GMP library for bignum operations.

DSA Written by Niels Möller. Uses the GMP library for bignum operations.

ECDSA Written by Niels Möller. Uses the GMP library for bignum operations. Development of Nettle's ECC support was funded by the .SE Internet Fund.

3 Conventions

For each supported algorithm, there is an include file that defines a *context struct*, a few constants, and declares functions for operating on the context. The context struct encapsulates all information needed by the algorithm, and it can be copied or moved in memory with no unexpected effects.

For consistency, functions for different algorithms are very similar, but there are some differences, for instance reflecting if the key setup or encryption function differ for encryption and decryption, and whether or not key setup can fail. There are also differences between algorithms that don't show in function prototypes, but which the application must nevertheless be aware of. There is no big difference between the functions for stream ciphers and for block ciphers, although they should be used quite differently by the application.

If your application uses more than one algorithm of the same type, you should probably create an interface that is tailor-made for your needs, and then write a few lines of glue code on top of Nettle.

By convention, for an algorithm named `foo`, the struct tag for the context struct is `foo_ctx`, constants and functions uses prefixes like `FOO_BLOCK_SIZE` (a constant) and `foo_set_key` (a function).

In all functions, strings are represented with an explicit length, of type `size_t`, and a pointer of type `uint8_t *` or `const uint8_t *`. For functions that transform one string to another, the argument order is length, destination pointer and source pointer. Source and destination areas are usually of the same length. When they differ, e.g., for `ccm_encrypt_message`, the length argument specifies the size of the destination area. Source and destination pointers may be equal, so that you can process strings in place, but source and destination areas *must not* overlap in any other way.

Many of the functions lack return value and can never fail. Those functions which can fail, return one on success and zero on failure.

4 Example

A simple example program that reads a file from standard input and writes its SHA1 checksum on standard output should give the flavor of Nettle.

```
#include <stdio.h>
#include <stdlib.h>

#include <nettle/sha1.h>

#define BUF_SIZE 1000

static void
display_hex(unsigned length, uint8_t *data)
{
  unsigned i;

  for (i = 0; i<length; i++)
    printf("%02x ", data[i]);

  printf("\n");
}

int
main(int argc, char **argv)
{
  struct sha1_ctx ctx;
  uint8_t buffer[BUF_SIZE];
  uint8_t digest[SHA1_DIGEST_SIZE];

  sha1_init(&ctx);
  for (;;)
  {
    int done = fread(buffer, 1, sizeof(buffer), stdin);
    sha1_update(&ctx, done, buffer);
    if (done < sizeof(buffer))
      break;
  }
  if (ferror(stdin))
    return EXIT_FAILURE;

  sha1_digest(&ctx, SHA1_DIGEST_SIZE, digest);

  display_hex(SHA1_DIGEST_SIZE, digest);
  return EXIT_SUCCESS;
}
```

On a typical Unix system, this program can be compiled and linked with the command line

```
gcc sha-example.c -o sha-example -lnettle
```

5 Linking

Nettle actually consists of two libraries, '`libnettle`' and '`libhogweed`'. The '`libhogweed`' library contains those functions of Nettle that uses bignum operations, and depends on the GMP library. With this division, linking works the same for both static and dynamic libraries.

If an application uses only the symmetric crypto algorithms of Nettle (i.e., block ciphers, hash functions, and the like), it's sufficient to link with `-lnettle`. If an application also uses public-key algorithms, the recommended linker flags are `-lhogweed -lnettle -lgmp`. If the involved libraries are installed as dynamic libraries, it may be sufficient to link with just `-lhogweed`, and the loader will resolve the dependencies automatically.

6 Compatibility

When you write a program using the Nettle library, it's desirable to have it work together not only with exactly the same version of Nettle you had at hand, but with other current and future versions. If a different version of Nettle is used at compile time, i.e., you recompile it using the header and library files belonging to a different version, we talk about API compatibility (for Application Programming Interface). If a different version of Nettle isn't used until link time, we talk about ABI compatibility (Application Binary Interface) or binary compatibility. ABI compatibility matters mainly when using dynamic linking with a shared library. E.g., a user has an executable linking at run-time with '`libnettle.so`', and then updates to a later version of the shared library, without updating or recompiling the executable.

Nettle aims to provide backwards compatibility, i.e., a program written for a particular version of the Nettle library should usually work fine with later version of the library. Note that the opposite is not supported: The program should *not* be expected to work with older versions of the Nettle library; and ABI breakage can be unobvious. E.g, the later version may define a new library symbol, and let header files redefine an old API name as an alias for the new symbol. If the later version ensures that the old symbol is still defined in the library, this change is backwards compatible: A program compiled using headers from the older version can be successfully linked with either version of the library. But if you compile the same program using headers from the later version of the library, and attempt to link with the older version, you'll get an undefined reference to the new symbol.

API compatibility is rarely broken; exceptions are noted in the NEWS file. For example, the key size argument to the function `cast128_set_key` was dropped in the Nettle-3.0 release, and all programs using that function had to be updated to work with the new version.

ABI compatibility is broken occasionally. This is also noted in the NEWS file, and the name of the shared library is updated to prevent accidental run-time linking with the wrong version. All programs have to be recompiled before they can link with the new version. Since names are different, multiple versions can be installed on the same system, with a mix of programs linking to one version or the other.

Under some circumstances, it is possible to have a single program linking dynamically with two binary incompatible versions of the Nettle library, thanks to the use of symbol versioning. Consider a program calling functions in both Nettle and GnuTLS. For the direct dependency on Nettle, the program is linked with a particular version of the Nettle shared library. GnuTLS uses Nettle internally, but does not expose any Nettle data structures or the like in its own ABI. In this situation, the GnuTLS shared library may link with a different version of the Nettle library. Then both versions of the Nettle library will be loaded into the program's address space, and each reference to a symbol will be resolved to the correct version.

Finally, some of Nettle's symbols are internal. They carry a leading underscore, and are not declared in installed header files. They can be used for local or experimental purposes, but programs referring directly to those symbols get neither API nor ABI compatibility, not even between minor versions.

7 Reference

This chapter describes all the Nettle functions, grouped by family.

7.1 Hash functions

A cryptographic *hash function* is a function that takes variable size strings, and maps them to strings of fixed, short, length. There are naturally lots of collisions, as there are more possible 1MB files than 20 byte strings. But the function is constructed such that is hard to find the collisions. More precisely, a cryptographic hash function `H` should have the following properties:

One-way Given a hash value `H(x)` it is hard to find a string `x` that hashes to that value.

Collision-resistant
It is hard to find two different strings, `x` and `y`, such that `H(x) = H(y)`.

Hash functions are useful as building blocks for digital signatures, message authentication codes, pseudo random generators, association of unique ids to documents, and many other things.

The most commonly used hash functions are MD5 and SHA1. Unfortunately, both these fail the collision-resistance requirement; cryptologists have found ways to construct colliding inputs. The recommended hash functions for new applications are SHA2 (with main variants SHA256 and SHA512). At the time of this writing (Autumn 2015), SHA3 has recently been standardized, and the new SHA3 and other top SHA3 candidates may also be reasonable alternatives.

7.1.1 Recommended hash functions

The following hash functions have no known weaknesses, and are suitable for new applications. The SHA2 family of hash functions were specified by *NIST*, intended as a replacement for SHA1.

7.1.1.1 SHA256

SHA256 is a member of the SHA2 family. It outputs hash values of 256 bits, or 32 octets. Nettle defines SHA256 in '`<nettle/sha2.h>`'.

`struct sha256_ctx` [Context struct]

`SHA256_DIGEST_SIZE` [Constant]
The size of a SHA256 digest, i.e. 32.

`SHA256_BLOCK_SIZE` [Constant]
The internal block size of SHA256. Useful for some special constructions, in particular HMAC-SHA256.

`void sha256_init (`*struct sha256_ctx* `*ctx)` [Function]
Initialize the SHA256 state.

`void sha256_update (`*struct sha256_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data)` [Function]
Hash some more data.

`void sha256_digest` (*struct sha256_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]

Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA256_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `sha256_init`.

Earlier versions of nettle defined SHA256 in the header file '`<nettle/sha.h>`', which is now deprecated, but kept for compatibility.

7.1.1.2 SHA224

SHA224 is a variant of SHA256, with a different initial state, and with the output truncated to 224 bits, or 28 octets. Nettle defines SHA224 in '`<nettle/sha2.h>`' (and in '`<nettle/sha.h>`', for backwards compatibility).

`struct sha224_ctx` [Context struct]

`SHA224_DIGEST_SIZE` [Constant]

The size of a SHA224 digest, i.e. 28.

`SHA224_BLOCK_SIZE` [Constant]

The internal block size of SHA224. Useful for some special constructions, in particular HMAC-SHA224.

`void sha224_init` (*struct sha224_ctx* ***ctx**) [Function]

Initialize the SHA224 state.

`void sha224_update` (*struct sha224_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]

Hash some more data.

`void sha224_digest` (*struct sha224_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]

Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA224_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `sha224_init`.

7.1.1.3 SHA512

SHA512 is a larger sibling to SHA256, with a very similar structure but with both the output and the internal variables of twice the size. The internal variables are 64 bits rather than 32, making it significantly slower on 32-bit computers. It outputs hash values of 512 bits, or 64 octets. Nettle defines SHA512 in '`<nettle/sha2.h>`' (and in '`<nettle/sha.h>`', for backwards compatibility).

`struct sha512_ctx` [Context struct]

`SHA512_DIGEST_SIZE` [Constant]

The size of a SHA512 digest, i.e. 64.

`SHA512_BLOCK_SIZE` [Constant]
The internal block size of SHA512, 128. Useful for some special constructions, in particular HMAC-SHA512.

`void sha512_init (`*struct sha512_ctx* `*ctx)` [Function]
Initialize the SHA512 state.

`void sha512_update (`*struct sha512_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data)` [Function]
Hash some more data.

`void sha512_digest (`*struct sha512_ctx* `*ctx`, *size_t* `length`, *uint8_t* `*digest)` [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA512_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `sha512_init`.

7.1.1.4 SHA384 and other variants of SHA512

Several variants of SHA512 have been defined, with a different initial state, and with the output truncated to shorter length than 512 bits. Naming is a bit confused, these algorithms are called SHA512-224, SHA512-256 and SHA384, for output sizes of 224, 256 and 384 bits, respectively. Nettle defines these in '`<nettle/sha2.h>`' (and in '`<nettle/sha.h>`', for backwards compatibility).

`struct sha512_224_ctx` [Context struct]
`struct sha512_256_ctx` [Context struct]
`struct sha384_ctx` [Context struct]
These context structs are all the same as sha512_ctx. They are defined as simple preprocessor aliases, which may cause some problems if used as identifiers for other purposes. So avoid doing that.

`SHA512_224_DIGEST_SIZE` [Constant]
`SHA512_256_DIGEST_SIZE` [Constant]
`SHA384_DIGEST_SIZE` [Constant]
The digest size for each variant, i.e., 28, 32, and 48, respectively.

`SHA512_224_BLOCK_SIZE` [Constant]
`SHA512_256_BLOCK_SIZE` [Constant]
`SHA384_BLOCK_SIZE` [Constant]
The internal block size, same as SHA512_BLOCK_SIZE, i.e., 128. Useful for some special constructions, in particular HMAC-SHA384.

`void sha512_224_init (`*struct sha512_224_ctx* `*ctx)` [Function]
`void sha512_256_init (`*struct sha512_256_ctx* `*ctx)` [Function]
`void sha384_init (`*struct sha384_ctx* `*ctx)` [Function]
Initialize the context struct.

`void sha512_224_update` (*struct sha512_224_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
`void sha512_256_update` (*struct sha512_256_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
`void sha384_update` (*struct sha384_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]

Hash some more data. These are all aliases for sha512_update, which does the same thing.

`void sha512_224_digest` (*struct sha512_224_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void sha512_256_digest` (*struct sha512_256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void sha384_digest` (*struct sha384_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than the specified digest size, in which case only the first *length* octets of the digest are written.

These function also reset the context in the same way as the corresponding init function.

7.1.1.5 SHA3-224

The SHA3 hash functions were specified by NIST in response to weaknesses in SHA1, and doubts about SHA2 hash functions which structurally are very similar to SHA1. SHA3 is a result of a competition, where the winner, also known as Keccak, was designed by Guido Bertoni, Joan Daemen, Michaël Peeters and Gilles Van Assche. It is structurally very different from all widely used earlier hash functions. Like SHA2, there are several variants, with output sizes of 224, 256, 384 and 512 bits (28, 32, 48 and 64 octets, respectively). In August 2015, it was formally standardized by NIST, as FIPS 202, `http://dx.doi.org/10.6028/NIST.FIPS.202`.

Note that the SHA3 implementation in earlier versions of Nettle was based on the specification at the time Keccak was announced as the winner of the competition, which is incompatible with the final standard and hence with current versions of Nettle. The '`nette/sha3.h`' defines a preprocessor symbol `NETTLE_SHA3_FIPS202` to indicate conformance with the standard.

`NETTLE_SHA3_FIPS202` [Constant]

Defined to 1 in Nettle versions supporting FIPS 202. Undefined in earlier versions.

Nettle defines SHA3-224 in '`<nettle/sha3.h>`'.

`struct sha3_224_ctx` [Context struct]

`SHA3_224_DIGEST_SIZE` [Constant]

The size of a SHA3_224 digest, i.e., 28.

`SHA3_224_BLOCK_SIZE` [Constant]

The internal block size of SHA3_224.

`void sha3_224_init` (*struct sha3_224_ctx* ***ctx**) [Function]
Initialize the SHA3-224 state.

`void sha3_224_update` (*struct sha3_224_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
Hash some more data.

`void sha3_224_digest` (*struct sha3_224_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA3_224_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context.

7.1.1.6 SHA3-256

This is SHA3 with 256-bit output size, and possibly the most useful of the SHA3 hash functions.

Nettle defines SHA3-256 in '`<nettle/sha3.h>`'.

`struct sha3_256_ctx` [Context struct]

`SHA3_256_DIGEST_SIZE` [Constant]
The size of a SHA3_256 digest, i.e., 32.

`SHA3_256_BLOCK_SIZE` [Constant]
The internal block size of SHA3_256.

`void sha3_256_init` (*struct sha3_256_ctx* ***ctx**) [Function]
Initialize the SHA3-256 state.

`void sha3_256_update` (*struct sha3_256_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
Hash some more data.

`void sha3_256_digest` (*struct sha3_256_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA3_256_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context.

7.1.1.7 SHA3-384

This is SHA3 with 384-bit output size.

Nettle defines SHA3-384 in '`<nettle/sha3.h>`'.

`struct sha3_384_ctx` [Context struct]

`SHA3_384_DIGEST_SIZE` [Constant]
The size of a SHA3_384 digest, i.e., 48.

`SHA3_384_BLOCK_SIZE` [Constant]
The internal block size of SHA3_384.

`void sha3_384_init` (*struct sha3_384_ctx* ***ctx**) [Function]
Initialize the SHA3-384 state.

`void sha3_384_update` (*struct sha3_384_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
Hash some more data.

`void sha3_384_digest` (*struct sha3_384_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA3_384_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context.

7.1.1.8 SHA3-512

This is SHA3 with 512-bit output size.

Nettle defines SHA3-512 in '`<nettle/sha3.h>`'.

`struct sha3_512_ctx` [Context struct]

`SHA3_512_DIGEST_SIZE` [Constant]
The size of a SHA3_512 digest, i.e. 64.

`SHA3_512_BLOCK_SIZE` [Constant]
The internal block size of SHA3_512.

`void sha3_512_init` (*struct sha3_512_ctx* ***ctx**) [Function]
Initialize the SHA3-512 state.

`void sha3_512_update` (*struct sha3_512_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
Hash some more data.

`void sha3_512_digest` (*struct sha3_512_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA3_512_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context.

7.1.1.9 SHAKE-256

In addition to those SHA-3 hash functions, Nettle also provides a SHA-3 extendable-output function (XOF), SHAKE-256. Unlike SHA-3 hash functions, SHAKE can produce an output digest of any desired length.

To use SHAKE256, the context struct, init and update functions are the same as for SHA3-256. To get a SHAKE256 digest, the following function is used instead of `sha3_256_digest`. For an output size of `SHA3_256_DIGEST_SIZE`, security is equivalent to SHA3-256

(but the digest is different). Increasing output size further does not increase security in terms of collision or preimage resistance. It can be seen as a built in pseudorandomness generator.

`void sha3_256_shake` (*struct shake256_ctx* *`ctx`, *size_t* `length`, *uint8_t* *`digest`) [Function]

Performs final processing and produces a SHAKE256 digest, writing it to *digest*. *length* can be of arbitrary size.

This function also resets the context.

7.1.2 Miscellaneous hash functions

7.1.2.1 STREEBOG512

STREEBOG512 is a member of the Streebog (GOST R 34.11-2012) family. It outputs hash values of 512 bits, or 64 octets. Nettle defines STREEBOG512 in '`<nettle/streebog.h>`'.

`struct streebog512_ctx` [Context struct]

`STREEBOG512_DIGEST_SIZE` [Constant]

The size of a STREEBOG512 digest, i.e. 64.

`STREEBOG512_BLOCK_SIZE` [Constant]

The internal block size of STREEBOG512. Useful for some special constructions, in particular HMAC-STREEBOG512.

`void streebog512_init` (*struct streebog512_ctx* *`ctx`) [Function]

Initialize the STREEBOG512 state.

`void streebog512_update` (*struct streebog512_ctx* *`ctx`, *size_t* `length`, *const uint8_t* *`data`) [Function]

Hash some more data.

`void streebog512_digest` (*struct streebog512_ctx* *`ctx`, *size_t* `length`, *uint8_t* *`digest`) [Function]

Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `STREEBOG512_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `streebog512_init`.

7.1.2.2 STREEBOG256

STREEBOG256 is a variant of STREEBOG512, with a different initial state, and with the output truncated to 256 bits, or 32 octets. Nettle defines STREEBOG256 in '`<nettle/streebog.h>`'.

`struct streebog256_ctx` [Context struct]

`STREEBOG256_DIGEST_SIZE` [Constant]

The size of a STREEBOG256 digest, i.e. 32.

`STREEBOG256_BLOCK_SIZE` [Constant]
The internal block size of STREEBOG256. Useful for some special constructions, in particular HMAC-STREEBOG256.

`void streebog256_init (`*struct streebog256_ctx* `*ctx)` [Function]
Initialize the STREEBOG256 state.

`void streebog256_update (`*struct streebog256_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data)` [Function]
Hash some more data.

`void streebog256_digest (`*struct streebog256_ctx* `*ctx`, *size_t* `length`, *uint8_t* `*digest)` [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `STREEBOG256_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `streebog256_init`.

7.1.3 Legacy hash functions

The hash functions in this section all have some known weaknesses, and should be avoided for new applications. These hash functions are mainly useful for compatibility with old applications and protocols. Some are still considered safe as building blocks for particular constructions, e.g., there seems to be no known attacks against HMAC-SHA1 or even HMAC-MD5. In some important cases, use of a "legacy" hash function does not in itself make the application insecure; if a known weakness is relevant depends on how the hash function is used, and on the threat model.

7.1.3.1 MD5

MD5 is a message digest function constructed by Ronald Rivest, and described in *RFC 1321*. It outputs message digests of 128 bits, or 16 octets. Nettle defines MD5 in '`<nettle/md5.h>`'.

`struct md5_ctx` [Context struct]

`MD5_DIGEST_SIZE` [Constant]
The size of an MD5 digest, i.e. 16.

`MD5_BLOCK_SIZE` [Constant]
The internal block size of MD5. Useful for some special constructions, in particular HMAC-MD5.

`void md5_init (`*struct md5_ctx* `*ctx)` [Function]
Initialize the MD5 state.

`void md5_update (`*struct md5_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data)` [Function]
Hash some more data.

`void md5_digest` (*struct md5_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]

Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `MD5_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `md5_init`.

The normal way to use MD5 is to call the functions in order: First `md5_init`, then `md5_update` zero or more times, and finally `md5_digest`. After `md5_digest`, the context is reset to its initial state, so you can start over calling `md5_update` to hash new data.

To start over, you can call `md5_init` at any time.

7.1.3.2 MD2

MD2 is another hash function of Ronald Rivest's, described in *RFC 1319*. It outputs message digests of 128 bits, or 16 octets. Nettle defines MD2 in '`<nettle/md2.h>`'.

`struct md2_ctx` [Context struct]

`MD2_DIGEST_SIZE` [Constant]

The size of an MD2 digest, i.e. 16.

`MD2_BLOCK_SIZE` [Constant]

The internal block size of MD2.

`void md2_init` (*struct md2_ctx* ***ctx**) [Function]

Initialize the MD2 state.

`void md2_update` (*struct md2_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]

Hash some more data.

`void md2_digest` (*struct md2_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***digest**) [Function]

Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `MD2_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `md2_init`.

7.1.3.3 MD4

MD4 is a predecessor of MD5, described in *RFC 1320*. Like MD5, it is constructed by Ronald Rivest. It outputs message digests of 128 bits, or 16 octets. Nettle defines MD4 in '`<nettle/md4.h>`'. Use of MD4 is not recommended, but it is sometimes needed for compatibility with existing applications and protocols.

`struct md4_ctx` [Context struct]

`MD4_DIGEST_SIZE` [Constant]

The size of an MD4 digest, i.e. 16.

`MD4_BLOCK_SIZE` [Constant]
The internal block size of MD4.

`void md4_init (`*struct md4_ctx* `*ctx)` [Function]
Initialize the MD4 state.

`void md4_update (`*struct md4_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data)` [Function]
Hash some more data.

`void md4_digest (`*struct md4_ctx* `*ctx`, *size_t* `length`, *uint8_t* `*digest)` [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `MD4_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `md4_init`.

7.1.3.4 RIPEMD160

RIPEMD160 is a hash function designed by Hans Dobbertin, Antoon Bosselaers, and Bart Preneel, as a strengthened version of RIPEMD (which, like MD4 and MD5, fails the collision-resistance requirement). It produces message digests of 160 bits, or 20 octets. Nettle defined RIPEMD160 in '`nettle/ripemd160.h`'.

`struct ripemd160_ctx` [Context struct]

`RIPEMD160_DIGEST_SIZE` [Constant]
The size of a RIPEMD160 digest, i.e. 20.

`RIPEMD160_BLOCK_SIZE` [Constant]
The internal block size of RIPEMD160.

`void ripemd160_init (`*struct ripemd160_ctx* `*ctx)` [Function]
Initialize the RIPEMD160 state.

`void ripemd160_update (`*struct ripemd160_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data)` [Function]
Hash some more data.

`void ripemd160_digest (`*struct ripemd160_ctx* `*ctx`, *size_t* `length`, *uint8_t* `*digest)` [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `RIPEMD160_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `ripemd160_init`.

7.1.3.5 SHA1

SHA1 is a hash function specified by *NIST* (The U.S. National Institute for Standards and Technology). It outputs hash values of 160 bits, or 20 octets. Nettle defines SHA1 in '`<nettle/sha1.h>`' (and in '`<nettle/sha.h>`', for backwards compatibility).

`struct sha1_ctx` [Context struct]

`SHA1_DIGEST_SIZE` [Constant]
The size of a SHA1 digest, i.e. 20.

`SHA1_BLOCK_SIZE` [Constant]
The internal block size of SHA1. Useful for some special constructions, in particular HMAC-SHA1.

`void sha1_init (`*struct sha1_ctx* `*ctx)` [Function]
Initialize the SHA1 state.

`void sha1_update (`*struct sha1_ctx* `*ctx,` *size_t* `length,` *const uint8_t* `*data)` [Function]
Hash some more data.

`void sha1_digest (`*struct sha1_ctx* `*ctx,` *size_t* `length,` *uint8_t* `*digest)` [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `SHA1_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `sha1_init`.

7.1.3.6 GOSTHASH94 and GOSTHASH94CP

The GOST94 or GOST R 34.11-94 hash algorithm is a Soviet-era algorithm used in Russian government standards (see *RFC 4357*). It outputs message digests of 256 bits, or 32 octets. The standard itself does not fix the S-box used by the hash algorith, so there are two popular variants (the testing S-box from the standard itself and the S-box defined by CryptoPro company, see RFC 4357). Nettle provides support for the former S-box in the form of GOSTHASH94 hash algorithm and for the latter in the form of GOSTHASH94CP hash algorithm. Nettle defines GOSTHASH94 and GOSTHASH94CP in '`<nettle/gosthash94.h>`'.

`struct gosthash94_ctx` [Context struct]

`GOSTHASH94_DIGEST_SIZE` [Constant]
The size of a GOSTHASH94 digest, i.e. 32.

`GOSTHASH94_BLOCK_SIZE` [Constant]
The internal block size of GOSTHASH94, i.e., 32.

`void gosthash94_init (`*struct gosthash94_ctx* `*ctx)` [Function]
Initialize the GOSTHASH94 state.

`void gosthash94_update (`*struct gosthash94_ctx* `*ctx,` *size_t* `length,` *const uint8_t* `*data)` [Function]
Hash some more data.

`void gosthash94_digest (`*struct gosthash94_ctx* `*ctx,` *size_t* `length,` *uint8_t* `*digest)` [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `GOSTHASH94_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `gosthash94_init`.

`struct gosthash94cp_ctx` [Context struct]

`GOSTHASH94CP_DIGEST_SIZE` [Constant]
The size of a GOSTHASH94CP digest, i.e. 32.

`GOSTHASH94CP_BLOCK_SIZE` [Constant]
The internal block size of GOSTHASH94CP, i.e., 32.

`void gosthash94cp_init (`*struct gosthash94cp_ctx* `*ctx`) [Function]
Initialize the GOSTHASH94CP state.

`void gosthash94cp_update (`*struct gosthash94cp_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data`) [Function]
Hash some more data.

`void gosthash94cp_digest (`*struct gosthash94cp_ctx* `*ctx`, *size_t* `length`, *uint8_t* `*digest`) [Function]
Performs final processing and extracts the message digest, writing it to *digest*. *length* may be smaller than `GOSTHASH94CP_DIGEST_SIZE`, in which case only the first *length* octets of the digest are written.

This function also resets the context in the same way as `gosthash94cp_init`.

7.1.4 The `struct nettle_hash` abstraction

Nettle includes a struct including information about the supported hash functions. It is defined in '`<nettle/nettle-meta.h>`', and is used by Nettle's implementation of HMAC (see Section 7.5 [Keyed hash functions], page 60).

`struct nettle_hash` *name context_size digest_size block_size init update digest* [Meta struct]
The last three attributes are function pointers, of types `nettle_hash_init_func *`, `nettle_hash_update_func *`, and `nettle_hash_digest_func *`. The first argument to these functions is `void *` pointer to a context struct, which is of size `context_size`.

`struct nettle_hash nettle_md2` [Constant Struct]
`struct nettle_hash nettle_md4` [Constant Struct]
`struct nettle_hash nettle_md5` [Constant Struct]
`struct nettle_hash nettle_ripemd160` [Constant Struct]
`struct nettle_hash nettle_sha1` [Constant Struct]
`struct nettle_hash nettle_sha224` [Constant Struct]
`struct nettle_hash nettle_sha256` [Constant Struct]
`struct nettle_hash nettle_sha384` [Constant Struct]
`struct nettle_hash nettle_sha512` [Constant Struct]
`struct nettle_hash nettle_sha3_256` [Constant Struct]
`struct nettle_hash nettle_gosthash94` [Constant Struct]
`struct nettle_hash nettle_gosthash94cp` [Constant Struct]
These are all the hash functions that Nettle implements.

Nettle also exports a list of all these hashes.

`const struct nettle_hash ** nettle_get_hashes` (*void*) [Function]
: Returns a NULL-terminated list of pointers to supported hash functions. This list can be used to dynamically enumerate or search the supported algorithms.

`nettle_hashes` [Macro]
: A macro expanding to a call to nettle_get_hashes, so that one could write, e.g., `nettle_hashes[0]->name` for the name of the first hash function on the list. In earlier versions, this was not a macro but the actual array of pointers. However, referring directly to the array makes the array size leak into the ABI in some cases.

7.2 Cipher functions

A *cipher* is a function that takes a message or *plaintext* and a secret *key* and transforms it to a *ciphertext*. Given only the ciphertext, but not the key, it should be hard to find the plaintext. Given matching pairs of plaintext and ciphertext, it should be hard to find the key.

There are two main classes of ciphers: Block ciphers and stream ciphers.

A block cipher can process data only in fixed size chunks, called *blocks*. Typical block sizes are 8 or 16 octets. To encrypt arbitrary messages, you usually have to pad it to an integral number of blocks, split it into blocks, and then process each block. The simplest way is to process one block at a time, independent of each other. That mode of operation is called *ECB*, Electronic Code Book mode. However, using ECB is usually a bad idea. For a start, plaintext blocks that are equal are transformed to ciphertext blocks that are equal; that leaks information about the plaintext. Usually you should apply the cipher is some "feedback mode", *CBC* (Cipher Block Chaining) and *CTR* (Counter mode) being two of of the most popular. See See Section 7.3 [Cipher modes], page 37, for information on how to apply CBC and CTR with Nettle.

A stream cipher can be used for messages of arbitrary length. A typical stream cipher is a keyed pseudo-random generator. To encrypt a plaintext message of n octets, you key the generator, generate n octets of pseudo-random data, and XOR it with the plaintext. To decrypt, regenerate the same stream using the key, XOR it to the ciphertext, and the plaintext is recovered.

Caution: The first rule for this kind of cipher is the same as for a One Time Pad: *never* ever use the same key twice.

A common misconception is that encryption, by itself, implies authentication. Say that you and a friend share a secret key, and you receive an encrypted message. You apply the key, and get a plaintext message that makes sense to you. Can you then be sure that it really was your friend that wrote the message you're reading? The answer is no. For example, if you were using a block cipher in ECB mode, an attacker may pick up the message on its way, and reorder, delete or repeat some of the blocks. Even if the attacker can't decrypt the message, he can change it so that you are not reading the same message as your friend wrote. If you are using a block cipher in CBC mode rather than ECB, or are using a stream cipher, the possibilities for this sort of attack are different, but the attacker can still make predictable changes to the message.

It is recommended to *always* use an authentication mechanism in addition to encrypting the messages. Popular choices are Message Authentication Codes like HMAC-SHA1 (see Section 7.5 [Keyed hash functions], page 60), or digital signatures like RSA.

Some ciphers have so called "weak keys", keys that results in undesirable structure after the key setup processing, and should be avoided. In Nettle, most key setup functions have no return value, but for ciphers with weak keys, the return value indicates whether or not the given key is weak. For good keys, key setup returns 1, and for weak keys, it returns 0. When possible, avoid algorithms that have weak keys. There are several good ciphers that don't have any weak keys.

To encrypt a message, you first initialize a cipher context for encryption or decryption with a particular key. You then use the context to process plaintext or ciphertext messages. The initialization is known as *key setup*. With Nettle, it is recommended to use each context struct for only one direction, even if some of the ciphers use a single key setup function that can be used for both encryption and decryption.

7.2.1 AES

AES is a block cipher, specified by NIST as a replacement for the older DES standard. The standard is the result of a competition between cipher designers. The winning design, also known as RIJNDAEL, was constructed by Joan Daemen and Vincent Rijnmen.

Like all the AES candidates, the winning design uses a block size of 128 bits, or 16 octets, and three possible key-size, 128, 192 and 256 bits (16, 24 and 32 octets) being the allowed key sizes. It does not have any weak keys. Nettle defines AES in '`<nettle/aes.h>`', and there is one context struct for each key size. (Earlier versions of Nettle used a single context struct, `struct aes_ctx`, for all key sizes. This interface kept for backwards compatibility).

`struct aes128_ctx` [Context struct]
`struct aes192_ctx` [Context struct]
`struct aes256_ctx` [Context struct]

`struct aes_ctx` [Context struct]
Alternative struct, for the old AES interface.

`AES_BLOCK_SIZE` [Constant]
The AES block-size, 16.

`AES128_KEY_SIZE` [Constant]
`AES192_KEY_SIZE` [Constant]
`AES256_KEY_SIZE` [Constant]
`AES_MIN_KEY_SIZE` [Constant]
`AES_MAX_KEY_SIZE` [Constant]

`AES_KEY_SIZE` [Constant]
Default AES key size, 32.

`void aes128_set_encrypt_key (`*struct aes128_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void aes128_set_decrypt_key (`*struct aes128_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void aes192_set_encrypt_key (`*struct aes192_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void aes192_set_decrypt_key (`*struct aes192_ctx* `*ctx`, *const uint8_t* `*key`) [Function]

`void aes256_set_encrypt_key` (*struct aes256_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

`void aes256_set_decrypt_key` (*struct aes256_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

`void aes_set_encrypt_key` (*struct aes_ctx* ***ctx***, *size_t* **length**, *const uint8_t* ***key***) [Function]

`void aes_set_decrypt_key` (*struct aes_ctx* ***ctx***, *size_t* **length**, *const uint8_t* ***key***) [Function]

Initialize the cipher, for encryption or decryption, respectively.

`void aes128_invert_key` (*struct aes128_ctx* ***dst***, *const struct aes128_ctx* ***src***) [Function]

`void aes192_invert_key` (*struct aes192_ctx* ***dst***, *const struct aes192_ctx* ***src***) [Function]

`void aes256_invert_key` (*struct aes256_ctx* ***dst***, *const struct aes256_ctx* ***src***) [Function]

`void aes_invert_key` (*struct aes_ctx* ***dst***, *const struct aes_ctx* ***src***) [Function]

Given a context *src* initialized for encryption, initializes the context struct *dst* for decryption, using the same key. If the same context struct is passed for both `src` and `dst`, it is converted in place. These functions are mainly useful for applications which needs to both encrypt and decrypt using the *same* key, because calling, e.g., `aes128_set_encrypt_key` and `aes128_invert_key`, is more efficient than calling `aes128_set_encrypt_key` and `aes128_set_decrypt_key`.

`void aes128_encrypt` (*struct aes128_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void aes192_encrypt` (*struct aes192_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void aes256_encrypt` (*struct aes256_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void aes_encrypt` (*struct aes_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void aes128_decrypt` (*struct aes128_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void aes192_decrypt` (*struct aes192_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void aes256_decrypt` (*struct aes256_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void aes_decrypt` (*struct aes_ctx* ***ctx***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Analogous to the encryption functions above.

7.2.2 ARCFOUR

ARCFOUR is a stream cipher, also known under the trade marked name RC4, and it is one of the fastest ciphers around. A problem is that the key setup of ARCFOUR is quite weak, you should never use keys with structure, keys that are ordinary passwords, or sequences of keys like "secret:1", "secret:2", ... If you have keys that don't look like random bit strings, and you want to use ARCFOUR, always hash the key before feeding it to ARCFOUR. Furthermore, the initial bytes of the generated key stream leak information about the key; for this reason, it is recommended to discard the first 512 bytes of the key stream.

```
/* A more robust key setup function for ARCFOUR */
void
arcfour_set_key_hashed(struct arcfour_ctx *ctx,
                       size_t length, const uint8_t *key)
{
  struct sha256_ctx hash;
  uint8_t digest[SHA256_DIGEST_SIZE];
  uint8_t buffer[0x200];

  sha256_init(&hash);
  sha256_update(&hash, length, key);
  sha256_digest(&hash, SHA256_DIGEST_SIZE, digest);

  arcfour_set_key(ctx, SHA256_DIGEST_SIZE, digest);
  arcfour_crypt(ctx, sizeof(buffer), buffer, buffer);
}
```

Nettle defines ARCFOUR in '`<nettle/arcfour.h>`'.

`struct arcfour_ctx` [Context struct]

`ARCFOUR_MIN_KEY_SIZE` [Constant]
Minimum key size, 1.

`ARCFOUR_MAX_KEY_SIZE` [Constant]
Maximum key size, 256.

`ARCFOUR_KEY_SIZE` [Constant]
Default ARCFOUR key size, 16.

`void arcfour_set_key` (*struct arcfour_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***key***) [Function]
Initialize the cipher. The same function is used for both encryption and decryption.

`void arcfour_crypt` (*struct arcfour_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Encrypt some data. The same function is used for both encryption and decryption. Unlike the block ciphers, this function modifies the context, so you can split the data into arbitrary chunks and encrypt them one after another. The result is the same as if you had called `arcfour_crypt` only once with all the data.

7.2.3 ARCTWO

ARCTWO (also known as the trade marked name RC2) is a block cipher specified in RFC 2268. Nettle also include a variation of the ARCTWO set key operation that lack one step, to be compatible with the reverse engineered RC2 cipher description, as described in a Usenet post to `sci.crypt` by Peter Gutmann.

ARCTWO uses a block size of 64 bits, and variable key-size ranging from 1 to 128 octets. Besides the key, ARCTWO also has a second parameter to key setup, the number of effective key bits, `ekb`. This parameter can be used to artificially reduce the key size. In practice, `ekb` is usually set equal to the input key size. Nettle defines ARCTWO in '`<nettle/arctwo.h>`'.

We do not recommend the use of ARCTWO; the Nettle implementation is provided primarily for interoperability with existing applications and standards.

`struct arctwo_ctx` [Context struct]

`ARCTWO_BLOCK_SIZE` [Constant]
The ARCTWO block-size, 8.

`ARCTWO_MIN_KEY_SIZE` [Constant]

`ARCTWO_MAX_KEY_SIZE` [Constant]

`ARCTWO_KEY_SIZE` [Constant]
Default ARCTWO key size, 8.

`void arctwo_set_key_ekb` (*struct arctwo_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***key***, *unsigned* ***ekb***) [Function]

`void arctwo_set_key` (*struct arctwo_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***key***) [Function]

`void arctwo_set_key_gutmann` (*struct arctwo_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***key***) [Function]
Initialize the cipher. The same function is used for both encryption and decryption. The first function is the most general one, which lets you provide both the variable size key, and the desired effective key size (in bits). The maximum value for *ekb* is 1024, and for convenience, `ekb = 0` has the same effect as `ekb = 1024`.

`arctwo_set_key(ctx, length, key)` is equivalent to `arctwo_set_key_ekb(ctx, length, key, 8*length)`, and `arctwo_set_key_gutmann(ctx, length, key)` is equivalent to `arctwo_set_key_ekb(ctx, length, key, 1024)`

`void arctwo_encrypt` (*struct arctwo_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void arctwo_decrypt` (*struct arctwo_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Analogous to `arctwo_encrypt`

7.2.4 BLOWFISH

BLOWFISH is a block cipher designed by Bruce Schneier. It uses a block size of 64 bits (8 octets), and a variable key size, up to 448 bits. It has some weak keys. Nettle defines BLOWFISH in '`<nettle/blowfish.h>`'.

`struct blowfish_ctx` [Context struct]

`BLOWFISH_BLOCK_SIZE` [Constant]
The BLOWFISH block-size, 8.

`BLOWFISH_MIN_KEY_SIZE` [Constant]
Minimum BLOWFISH key size, 8.

`BLOWFISH_MAX_KEY_SIZE` [Constant]
Maximum BLOWFISH key size, 56.

`BLOWFISH_KEY_SIZE` [Constant]
Default BLOWFISH key size, 16.

`int blowfish_set_key` (*struct blowfish_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***key**) [Function]
Initialize the cipher. The same function is used for both encryption and decryption. Checks for weak keys, returning 1 for good keys and 0 for weak keys. Applications that don't care about weak keys can ignore the return value.

`blowfish_encrypt` or `blowfish_decrypt` with a weak key will crash with an assert violation.

`void blowfish_encrypt` (*struct blowfish_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]
Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void blowfish_decrypt` (*struct blowfish_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]
Analogous to `blowfish_encrypt`

`int blowfish_bcrypt_hash` (*char* ***dst**, *size_t* **lenkey**, *const char* ***key**, *size_t* **lenscheme**, *const char* ***scheme**, *int* **log2rounds**, *const uint8_t* ***salt**) [Function]
Compute the bcrypt password hash. The function will return `0` if the hash cannot be computed due to invalid input. The function will return `1` and store the computed hash in the array pointed to by *dst*. The hash is computed based on the chosen *scheme*, number of rounds *log2rounds* and specified *salt*.

dst must point to a character array of at least `BLOWFISH_BCRYPT_HASH_SIZE` bytes.

key contains the plaintext password string of size *lenkey*.

scheme is of size *lenscheme* and contains either just the chosen scheme (valid schemes are: `2a`, `2b`, `2x` or `2y`), or (the prefix of) an existing hashed password (typically `$2b$10$...`).

log2rounds contains the log2 of the number of encryption rounds that must be used to compute the hash. If it is `-1` the value will be extracted from *scheme*.

salt should point to an array of `BLOWFISH_BCRYPT_BINSALT_SIZE` random bytes to be used to perturb the hash computation. If it is `NULL` the salt will be extracted from *scheme*.

Sample code to generate a bcrypt hash:

```
char cleartxtpassword[] = "ExamplePassword";
char scheme[] = "2b";
uint8_t salt[BLOWFISH_BCRYPT_BINSALT_SIZE];
...
/* Make sure that salt is filled with random bytes */
...
char hashedresult[BLOWFISH_BCRYPT_HASH_SIZE];
int result = blowfish_bcrypt(hashedresult,
                             sizeof(cleartxtpassword) - 1, cleartxtpassword,
                             sizeof(scheme) - 1, scheme, 10, salt);
if (result)
  printf("%s\n", hashedresult);
```

`int blowfish_bcrypt_verify` (*size_t* **`lenkey`**, *const char* ***`key`**, *size_t* **`lenhashed`**, *const char* ***`hashed`**) [Function]

Verifies the bcrypt password hash against the supplied plaintext password. The function will return `0` if the password does not match. The function will return `1` if the password matches.

key contains the plaintext password string of size *lenkey*.

hashed contains the hashed string of size *lenhashed* to compare with.

Sample code to verify a bcrypt hash:

```
char cleartxtpassword[] = "ExamplePassword";
char existinghashed[] =
           "$2y$"  /* Hash algorithm version */
           "10"   /* 2^10 hash rounds (strength) */
           "$"   /* separator */
           "1b2lPgo4XumibnJGN3r3sO" /* base64 encoded 16-byte salt */
           "u7wE7xNfYDKlAxZffJDCJdVfFTAyevu"; /* Hashedpart */
if (blowfish_bcrypt_verify(sizeof(cleartxtpassword) - 1, cleartxtpassword,
                           sizeof(existinghashed) - 1, existinghashed))
  printf("Password is correct.");
else
  printf("Password is incorrect.");
```

7.2.5 Camellia

Camellia is a block cipher developed by Mitsubishi and Nippon Telegraph and Telephone Corporation, described in *RFC3713*. It is recommended by some Japanese and European authorities as an alternative to AES, and it is one of the selected algorithms in the New European Schemes for Signatures, Integrity and Encryption (NESSIE) project. The algorithm is patented. The implementation in Nettle is derived from the implementation

released by NTT under the GNU LGPL (v2.1 or later), and relies on the implicit patent license of the LGPL. There is also a statement of royalty-free licensing for Camellia at `http://www.ntt.co.jp/news/news01e/0104/010417.html`, but this statement has some limitations which seem problematic for free software.

Camellia uses a the same block size and key sizes as AES: The block size is 128 bits (16 octets), and the supported key sizes are 128, 192, and 256 bits. The variants with 192 and 256 bit keys are identical, except for the key setup. Nettle defines Camellia in '`<nettle/camellia.h>`', and there is one context struct for each key size. (Earlier versions of Nettle used a single context struct, `struct camellia_ctx`, for all key sizes. This interface kept for backwards compatibility).

`struct camellia128_ctx` [Context struct]
`struct camellia192_ctx` [Context struct]
`struct camellia256_ctx` [Context struct]
Contexts structs. Actually, `camellia192_ctx` is an alias for `camellia256_ctx`.

`struct camellia_ctx` [Context struct]
Alternative struct, for the old Camellia interface.

`CAMELLIA_BLOCK_SIZE` [Constant]
The CAMELLIA block-size, 16.

`CAMELLIA128_KEY_SIZE` [Constant]
`CAMELLIA192_KEY_SIZE` [Constant]
`CAMELLIA256_KEY_SIZE` [Constant]
`CAMELLIA_MIN_KEY_SIZE` [Constant]
`CAMELLIA_MAX_KEY_SIZE` [Constant]

`CAMELLIA_KEY_SIZE` [Constant]
Default CAMELLIA key size, 32.

`void camellia128_set_encrypt_key (`*struct camellia128_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void camellia128_set_decrypt_key (`*struct camellia128_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void camellia192_set_encrypt_key (`*struct camellia192_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void camellia192_set_decrypt_key (`*struct camellia192_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void camellia256_set_encrypt_key (`*struct camellia256_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void camellia256_set_decrypt_key (`*struct camellia256_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
`void camellia_set_encrypt_key (`*struct camellia_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*key`) [Function]
`void camellia_set_decrypt_key (`*struct camellia_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*key`) [Function]
Initialize the cipher, for encryption or decryption, respectively.

`void camellia128_invert_key` (*struct camellia128_ctx* ***dst***, *const struct camellia128_ctx* ***src***) [Function]

`void camellia192_invert_key` (*struct camellia192_ctx* ***dst***, *const struct camellia192_ctx* ***src***) [Function]

`void camellia256_invert_key` (*struct camellia256_ctx* ***dst***, *const struct camellia256_ctx* ***src***) [Function]

`void camellia_invert_key` (*struct camellia_ctx* ***dst***, *const struct camellia_ctx* ***src***) [Function]

Given a context *src* initialized for encryption, initializes the context struct *dst* for decryption, using the same key. If the same context struct is passed for both `src` and `dst`, it is converted in place. These functions are mainly useful for applications which needs to both encrypt and decrypt using the *same* key.

`void camellia128_crypt` (*struct camellia128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void camellia192_crypt` (*struct camellia192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void camellia256_crypt` (*struct camellia256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void camellia_crypt` (*struct camellia_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

The same function is used for both encryption and decryption. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

7.2.6 CAST128

CAST-128 is a block cipher, specified in *RFC 2144*. It uses a 64 bit (8 octets) block size, and a key size of 128 bits. It is possible, but discouraged, to use the same algorithm with shorter keys. Nettle refers to the variant with variable key size as CAST-5. Keys for CAST-5 are zero padded to 128 bits, and with very short keys, less than 80 bits, encryption also uses fewer rounds than CAST128. Nettle defines cast128 in '`<nettle/cast128.h>`'.

`struct cast128_ctx` [Context struct]

`CAST128_BLOCK_SIZE` [Constant]

The CAST128 block-size, 8.

`CAST128_KEY_SIZE` [Constant]

The CAST128 key size, 16.

`CAST5_MIN_KEY_SIZE` [Constant]

Minimum CAST5 key size, 5.

`CAST5_MAX_KEY_SIZE` [Constant]

Maximum CAST5 key size, 16. With 16 octets key (128 bits), CAST-5 is the same as CAST-128.

`void cast128_set_key` (*struct cast128_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

Initialize the cipher. The same function is used for both encryption and decryption.

`void cast128_encrypt` (*struct cast128_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void cast128_decrypt` (*struct cast128_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

Analogous to `cast128_encrypt`

`void cast5_set_key` (*struct cast128_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***key**) [Function]

Initialize the cipher. This variant of the key setup takes the key size as argument. The same function is used for both encryption and decryption.

7.2.7 ChaCha

ChaCha is a variant of the stream cipher Salsa20, also designed by D. J. Bernstein. For more information on Salsa20, see below. Nettle defines ChaCha in '`<nettle/chacha.h>`'.

`struct chacha_ctx` [Context struct]

`CHACHA_KEY_SIZE` [Constant]

ChaCha key size, 32.

`CHACHA_BLOCK_SIZE` [Constant]

ChaCha block size, 64.

`CHACHA_NONCE_SIZE` [Constant]

Size of the nonce, 8.

`CHACHA_COUNTER_SIZE` [Constant]

Size of the counter, 8.

`void chacha_set_key` (*struct chacha_ctx* ***ctx**, *const uint8_t* ***key**) [Function]

Initialize the cipher. The same function is used for both encryption and decryption. Before using the cipher, you *must* also call `chacha_set_nonce`, see below.

`void chacha_set_nonce` (*struct chacha_ctx* ***ctx**, *const uint8_t* ***nonce**) [Function]

Sets the nonce. It is always of size `CHACHA_NONCE_SIZE`, 8 octets. This function also initializes the block counter, setting it to zero.

`void chacha_set_counter` (*struct chacha_ctx* ***ctx**, *const uint8_t* ***counter**) [Function]

Sets the block counter. It is always of size `CHACHA_COUNTER_SIZE`, 8 octets. This is rarely needed since `chacha_set_nonce` initializes the block counter to zero. When it is still necessary, this function must be called after `chacha_set_nonce`.

`void chacha_crypt` (*struct chacha_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

Encrypts or decrypts the data of a message, using ChaCha. When a message is encrypted using a sequence of calls to `chacha_crypt`, all but the last call *must* use a length that is a multiple of `CHACHA_BLOCK_SIZE`.

7.2.7.1 32-bit counter variant

While the original paper uses 64-bit counter value, the variant defined in *RFC 8439* uses 32-bit counter value. This variant is particularly useful for see Section 7.4.4 [ChaCha-Poly1305], page 57 AEAD construction, which supports 12-octet nonces.

`CHACHA_NONCE96_SIZE` [Constant]
Size of the nonce, 12.

`CHACHA_COUNTER32_SIZE` [Constant]
Size of the counter, 4.

`void chacha_set_nonce96 (`*`struct chacha_ctx *ctx, const uint8_t *nonce`*`)` [Function]
Sets the nonce. This is similar to the above `chacha_set_nonce`, but the input is always of size `CHACHA_NONCE96_SIZE`, 12 octets.

`void chacha_set_counter32 (`*`struct chacha_ctx *ctx, const uint8_t *counter`*`)` [Function]
Sets the block counter. This is similar to the above `chacha_set_counter`, but the input is always of size `CHACHA_COUNTER32_SIZE`, 4 octets.

`void chacha_crypt32 (`*`struct chacha_ctx *ctx, size_t length, uint8_t *dst, const uint8_t *src`*`)` [Function]
Encrypts or decrypts the data of a message, using ChaCha. This is similar to the above `chacha_crypt`, but it assumes the internal counter value is 32-bit long and the nonce is 96-bit long.

7.2.8 DES

DES is the old Data Encryption Standard, specified by NIST. It uses a block size of 64 bits (8 octets), and a key size of 56 bits. However, the key bits are distributed over 8 octets, where the least significant bit of each octet may be used for parity. A common way to use DES is to generate 8 random octets in some way, then set the least significant bit of each octet to get odd parity, and initialize DES with the resulting key.

The key size of DES is so small that keys can be found by brute force, using specialized hardware or lots of ordinary work stations in parallel. One shouldn't be using plain DES at all today, if one uses DES at all one should be using "triple DES", see DES3 below.

DES also has some weak keys. Nettle defines DES in '`<nettle/des.h>`'.

`struct des_ctx` [Context struct]

`DES_BLOCK_SIZE` [Constant]
The DES block-size, 8.

`DES_KEY_SIZE` [Constant]
DES key size, 8.

`int des_set_key (`*`struct des_ctx *ctx, const uint8_t *key`*`)` [Function]
Initialize the cipher. The same function is used for both encryption and decryption. Parity bits are ignored. Checks for weak keys, returning 1 for good keys and 0 for weak keys. Applications that don't care about weak keys can ignore the return value.

`void des_encrypt` (*struct des_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void des_decrypt` (*struct des_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

Analogous to `des_encrypt`

`int des_check_parity` (*size_t* **length**, *const uint8_t* ***key**); [Function]

Checks that the given key has correct, odd, parity. Returns 1 for correct parity, and 0 for bad parity.

`void des_fix_parity` (*size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

Adjusts the parity bits to match DES's requirements. You need this function if you have created a random-looking string by a key agreement protocol, and want to use it as a DES key. *dst* and *src* may be equal.

7.2.9 DES3

The inadequate key size of DES has already been mentioned. One way to increase the key size is to pipe together several DES boxes with independent keys. It turns out that using two DES ciphers is not as secure as one might think, even if the key size of the combination is a respectable 112 bits.

The standard way to increase DES's key size is to use three DES boxes. The mode of operation is a little peculiar: the middle DES box is wired in the reverse direction. To encrypt a block with DES3, you encrypt it using the first 56 bits of the key, then *decrypt* it using the middle 56 bits of the key, and finally encrypt it again using the last 56 bits of the key. This is known as "ede" triple-DES, for "encrypt-decrypt-encrypt".

The "ede" construction provides some backward compatibility, as you get plain single DES simply by feeding the same key to all three boxes. That should help keeping down the gate count, and the price, of hardware circuits implementing both plain DES and DES3.

DES3 has a key size of 168 bits, but just like plain DES, useless parity bits are inserted, so that keys are represented as 24 octets (192 bits). As a 112 bit key is large enough to make brute force attacks impractical, some applications uses a "two-key" variant of triple-DES. In this mode, the same key bits are used for the first and the last DES box in the pipe, while the middle box is keyed independently. The two-key variant is believed to be secure, i.e. there are no known attacks significantly better than brute force.

Naturally, it's simple to implement triple-DES on top of Nettle's DES functions. Nettle includes an implementation of three-key "ede" triple-DES, it is defined in the same place as plain DES, '`<nettle/des.h>`'.

`struct des3_ctx` [Context struct]

`DES3_BLOCK_SIZE` [Constant]

The DES3 block-size is the same as DES_BLOCK_SIZE, 8.

`DES3_KEY_SIZE` [Constant]
DES key size, 24.

`int des3_set_key` (*struct des3_ctx* *`ctx`, *const uint8_t* *`key`) [Function]
Initialize the cipher. The same function is used for both encryption and decryption. Parity bits are ignored. Checks for weak keys, returning 1 if all three keys are good keys, and 0 if one or more key is weak. Applications that don't care about weak keys can ignore the return value.

For random-looking strings, you can use `des_fix_parity` to adjust the parity bits before calling `des3_set_key`.

`void des3_encrypt` (*struct des3_ctx* *`ctx`, *size_t* `length`, *uint8_t* *`dst`, *const uint8_t* *`src`) [Function]
Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void des3_decrypt` (*struct des3_ctx* *`ctx`, *size_t* `length`, *uint8_t* *`dst`, *const uint8_t* *`src`) [Function]
Analogous to `des_encrypt`

7.2.10 Salsa20

Salsa20 is a fairly recent stream cipher designed by D. J. Bernstein. It is built on the observation that a cryptographic hash function can be used for encryption: Form the hash input from the secret key and a counter, xor the hash output and the first block of the plaintext, then increment the counter to process the next block (similar to CTR mode, see see Section 7.3.2 [CTR], page 38). Bernstein defined an encryption algorithm, Snuffle, in this way to ridicule United States export restrictions which treated hash functions as nice and harmless, but ciphers as dangerous munitions.

Salsa20 uses the same idea, but with a new specialized hash function to mix key, block counter, and a couple of constants. It's also designed for speed; on x86_64, it is currently the fastest cipher offered by nettle. It uses a block size of 512 bits (64 octets) and there are two specified key sizes, 128 and 256 bits (16 and 32 octets).

Caution: The hash function used in Salsa20 is *not* directly applicable for use as a general hash function. It's *not* collision resistant if arbitrary inputs are allowed, and furthermore, the input and output is of fixed size.

When using Salsa20 to process a message, one specifies both a key and a *nonce*, the latter playing a similar rôle to the initialization vector (IV) used with CBC or CTR mode. One can use the same key for several messages, provided one uses a unique random iv for each message. The iv is 64 bits (8 octets). The block counter is initialized to zero for each message, and is also 64 bits (8 octets). Nettle defines Salsa20 in '`<nettle/salsa20.h>`'.

`struct salsa20_ctx` [Context struct]

`SALSA20_128_KEY_SIZE` [Constant]
`SALSA20_256_KEY_SIZE` [Constant]
The two supported key sizes, 16 and 32 octets.

`SALSA20_KEY_SIZE` [Constant]
Recommended key size, 32.

`SALSA20_BLOCK_SIZE` [Constant]
Salsa20 block size, 64.

`SALSA20_NONCE_SIZE` [Constant]
Size of the nonce, 8.

`void salsa20_128_set_key` (*struct salsa20_ctx* ***ctx**, *const uint8_t* ***key**) [Function]
`void salsa20_256_set_key` (*struct salsa20_ctx* ***ctx**, *const uint8_t* ***key**) [Function]
`void salsa20_set_key` (*struct salsa20_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***key**) [Function]
Initialize the cipher. The same function is used for both encryption and decryption. `salsa20_128_set_key` and `salsa20_128_set_key` use a fix key size each, 16 and 32 octets, respectively. The function `salsa20_set_key` is provided for backwards compatibility, and the *length* argument must be either 16 or 32. Before using the cipher, you *must* also call `salsa20_set_nonce`, see below.

`void salsa20_set_nonce` (*struct salsa20_ctx* ***ctx**, *const uint8_t* ***nonce**) [Function]
Sets the nonce. It is always of size `SALSA20_NONCE_SIZE`, 8 octets. This function also initializes the block counter, setting it to zero.

`void salsa20_crypt` (*struct salsa20_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]
Encrypts or decrypts the data of a message, using salsa20. When a message is encrypted using a sequence of calls to `salsa20_crypt`, all but the last call *must* use a length that is a multiple of `SALSA20_BLOCK_SIZE`.

The full salsa20 cipher uses 20 rounds of mixing. Variants of Salsa20 with fewer rounds are possible, and the 12-round variant is specified by eSTREAM, see `http://www.ecrypt.eu.org/stream/finallist.html`. Nettle calls this variant `salsa20r12`. It uses the same context struct and key setup as the full salsa20 cipher, but a separate function for encryption and decryption.

`void salsa20r12_crypt` (*struct salsa20_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]
Encrypts or decrypts the data of a message, using salsa20 reduced to 12 rounds.

7.2.11 SERPENT

SERPENT is one of the AES finalists, designed by Ross Anderson, Eli Biham and Lars Knudsen. Thus, the interface and properties are similar to AES'. One peculiarity is that it is quite pointless to use it with anything but the maximum key size, smaller keys are just padded to larger ones. Nettle defines SERPENT in '`<nettle/serpent.h>`'.

`struct serpent_ctx` [Context struct]

`SERPENT_BLOCK_SIZE` [Constant]
The SERPENT block-size, 16.

`SERPENT_MIN_KEY_SIZE` [Constant]
Minimum SERPENT key size, 16.

`SERPENT_MAX_KEY_SIZE` [Constant]
Maximum SERPENT key size, 32.

`SERPENT_KEY_SIZE` [Constant]
Default SERPENT key size, 32.

`void serpent_set_key` (*struct serpent_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***key***) [Function]
Initialize the cipher. The same function is used for both encryption and decryption.

`void serpent_encrypt` (*struct serpent_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void serpent_decrypt` (*struct serpent_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Analogous to `serpent_encrypt`

7.2.12 TWOFISH

Another AES finalist, this one designed by Bruce Schneier and others. Nettle defines it in '`<nettle/twofish.h>`'.

`struct twofish_ctx` [Context struct]

`TWOFISH_BLOCK_SIZE` [Constant]
The TWOFISH block-size, 16.

`TWOFISH_MIN_KEY_SIZE` [Constant]
Minimum TWOFISH key size, 16.

`TWOFISH_MAX_KEY_SIZE` [Constant]
Maximum TWOFISH key size, 32.

`TWOFISH_KEY_SIZE` [Constant]
Default TWOFISH key size, 32.

`void twofish_set_key` (*struct twofish_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***key***) [Function]
Initialize the cipher. The same function is used for both encryption and decryption.

`void twofish_encrypt` (*struct twofish_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Encryption function. *length* must be an integral multiple of the block size. If it is more than one block, the data is processed in ECB mode. `src` and `dst` may be equal, but they must not overlap in any other way.

`void twofish_decrypt` (*struct twofish_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Analogous to `twofish_encrypt`

7.2.13 The `struct nettle_cipher` abstraction

Nettle includes a struct including information about some of the more regular cipher functions. It can be useful for applications that need a simple way to handle various algorithms. Nettle defines these structs in '`<nettle/nettle-meta.h>`'.

`struct nettle_cipher` *name context_size block_size key_size set_encrypt_key set_decrypt_key encrypt decrypt* [Meta struct]

The last four attributes are function pointers, of types `nettle_set_key_func *` and `nettle_cipher_func *`. The first argument to these functions is a `const void *` pointer to a context struct, which is of size `context_size`.

`struct nettle_cipher nettle_aes128` [Constant Struct]
`struct nettle_cipher nettle_aes192` [Constant Struct]
`struct nettle_cipher nettle_aes256` [Constant Struct]
`struct nettle_cipher nettle_arctwo40` [Constant Struct]
`struct nettle_cipher nettle_arctwo64` [Constant Struct]
`struct nettle_cipher nettle_arctwo128` [Constant Struct]
`struct nettle_cipher nettle_arctwo_gutmann128` [Constant Struct]
`struct nettle_cipher nettle_arcfour128` [Constant Struct]
`struct nettle_cipher nettle_camellia128` [Constant Struct]
`struct nettle_cipher nettle_camellia192` [Constant Struct]
`struct nettle_cipher nettle_camellia256` [Constant Struct]
`struct nettle_cipher nettle_cast128` [Constant Struct]
`struct nettle_cipher nettle_serpent128` [Constant Struct]
`struct nettle_cipher nettle_serpent192` [Constant Struct]
`struct nettle_cipher nettle_serpent256` [Constant Struct]
`struct nettle_cipher nettle_twofish128` [Constant Struct]
`struct nettle_cipher nettle_twofish192` [Constant Struct]
`struct nettle_cipher nettle_twofish256` [Constant Struct]

Nettle includes such structs for all the *regular* ciphers, i.e. ones without weak keys or other oddities.

Nettle also exports a list of all these ciphers without weak keys or other oddities.

`const struct nettle_cipher ** nettle_get_ciphers` (*void*) [Function]

Returns a NULL-terminated list of pointers to supported block ciphers. This list can be used to dynamically enumerate or search the supported algorithms.

`nettle_ciphers` [Macro]
A macro expanding to a call to nettle_get_ciphers. In earlier versions, this was not a macro but the actual array of pointers.

7.3 Cipher modes

Cipher modes of operation specifies the procedure to use when encrypting a message that is larger than the cipher's block size. As explained in See Section 7.2 [Cipher functions], page 21, splitting the message into blocks and processing them independently with the block cipher (Electronic Code Book mode, ECB), leaks information.

Besides ECB, Nettle provides several other modes of operation: Cipher Block Chaining (CBC), Counter mode (CTR), Cipher Feedback (CFB and CFB8), XEX-based tweaked-codebook mode with ciphertext stealing (XTS) and a couple of AEAD modes (see Section 7.4 [Authenticated encryption], page 44). CBC is widely used, but there are a few subtle issues of information leakage, see, e.g., SSH CBC vulnerability (`http://www.kb.cert.org/vuls/id/958563`). Today, CTR is usually preferred over CBC.

Modes like CBC, CTR, CFB and CFB8 provide *no* message authentication, and should always be used together with a MAC (see Section 7.5 [Keyed hash functions], page 60) or signature to authenticate the message.

7.3.1 Cipher Block Chaining

When using CBC mode, plaintext blocks are not encrypted independently of each other, like in Electronic Cook Book mode. Instead, when encrypting a block in CBC mode, the previous ciphertext block is XORed with the plaintext before it is fed to the block cipher. When encrypting the first block, a random block called an *IV*, or Initialization Vector, is used as the "previous ciphertext block". The IV should be chosen randomly, but it need not be kept secret, and can even be transmitted in the clear together with the encrypted data.

In symbols, if `E_k` is the encryption function of a block cipher, and `IV` is the initialization vector, then `n` plaintext blocks `M_1`,... `M_n` are transformed into `n` ciphertext blocks `C_1`,... `C_n` as follows:

```
C_1 = E_k(IV  XOR M_1)
C_2 = E_k(C_1 XOR M_2)

...

C_n = E_k(C_(n-1) XOR M_n)
```

Nettle's includes two functions for applying a block cipher in Cipher Block Chaining (CBC) mode, one for encryption and one for decryption. These functions uses `void *` to pass cipher contexts around.

`void cbc_encrypt` (*const void *ctx*, *nettle_cipher_func *f*, *size_t* `block_size`, *uint8_t *iv*, *size_t* `length`, *uint8_t *dst*, *const uint8_t *src*) [Function]

`void cbc_decrypt` (*const void *ctx*, *nettle_cipher_func *f*, *size_t* `block_size`, *uint8_t *iv*, *size_t* `length`, *uint8_t *dst*, *const uint8_t *src*) [Function]

Applies the encryption or decryption function *f* in CBC mode. The final ciphertext block processed is copied into *iv* before returning, so that a large message can be processed by a sequence of calls to `cbc_encrypt`. The function *f* is of type

`void f (void *ctx, size_t length, uint8_t dst, const uint8_t *src)`,

and the `cbc_encrypt` and `cbc_decrypt` functions pass their argument *ctx* on to *f*.

There are also some macros to help use these functions correctly.

`CBC_CTX (context_type, block_size)` [Macro]

Expands to

```
{
   context_type ctx;
   uint8_t iv[block_size];
}
```

It can be used to define a CBC context struct, either directly,

```
struct CBC_CTX(struct aes_ctx, AES_BLOCK_SIZE) ctx;
```

or to give it a struct tag,

```
struct aes_cbc_ctx CBC_CTX (struct aes_ctx, AES_BLOCK_SIZE);
```

`CBC_SET_IV (ctx, iv)` [Macro]

First argument is a pointer to a context struct as defined by `CBC_CTX`, and the second is a pointer to an Initialization Vector (IV) that is copied into that context.

`CBC_ENCRYPT (ctx, f, length, dst, src)` [Macro]

`CBC_DECRYPT (ctx, f, length, dst, src)` [Macro]

A simpler way to invoke `cbc_encrypt` and `cbc_decrypt`. The first argument is a pointer to a context struct as defined by `CBC_CTX`, and the second argument is an encryption or decryption function following Nettle's conventions. The last three arguments define the source and destination area for the operation.

These macros use some tricks to make the compiler display a warning if the types of *f* and *ctx* don't match, e.g. if you try to use an `struct aes_ctx` context with the `des_encrypt` function.

7.3.2 Counter mode

Counter mode (CTR) uses the block cipher as a keyed pseudo-random generator. The output of the generator is XORed with the data to be encrypted. It can be understood as a way to transform a block cipher to a stream cipher.

The message is divided into `n` blocks `M_1`,... `M_n`, where `M_n` is of size `m` which may be smaller than the block size. Except for the last block, all the message blocks must be of size equal to the cipher's block size.

If `E_k` is the encryption function of a block cipher, `IC` is the initial counter, then the `n` plaintext blocks are transformed into `n` ciphertext blocks `C_1`,... `C_n` as follows:

```
C_1 = E_k(IC) XOR M_1
C_2 = E_k(IC + 1) XOR M_2

...

C_(n-1) = E_k(IC + n - 2) XOR M_(n-1)
C_n = E_k(IC + n - 1) [1..m] XOR M_n
```

The IC is the initial value for the counter, it plays a similar rôle as the IV for CBC. When adding, `IC + x`, IC is interpreted as an integer, in network byte order. For the last block, `E_k(IC + n - 1) [1..m]` means that the cipher output is truncated to `m` bytes.

`void ctr_crypt` (*const void ***ctx***, *nettle_cipher_func ***f***, *size_t* ***block_size***, *uint8_t *ctr*, *size_t* ***length***, *uint8_t *dst*, *const uint8_t *src*) [Function]

Applies the encryption function *f* in CTR mode. Note that for CTR mode, encryption and decryption is the same operation, and hence *f* should always be the encryption function for the underlying block cipher.

When a message is encrypted using a sequence of calls to `ctr_crypt`, all but the last call *must* use a length that is a multiple of the block size.

Like for CBC, there are also a couple of helper macros.

`CTR_CTX` (*context_type*, *block_size*) [Macro]

Expands to

```
{
   context_type ctx;
   uint8_t ctr[block_size];
}
```

`CTR_SET_COUNTER` (*ctx*, *iv*) [Macro]

First argument is a pointer to a context struct as defined by `CTR_CTX`, and the second is a pointer to an initial counter that is copied into that context.

`CTR_CRYPT` (*ctx*, *f*, *length*, *dst*, *src*) [Macro]

A simpler way to invoke `ctr_crypt`. The first argument is a pointer to a context struct as defined by `CTR_CTX`, and the second argument is an encryption function following Nettle's conventions. The last three arguments define the source and destination area for the operation.

7.3.3 Cipher Feedback mode

Cipher Feedback mode (CFB) and Cipher Feedback 8-bit mode (CFB8) being close relatives to both CBC mode and CTR mode borrow some characteristics from stream ciphers.

For CFB the message is divided into `n` blocks `M_1`,... `M_n`, where `M_n` is of size `m` which may be smaller than the block size. Except for the last block, all the message blocks must be of size equal to the cipher's block size.

If `E_k` is the encryption function of a block cipher, `IV` is the initialization vector, then the `n` plaintext blocks are transformed into `n` ciphertext blocks `C_1`,... `C_n` as follows:

```
C_1 = E_k(IV) XOR M_1
C_2 = E_k(C_1) XOR M_2

...

C_(n-1) = E_k(C_(n - 2)) XOR M_(n-1)
C_n = E_k(C_(n - 1)) [1..m] XOR M_n
```

Cipher Feedback 8-bit mode (CFB8) transforms block cipher into a stream cipher. The message is encrypted byte after byte, not requiring any padding.

If `E_k` is the encryption function of a block cipher, `b` is `E_k` block size, `IV` is the initialization vector, then the `n` plaintext bytes are transformed into `n` ciphertext bytes `C_1`,... `C_n` as follows:

```
I_1 = IV
C_1 = E_k(I_1) [1..8] XOR M_1
I_2 = I_1 [9..b] << 8 | C_1
C_2 = E_k(I_2) [1..8] XOR M_2

...

I_(n-1) = I_(n-2) [9..b] << 8 | C_(n-2)
C_(n-1) = E_k(I_(n-1)) [1..8] XOR M_(n-1)
I_n = I_(n-1) [9..b] << 8 | C_(n-1)
C_n = E_k(I_n) [1..8] XOR M_n
```

Nettle's includes functions for applying a block cipher in Cipher Feedback (CFB) and Cipher Feedback 8-bit (CFB8) modes. These functions uses `void *` to pass cipher contexts around.

`void cfb_encrypt` (*const void ***ctx***, *nettle_cipher_func **f***, *size_t* ***block_size***, *uint8_t **iv***, *size_t* ***length***, *uint8_t **dst***, *const uint8_t **src***) [Function]

`void cfb_decrypt` (*const void ***ctx***, *nettle_cipher_func **f***, *size_t* ***block_size***, *uint8_t **iv***, *size_t* ***length***, *uint8_t **dst***, *const uint8_t **src***) [Function]

Applies the encryption or decryption function *f* in CFB mode. The final ciphertext block processed is copied into *iv* before returning, so that a large message can be processed by a sequence of calls to `cfb_encrypt`. Note that for CFB mode internally uses encryption only function and hence *f* should always be the encryption function for the underlying block cipher.

When a message is encrypted using a sequence of calls to `cfb_encrypt`, all but the last call *must* use a length that is a multiple of the block size.

`void cfb8_encrypt` (*const void ***ctx***, *nettle_cipher_func **f***, *size_t* ***block_size***, *uint8_t **iv***, *size_t* ***length***, *uint8_t **dst***, *const uint8_t **src***) [Function]

`void cfb8_decrypt` (*const void ***ctx***, *nettle_cipher_func **f***, *size_t* ***block_size***, *uint8_t **iv***, *size_t* ***length***, *uint8_t **dst***, *const uint8_t **src***) [Function]

Applies the encryption or decryption function *f* in CFB8 mode. The final IV block processed is copied into *iv* before returning, so that a large message can be processed by a sequence of calls to `cfb8_encrypt`. Note that for CFB8 mode internally uses

encryption only function and hence *f* should always be the encryption function for the underlying block cipher.

Like for CBC, there are also a couple of helper macros.

`CFB_CTX` (*context_type*, *block_size*) [Macro]
Expands to

```
{
   context_type ctx;
   uint8_t iv[block_size];
}
```

`CFB_SET_IV`(*ctx*, *iv*) [Macro]
First argument is a pointer to a context struct as defined by `CFB_CTX`, and the second is a pointer to an initialization vector that is copied into that context.

`CFB_ENCRYPT` (*ctx*, *f*, *length*, *dst*, *src*) [Macro]
A simpler way to invoke `cfb_encrypt`. The first argument is a pointer to a context struct as defined by `CFB_CTX`, and the second argument is an encryption function following Nettle's conventions. The last three arguments define the source and destination area for the operation.

`CFB_DECRYPT` (*ctx*, *f*, *length*, *dst*, *src*) [Macro]
A simpler way to invoke `cfb_decrypt`. The first argument is a pointer to a context struct as defined by `CFB_CTX`, and the second argument is an encryption function following Nettle's conventions. The last three arguments define the source and destination area for the operation.

`CFB8_CTX` (*context_type*, *block_size*) [Macro]
Expands to

```
{
   context_type ctx;
   uint8_t iv[block_size];
}
```

`CFB8_SET_IV` (*ctx*, *iv*) [Macro]
First argument is a pointer to a context struct as defined by `CFB8_CTX`, and the second is a pointer to an initialization vector that is copied into that context.

`CFB8_ENCRYPT` (*ctx*, *f*, *length*, *dst*, *src*) [Macro]
A simpler way to invoke `cfb8_encrypt`. The first argument is a pointer to a context struct as defined by `CFB8_CTX`, and the second argument is an encryption function following Nettle's conventions. The last three arguments define the source and destination area for the operation.

`CFB8_DECRYPT` (*ctx*, *f*, *length*, *dst*, *src*) [Macro]
A simpler way to invoke `cfb8_decrypt`. The first argument is a pointer to a context struct as defined by `CFB8_CTX`, and the second argument is an encryption function following Nettle's conventions. The last three arguments define the source and destination area for the operation.

7.3.4 XEX-based tweaked-codebook mode with ciphertext stealing

XEX-based tweaked-codebook mode with ciphertext stealing (XTS) is a block mode like (CBC) but tweaked to be able to encrypt partial blocks via a technique called ciphertext stealing, where the last complete block of ciphertext is split and part returned as the last block and part used as plaintext for the second to last block. This mode is principally used to encrypt data at rest where it is not possible to store additional metadata or blocks larger than the plain text. The most common usage is for disk encryption. Due to the fact that ciphertext expansion is not possible, data is not authenticated. This mode should not be used where authentication is critical.

The message is divided into `n` blocks `M_1`,... `M_n`, where `M_n` is of size `m` which may be smaller than the block size. XTS always uses a fixed blocksize of 128 bit (16 bytes) length.

Unlike other modes, the key is double the size of that for the used cipher mode (for example 256bit for AES-128 and 512bit for AES-256).

XTS encryption mode operates given:

- A multiplication by a primitive element alpha. `MUL a^j` here represents the multiplication, where `j` is the power of alpha, and the input value is converted into a 16 bytes array `a_0[k], k = 0,1,..,15`. The multiplication is calculated as `a_(j+1)[0] = (2(a_j[0] mod 128)) XOR (135 * floor(a_j[15]/128)  a_(j+1)[k] = (2(a_j[k] mod 128)) XOR (floor(a_j[k-1]/128), k = 1,2,..15` Note that this operation is practically a 1 bit left shift operation with carry propagating from one byte to the next, and if the last bit shift results in a carry the decimal value 135 is XORed into the first byte.
- The encryption key is provided as the `Key = K1 | K2`, where `|` denotes string concatenation. `E_k1` is the encryption function of the block cipher using `K1` as the key, and `E_k2` is the same encryption function using `K2`
- A 128 bit tweak value is provided as input and is denoted as `IV`

The `n` plaintext blocks are transformed into `n` ciphertext blocks `C_1`,... `C_n` as follows.

For a plaintext length that is a perfect multiple of the XTS block size:

```
T_1 = E_k2(IV)
C_1 = E_k1(P_1 XOR T_1) XOR T_1

...

T_n = T_(n-1) MUL a
C_n = E_k1(P_n XOR T_n) XOR T_n
```

For any other plaintext lengths:

```
T_1 = E_k2(IV)
C_1 = E_k1(P_1 XOR T_1) XOR T_1

...

T_(n-2) = T_(n-3) MUL a
C_(n-2) = E_k1(P_(n-2) XOR T_(n-2)) XOR T_(n-2)
```

```
T_(n-1) = T_(n-2) MUL a
CC_(n-1) = E_k1(P_(n-1) XOR T_(n-1)) XOR T_(n-1)

T_n = T_(n-1) MUL a
PP = [1..m]Pn | [m+1..128]CC_(n-1)
C_(n-1) = E_k1(PP XOR T_n) XOR T_n

C_n = [1..m]CC_(n-1)
```

7.3.4.1 General (XTS) interface.

The two general functions to encrypt and decrypt using the XTS block cipher mode are the following:

`void xts_encrypt_message` (*const void* ***enc_ctx***, *const void* ***twk_ctx***, *nettle_cipher_func* ***encf***, *const uint8_t* ***tweak***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void xts_decrypt_message` (*const void* ***dec_ctx***, *const void* ***twk_ctx***, *nettle_cipher_func* ***decf***, *nettle_cipher_func* ***encf***, *const uint8_t* ***tweak***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Applies the encryption function *encf* or the decryption function *decf* in XTS mode. At least one block (16 bytes) worth of data must be available therefore specifying a length less than 16 bytes is illegal.

The functions *encf* *decf* are of type

`void f (const void *ctx, size_t length, uint8_t *dst, const uint8_t *src)`,

and the `xts_encrypt_message` and `xts_decrypt_message` functions pass their arguments *enc_ctx*, *twk_ctx* and *dec_ctx* to the functions *encf*, *decf* as *ctx*.

7.3.4.2 XTS-AES interface

The AES XTS functions provide an API for using the XTS mode with the AES block ciphers. The parameters all have the same meaning as the general interface, except that the *enc_ctx*, *dec_ctx*, *twk_ctx*, *encf* and *decf* are replaced with an AES context structure called *ctx*, and a appropriate set-key function must be called before using any of the encryption or decryption functions in this interface.

`struct xts_aes128_key` [Context struct]

Holds state corresponding to the AES-128 block cipher.

`struct xts_aes256_key` [Context struct]

Holds state corresponding to the AES-256 block cipher.

`void xts_aes128_set_encrypt_key` (*struct xts_aes128_key* ***ctx***, *const uint8_t* ***key***) [Function]

`void xts_aes256_set_encrypt_key` (*struct xts_aes256_key* ***ctx***, *const uint8_t* ***key***) [Function]

`void xts_aes128_set_decrypt_key` (*struct xts_aes128_key* ***ctx***, *const uint8_t* ***key***) [Function]

`void xts_aes256_set_decrypt_key` (*struct xts_aes256_key* ***ctx**, *const uint8_t* ***key**) [Function]

Initializes the encryption or decryption key for the AES block cipher. The length of the key must be double the size of the key for the corresponding cipher (256 bits for AES-128 and 512 bits for AES-256). One of these functions must be called before any of the other functions.

`void xts_aes128_encrypt_message(struct` *xts_aes128_key* ***ctx**, *uint8_t* ***tweak**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

`void xts_aes256_encrypt_message(struct` *xts_aes256_key* ***ctx**, *uint8_t* ***tweak**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

`void xts_aes128_decrypt_message(struct` *xts_aes128_key* ***ctx**, *uint8_t* ***tweak**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

`void xts_aes256_decrypt_message(struct` *xts_aes256_key* ***ctx**, *uint8_t* ***tweak**, *size_t* **length**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

These are identical to `xts_encrypt_message` and `xts_decrypt_message`, except that *enc_ctx*, *dec_ctx*, *twk_ctx*, *encf* and *decf* are replaced by the *ctx* context structure.

7.4 Authenticated encryption with associated data

Since there are some subtle design choices to be made when combining a block cipher mode with out authentication with a MAC. In recent years, several constructions that combine encryption and authentication have been defined. These constructions typically also have an additional input, the "associated data", which is authenticated but not included with the message. A simple example is an implicit message number which is available at both sender and receiver, and which needs authentication in order to detect deletions or replay of messages. This family of building blocks are therefore called AEAD, Authenticated encryption with associated data.

The aim is to provide building blocks that it is easier for designers of protocols and applications to use correctly. There is also some potential for improved performance, if encryption and authentication can be done in a single step, although that potential is not realized for the constructions currently supported by Nettle.

For encryption, the inputs are:

- The key, which can be used for many messages.
- A nonce, which must be unique for each message using the same key.
- Additional associated data to be authenticated, but not included in the message.
- The cleartext message to be encrypted.

The outputs are:

- The ciphertext, of the same size as the cleartext.
- A digest or "authentication tag".

Decryption works the same, but with cleartext and ciphertext interchanged. All currently supported AEAD algorithms always use the encryption function of the underlying block cipher, for both encryption and decryption.

Usually, the authentication tag should be appended at the end of the ciphertext, producing an encrypted message which is slightly longer than the cleartext. However, Nettle's

low level AEAD functions produce the authentication tag as a separate output for both encryption and decryption.

Both associated data and the message data (cleartext or ciphertext) can be processed incrementally. In general, all associated data must be processed before the message data, and all calls but the last one must use a length that is a multiple of the block size, although some AEAD may implement more liberal conventions. The CCM mode is a bit special in that it requires the message lengths up front, other AEAD constructions don't have this restriction.

The supported AEAD constructions are Galois/Counter mode (GCM), EAX, ChaCha-Poly1305, and Counter with CBC-MAC (CCM). There are some weaknesses in GCM authentication, see `http://csrc.nist.gov/groups/ST/toolkit/BCM/documents/comments/CWC-GCM/Ferguson2` CCM and EAX use the same building blocks, but the EAX design is cleaner and avoids a couple of inconveniences of CCM. Therefore, EAX seems like a good conservative choice. The more recent ChaCha-Poly1305 may also be an attractive but more adventurous alternative, in particular if performance is important.

7.4.1 EAX

The EAX mode is an AEAD mode which combines CTR mode encryption, See Section 7.3.2 [CTR], page 38, with a message authentication based on CBC, See Section 7.3.1 [CBC], page 37. The implementation in Nettle is restricted to ciphers with a block size of 128 bits (16 octets). EAX was defined as a reaction to the CCM mode, See Section 7.4.3 [CCM], page 52, which uses the same primitives but has some undesirable and inelegant properties.

EAX supports arbitrary nonce size; it's even possible to use an empty nonce in case only a single message is encrypted for each key.

Nettle's support for EAX consists of a low-level general interface, some convenience macros, and specific functions for EAX using AES-128 as the underlying cipher. These interfaces are defined in '`<nettle/eax.h>`'

7.4.1.1 General EAX interface

`struct eax_key` [Context struct]
EAX state which depends only on the key, but not on the nonce or the message.

`struct eax_ctx` [Context struct]
Holds state corresponding to a particular message.

`EAX_BLOCK_SIZE` [Constant]
EAX's block size, 16.

`EAX_DIGEST_SIZE` [Constant]
Size of the EAX digest, also 16.

`void eax_set_key` (*struct eax_key* ***key**, *const void* ***cipher**, *nettle_cipher_func* ***f**) [Function]
Initializes *key*. *cipher* gives a context struct for the underlying cipher, which must have been previously initialized for encryption, and *f* is the encryption function.

`void eax_set_nonce` (*struct eax_ctx* ***eax***, *const struct eax_key* ***key***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* **nonce_length**, *const uint8_t* ***nonce***) [Function]

Initializes *ctx* for processing a new message, using the given nonce.

`void eax_update` (*struct eax_ctx* ***eax***, *const struct eax_key* ***key***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* **data_length**, *const uint8_t* ***data***) [Function]

Process associated data for authentication. All but the last call for each message *must* use a length that is a multiple of the block size. Unlike many other AEAD constructions, for EAX it's not necessary to complete the processing of all associated data before encrypting or decrypting the message data.

`void eax_encrypt` (*struct eax_ctx* ***eax***, *const struct eax_key* ***key***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void eax_decrypt` (*struct eax_ctx* ***eax***, *const struct eax_key* ***key***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* **length**, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Encrypts or decrypts the data of a message. *cipher* is the context struct for the underlying cipher and *f* is the encryption function. All but the last call for each message *must* use a length that is a multiple of the block size.

`void eax_digest` (*struct eax_ctx* ***eax***, *const struct eax_key* ***key***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* **length**, *uint8_t* ***digest***); [Function]

Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. If *length* is smaller than `EAX_DIGEST_SIZE`, only the first *length* octets of the digest are written.

7.4.1.2 EAX helper macros

The following macros are defined.

`EAX_CTX` (***context_type***) [Macro]

This defines an all-in-one context struct, including the context of the underlying cipher and all EAX state. It expands to

```
{
   struct eax_key key;
   struct eax_ctx eax;
   context_type cipher;
}
```

For all these macros, *ctx*, is a context struct as defined by `EAX_CTX`, and *encrypt* is the encryption function of the underlying cipher.

`EAX_SET_KEY` (***ctx***, ***set_key***, ***encrypt***, ***key***) [Macro]

set_key is the function for setting the encryption key for the underlying cipher, and *key* is the key.

`EAX_SET_NONCE` (***ctx***, ***encrypt***, ***length***, ***nonce***) [Macro]

Sets the nonce to be used for the message.

`EAX_UPDATE` (*ctx*, *encrypt*, *length*, *data*) [Macro]
Process associated data for authentication.

`EAX_ENCRYPT` (*ctx*, *encrypt*, *length*, *dst*, *src*) [Macro]
`EAX_DECRYPT` (*ctx*, *encrypt*, *length*, *dst*, *src*) [Macro]
Process message data for encryption or decryption.

`EAX_DIGEST` (*ctx*, *encrypt*, *length*, *digest*) [Macro]
Extract the authentication tag for the message.

7.4.1.3 EAX-AES128 interface

The following functions implement EAX using AES-128 as the underlying cipher.

`struct eax_aes128_ctx` [Context struct]
The context struct, defined using `EAX_CTX`.

`void eax_aes128_set_key` (*struct eax_aes128_ctx* ***ctx***, *const uint8_t* ***key***) [Function]
Initializes *ctx* using the given key.

`void eax_aes128_set_nonce` (*struct eax_aes128_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***iv***) [Function]
Initializes the per-message state, using the given nonce.

`void eax_aes128_update` (*struct eax_aes128_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
Process associated data for authentication. All but the last call for each message *must* use a length that is a multiple of the block size.

`void eax_aes128_encrypt` (*struct eax_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void eax_aes128_decrypt` (*struct eax_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Encrypts or decrypts the data of a message. All but the last call for each message *must* use a length that is a multiple of the block size.

`void eax_aes128_digest` (*struct eax_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***); [Function]
Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. If *length* is smaller than `EAX_DIGEST_SIZE`, only the first *length* octets of the digest are written.

7.4.2 Galois counter mode

Galois counter mode is an AEAD constructions combining counter mode with message authentication based on universal hashing. The main objective of the design is to provide high performance for hardware implementations, where other popular MAC algorithms (see Section 7.5 [Keyed hash functions], page 60) become a bottleneck for high-speed hardware implementations. It was proposed by David A. McGrew and John Viega in 2005, and recommended by NIST in 2007, NIST Special Publication 800-38D

(http://csrc.nist.gov/publications/nistpubs/800-38D/SP-800-38D.pdf). It is constructed on top of a block cipher which must have a block size of 128 bits.

The authentication in GCM has some known weaknesses, see http://csrc.nist.gov/groups/ST/toolk In particular, don't use GCM with short authentication tags.

Nettle's support for GCM consists of a low-level general interface, some convenience macros, and specific functions for GCM using AES or Camellia as the underlying cipher. These interfaces are defined in '<nettle/gcm.h>'

7.4.2.1 General GCM interface

`struct gcm_key` [Context struct]
Message independent hash sub-key, and related tables.

`struct gcm_ctx` [Context struct]
Holds state corresponding to a particular message.

`GCM_BLOCK_SIZE` [Constant]
GCM's block size, 16.

`GCM_DIGEST_SIZE` [Constant]
Size of the GCM digest, also 16.

`GCM_IV_SIZE` [Constant]
Recommended size of the IV, 12. Arbitrary sizes are allowed.

`void gcm_set_key` (*struct gcm_key ***key**, const void ***cipher**, nettle_cipher_func ***f***) [Function]
Initializes *key*. *cipher* gives a context struct for the underlying cipher, which must have been previously initialized for encryption, and *f* is the encryption function.

`void gcm_set_iv` (*struct gcm_ctx ***ctx**, const struct gcm_key ***key**, size_t **length**, const uint8_t *iv*) [Function]
Initializes *ctx* using the given IV. The *key* argument is actually needed only if *length* differs from `GCM_IV_SIZE`.

`void gcm_update` (*struct gcm_ctx ***ctx**, const struct gcm_key ***key**, size_t **length**, const uint8_t ***data**) [Function]
Provides associated data to be authenticated. If used, must be called before `gcm_encrypt` or `gcm_decrypt`. All but the last call for each message *must* use a length that is a multiple of the block size.

`void gcm_encrypt` (*struct gcm_ctx ***ctx**, const struct gcm_key ***key**, const void ***cipher**, nettle_cipher_func ***f**, size_t **length**, uint8_t ***dst**, const uint8_t ***src***) [Function]
`void gcm_decrypt` (*struct gcm_ctx ***ctx**, const struct gcm_key ***key**, const void ***cipher**, nettle_cipher_func ***f**, size_t **length**, uint8_t ***dst**, const uint8_t ***src***) [Function]
Encrypts or decrypts the data of a message. *cipher* is the context struct for the underlying cipher and *f* is the encryption function. All but the last call for each message *must* use a length that is a multiple of the block size.

`void gcm_digest` (*struct gcm_ctx ***ctx***, *const struct gcm_key ***key***, *const void ***cipher***, *nettle_cipher_func ***f***, *size_t* **length**, *uint8_t ***digest***) [Function]

Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. It's strongly recommended that *length* is `GCM_DIGEST_SIZE`, but if you provide a smaller value, only the first *length* octets of the digest are written.

To encrypt a message using GCM, first initialize a context for the underlying block cipher with a key to use for encryption. Then call the above functions in the following order: `gcm_set_key`, `gcm_set_iv`, `gcm_update`, `gcm_encrypt`, `gcm_digest`. The decryption procedure is analogous, just calling `gcm_decrypt` instead of `gcm_encrypt` (note that GCM decryption still uses the encryption function of the underlying block cipher). To process a new message, using the same key, call `gcm_set_iv` with a new iv.

7.4.2.2 GCM helper macros

The following macros are defined.

`GCM_CTX` (*context_type*) [Macro]

This defines an all-in-one context struct, including the context of the underlying cipher, the hash sub-key, and the per-message state. It expands to

```
{
   struct gcm_key key;
   struct gcm_ctx gcm;
   context_type cipher;
}
```

Example use:

```
struct gcm_aes128_ctx GCM_CTX(struct aes128_ctx);
```

The following macros operate on context structs of this form.

`GCM_SET_KEY` (*ctx*, *set_key*, *encrypt*, *key*) [Macro]

First argument, *ctx*, is a context struct as defined by `GCM_CTX`. *set_key* and *encrypt* are functions for setting the encryption key and for encrypting data using the underlying cipher.

`GCM_SET_IV` (*ctx*, *length*, *data*) [Macro]

First argument is a context struct as defined by `GCM_CTX`. *length* and *data* give the initialization vector (IV).

`GCM_UPDATE` (*ctx*, *length*, *data*) [Macro]

Simpler way to call `gcm_update`. First argument is a context struct as defined by `GCM_CTX`

`GCM_ENCRYPT` (*ctx*, *encrypt*, *length*, *dst*, *src*) [Macro]
`GCM_DECRYPT` (*ctx*, *encrypt*, *length*, *dst*, *src*) [Macro]
`GCM_DIGEST` (*ctx*, *encrypt*, *length*, *digest*) [Macro]

Simpler way to call `gcm_encrypt`, `gcm_decrypt` or `gcm_digest`. First argument is a context struct as defined by `GCM_CTX`. Second argument, *encrypt*, is the encryption function of the underlying cipher.

7.4.2.3 GCM-AES interface

The following functions implement the common case of GCM using AES as the underlying cipher. The variants with a specific AES flavor are recommended, while the fucntinos using `struct gcm_aes_ctx` are kept for compatibility with older versiosn of Nettle.

`struct gcm_aes128_ctx` [Context struct]
`struct gcm_aes192_ctx` [Context struct]
`struct gcm_aes256_ctx` [Context struct]
Context structs, defined using `GCM_CTX`.

`struct gcm_aes_ctx` [Context struct]
Alternative context struct, using the old AES interface.

`void gcm_aes128_set_key (`*struct gcm_aes128_ctx* `*ctx`, *const uint8_t* `*key``)` [Function]
`void gcm_aes192_set_key (`*struct gcm_aes192_ctx* `*ctx`, *const uint8_t* `*key``)` [Function]
`void gcm_aes256_set_key (`*struct gcm_aes256_ctx* `*ctx`, *const uint8_t* `*key``)` [Function]
Initializes *ctx* using the given key.

`void gcm_aes_set_key (`*struct gcm_aes_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*key``)` [Function]
Corresponding function, using the old AES interface. All valid AES key sizes can be used.

`void gcm_aes128_set_iv (`*struct gcm_aes128_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*iv``)` [Function]
`void gcm_aes192_set_iv (`*struct gcm_aes192_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*iv``)` [Function]
`void gcm_aes256_set_iv (`*struct gcm_aes256_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*iv``)` [Function]
`void gcm_aes_set_iv (`*struct gcm_aes_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*iv``)` [Function]
Initializes the per-message state, using the given IV.

`void gcm_aes128_update (`*struct gcm_aes128_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data`)` [Function]
`void gcm_aes192_update (`*struct gcm_aes192_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data`)` [Function]
`void gcm_aes256_update (`*struct gcm_aes256_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data`)` [Function]
`void gcm_aes_update (`*struct gcm_aes_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data`)` [Function]
Provides associated data to be authenticated. If used, must be called before `gcm_aes_encrypt` or `gcm_aes_decrypt`. All but the last call for each message *must* use a length that is a multiple of the block size.

`void gcm_aes128_encrypt` (*struct gcm_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes192_encrypt` (*struct gcm_aes192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes256_encrypt` (*struct gcm_aes256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes_encrypt` (*struct gcm_aes_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes128_decrypt` (*struct gcm_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes192_decrypt` (*struct gcm_aes192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes256_decrypt` (*struct gcm_aes256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_aes_decrypt` (*struct gcm_aes_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Encrypts or decrypts the data of a message. All but the last call for each message *must* use a length that is a multiple of the block size.

`void gcm_aes128_digest` (*struct gcm_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void gcm_aes192_digest` (*struct gcm_aes192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void gcm_aes256_digest` (*struct gcm_aes256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void gcm_aes_digest` (*struct gcm_aes_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. It's strongly recommended that *length* is `GCM_DIGEST_SIZE`, but if you provide a smaller value, only the first *length* octets of the digest are written.

7.4.2.4 GCM-Camellia interface

The following functions implement the case of GCM using Camellia as the underlying cipher.

`struct gcm_camellia128_ctx` [Context struct]
`struct gcm_camellia256_ctx` [Context struct]

Context structs, defined using `GCM_CTX`.

`void gcm_camellia128_set_key` (*struct gcm_camellia128_ctx* ***ctx***, *const uint8_t* ***key***) [Function]
`void gcm_camellia256_set_key` (*struct gcm_camellia256_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

Initializes *ctx* using the given key.

`void gcm_camellia128_set_iv` (*struct gcm_camellia128_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***iv***) [Function]
`void gcm_camellia256_set_iv` (*struct gcm_camellia256_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***iv***) [Function]
Initializes the per-message state, using the given IV.

`void gcm_camellia128_update` (*struct gcm_camellia128_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
`void gcm_camellia256_update` (*struct gcm_camellia256_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
Provides associated data to be authenticated. If used, must be called before `gcm_camellia_encrypt` or `gcm_camellia_decrypt`. All but the last call for each message *must* use a length that is a multiple of the block size.

`void gcm_camellia128_encrypt` (*struct gcm_camellia128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_camellia256_encrypt` (*struct gcm_camellia256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_camellia128_decrypt` (*struct gcm_camellia128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void gcm_camellia256_decrypt` (*struct gcm_camellia256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Encrypts or decrypts the data of a message. All but the last call for each message *must* use a length that is a multiple of the block size.

`void gcm_camellia128_digest` (*struct gcm_camellia128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void gcm_camellia192_digest` (*struct gcm_camellia192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void gcm_camellia256_digest` (*struct gcm_camellia256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void gcm_camellia_digest` (*struct gcm_camellia_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. It's strongly recommended that *length* is `GCM_DIGEST_SIZE`, but if you provide a smaller value, only the first *length* octets of the digest are written.

7.4.3 Counter with CBC-MAC mode

CCM mode is a combination of counter mode with message authentication based on cipher block chaining, the same building blocks as EAX, see Section 7.4.1 [EAX], page 45. It is constructed on top of a block cipher which must have a block size of 128 bits. CCM mode is recommended by NIST in NIST Special Publication 800-38C (`http://csrc.nist.gov/publications/nistpubs/800-38C/SP800-38C_updated-July20_2007.pdf`). Nettle's support for CCM consists of a low-level general interface, a message encryption and authentication interface, and specific functions for CCM using AES as the underlying block cipher. These interfaces are defined in '`<nettle/ccm.h>`'.

In CCM, the length of the message must be known before processing. The maximum message size depends on the size of the nonce, since the message size is encoded in a field which must fit in a single block, together with the nonce and a flag byte. E.g., with a nonce size of 12 octets, there are three octets left for encoding the message length, the maximum message length is $2^24 - 1$ octets.

CCM mode encryption operates as follows:

- The nonce and message length are concatenated to create `B_0 = flags | nonce | mlength`
- The authenticated data and plaintext is formatted into the string `B = L(adata) | adata | padding | plaintext | padding` with `padding` being the shortest string of zero bytes such that the length of the string is a multiple of the block size, and `L(adata)` is an encoding of the length of `adata`.
- The string `B` is separated into blocks `B_1` ... `B_n`
- The authentication tag `T` is calculated as `T=0, for i=0 to n, do T = E_k(B_i XOR T)`
- An initial counter is then initialized from the nonce to create `IC = flags | nonce | padding`, where `padding` is the shortest string of zero bytes such that `IC` is exactly one block in length.
- The authentication tag is encrypted using using CTR mode: `MAC = E_k(IC) XOR T`
- The plaintext is then encrypted using CTR mode with an initial counter of `IC+1`.

CCM mode decryption operates similarly, except that the ciphertext and MAC are first decrypted using CTR mode to retrieve the plaintext and authentication tag. The authentication tag can then be recalculated from the authenticated data and plaintext, and compared to the value in the message to check for authenticity.

7.4.3.1 General CCM interface

For all of the functions in the CCM interface, *cipher* is the context struct for the underlying cipher and *f* is the encryption function. The cipher's encryption key must be set before calling any of the CCM functions. The cipher's decryption function and key are never used.

`struct ccm_ctx` [Context struct]
Holds state corresponding to a particular message.

`CCM_BLOCK_SIZE` [Constant]
CCM's block size, 16.

`CCM_DIGEST_SIZE` [Constant]
Size of the CCM digest, 16.

`CCM_MIN_NONCE_SIZE` [Constant]
`CCM_MAX_NONCE_SIZE` [Constant]
The the minimum and maximum sizes for an CCM nonce, 7 and 14, respectively.

`CCM_MAX_MSG_SIZE (`*`nonce_size`*`)` [Macro]
The largest allowed plaintext length, when using CCM with a nonce of the given size.

`void ccm_set_nonce` (*struct ccm_ctx* ***ctx***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***noncelen***, *const uint8_t* ***nonce***, *size_t* ***authlen***, *size_t* ***msglen***, *size_t* ***taglen***) [Function]

Initializes *ctx* using the given nonce and the sizes of the authenticated data, message, and MAC to be processed.

`void ccm_update` (*struct ccm_ctx* ***ctx***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***length***, *const uint8_t* ***data***) [Function]

Provides associated data to be authenticated. Must be called after `ccm_set_nonce`, and before `ccm_encrypt`, `ccm_decrypt`, or `ccm_digest`.

`void ccm_encrypt` (*struct ccm_ctx* ***ctx***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`void ccm_decrypt` (*struct ccm_ctx* ***ctx***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Encrypts or decrypts the message data. Must be called after `ccm_set_nonce` and before `ccm_digest`. All but the last call for each message *must* use a length that is a multiple of the block size.

`void ccm_digest` (*struct ccm_ctx* ***ctx***, *const void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. *length* is usually equal to the *taglen* parameter supplied to `ccm_set_nonce`, but if you provide a smaller value, only the first *length* octets of the digest are written.

To encrypt a message using the general CCM interface, set the message nonce and length using `ccm_set_nonce` and then call `ccm_update` to generate the digest of any authenticated data. After all of the authenticated data has been digested use `ccm_encrypt` to encrypt the plaintext. Finally, use `ccm_digest` to return the encrypted MAC.

To decrypt a message, use `ccm_set_nonce` and `ccm_update` the same as you would for encryption, and then call `ccm_decrypt` to decrypt the ciphertext. After decrypting the ciphertext `ccm_digest` will return the encrypted MAC which should be identical to the MAC in the received message.

7.4.3.2 CCM message interface

The CCM message fuctions provides a simple interface that will perform authentication and message encryption in a single function call. The length of the cleartext is given by *mlength* and the length of the ciphertext is given by *clength*, always exactly *tlength* bytes longer than the corresponding plaintext. The length argument passed to a function is always the size for the result, *clength* for the encryption functions, and *mlength* for the decryption functions.

`void ccm_encrypt_message` (*void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***clength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Computes the message digest from the *adata* and *src* parameters, encrypts the plaintext from *src*, appends the encrypted MAC to ciphertext and outputs it to *dst*.

`int ccm_decrypt_message` (*void* ***cipher***, *nettle_cipher_func* ***f***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***mlength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

Decrypts the ciphertext from *src*, outputs the plaintext to *dst*, recalculates the MAC from *adata* and the plaintext, and compares it to the final *tlength* bytes of *src*. If the values of the received and calculated MACs are equal, this will return 1 indicating a valid and authenticated message. Otherwise, this function will return zero.

7.4.3.3 CCM-AES interface

The AES CCM functions provide an API for using CCM mode with the AES block ciphers. The parameters all have the same meaning as the general and message interfaces, except that the *cipher*, *f*, and *ctx* parameters are replaced with an AES context structure, and a set-key function must be called before using any of the other functions in this interface.

`struct ccm_aes128_ctx` [Context struct]

Holds state corresponding to a particular message encrypted using the AES-128 block cipher.

`struct ccm_aes192_ctx` [Context struct]

Holds state corresponding to a particular message encrypted using the AES-192 block cipher.

`struct ccm_aes256_ctx` [Context struct]

Holds state corresponding to a particular message encrypted using the AES-256 block cipher.

`void ccm_aes128_set_key` (*struct ccm_aes128_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

`void ccm_aes192_set_key` (*struct ccm_aes192_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

`void ccm_aes256_set_key` (*struct ccm_aes256_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

Initializes the encryption key for the AES block cipher. One of these functions must be called before any of the other functions in the AES CCM interface.

`void ccm_aes128_set_nonce` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***noncelen***, *const uint8_t* ***nonce***, *size_t* ***authlen***, *size_t* ***msglen***, *size_t* ***taglen***) [Function]

`void ccm_aes192_set_nonce` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***noncelen***, *const uint8_t* ***nonce***, *size_t* ***authlen***, *size_t* ***msglen***, *size_t* ***taglen***) [Function]

`void ccm_aes256_set_nonce` (*struct ccm_aes256_ctx* ***ctx***, *size_t* ***noncelen***, *const uint8_t* ***nonce***, *size_t* ***authlen***, *size_t* ***msglen***, *size_t* ***taglen***) [Function]

These are identical to `ccm_set_nonce`, except that *cipher*, *f*, and *ctx* are replaced with a context structure.

`void ccm_aes128_update` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
`void ccm_aes192_update` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
`void ccm_aes256_update` (*struct ccm_aes256_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]

These are identical to `ccm_set_update`, except that *cipher*, *f*, and *ctx* are replaced with a context structure.

`void ccm_aes128_encrypt` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes192_encrypt` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes256_encrypt` (*struct ccm_aes256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes128_decrypt` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes192_decrypt` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes256_decrypt` (*struct ccm_aes256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

These are identical to `ccm_set_encrypt` and `ccm_set_decrypt`, except that *cipher*, *f*, and *ctx* are replaced with a context structure.

`void ccm_aes128_digest` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void ccm_aes192_digest` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
`void ccm_aes256_digest` (*struct ccm_aes256_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

These are identical to `ccm_set_digest`, except that *cipher*, *f*, and *ctx* are replaced with a context structure.

`void ccm_aes128_encrypt_message` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***clength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes192_encrypt_message` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***clength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void ccm_aes256_encrypt_message` (*struct ccm_aes256_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***clength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`int ccm_aes128_decrypt_message` (*struct ccm_aes128_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***mlength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`int ccm_aes192_decrypt_message` (*struct ccm_aes192_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***tlength***, *size_t* ***mlength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]

`int ccm_aes192_decrypt_message` (*struct ccm_aes256_ctx* ***ctx**, *size_t* **nlength**, *const uint8_t* ***nonce**, *size_t* **alength**, *const uint8_t* ***adata**, *size_t* **tlength**, *size_t* **mlength**, *uint8_t* ***dst**, *const uint8_t* ***src**) [Function]

These are identical to `ccm_encrypt_message` and `ccm_decrypt_message` except that *cipher* and *f* are replaced with a context structure.

7.4.4 ChaCha-Poly1305

ChaCha-Poly1305 is a combination of the ChaCha stream cipher and the poly1305 message authentication code (see Section 7.5.5 [Poly1305], page 67). It originates from the NaCl cryptographic library by D. J. Bernstein et al, which defines a similar construction but with Salsa20 instead of ChaCha.

Nettle's implementation of ChaCha-Poly1305 follows *RFC 8439*, where the ChaCha cipher is initialized with a 12-byte nonce and a 4-byte block counter. This allows up to 256 gigabytes of data to be encrypted using the same key and nonce.

For ChaCha-Poly1305, the ChaCha cipher is initialized with a key, of 256 bits, and a per-message nonce. The first block of the key stream (counter all zero) is set aside for the authentication subkeys. Of this 64-octet block, the first 16 octets specify the poly1305 evaluation point, and the next 16 bytes specify the value to add in for the final digest. The final 32 bytes of this block are unused. Note that unlike poly1305-aes, the evaluation point depends on the nonce. This is preferable, because it leaks less information in case the attacker for some reason is lucky enough to forge a valid authentication tag, and observe (from the receiver's behaviour) that the forgery succeeded.

The ChaCha key stream, starting with counter value 1, is then used to encrypt the message. For authentication, poly1305 is applied to the concatenation of the associated data, the cryptotext, and the lengths of the associated data and the message, each a 64-bit number (eight octets, little-endian). Nettle defines ChaCha-Poly1305 in '`<nettle/chacha-poly1305.h>`'.

`CHACHA_POLY1305_BLOCK_SIZE` [Constant]

Same as the ChaCha block size, 64.

`CHACHA_POLY1305_KEY_SIZE` [Constant]

ChaCha-Poly1305 key size, 32.

`CHACHA_POLY1305_NONCE_SIZE` [Constant]

ChaCha-Poly1305 nonce size, 12.

`CHACHA_POLY1305_DIGEST_SIZE` [Constant]

Digest size, 16.

`struct chacha_poly1305_ctx` [Context struct]

`void chacha_poly1305_set_key` (*struct chacha_poly1305_ctx* ***ctx**, *const uint8_t* ***key**) [Function]

Initializes *ctx* using the given key. Before using the context, you *must* also call `chacha_poly1305_set_nonce`, see below.

`void chacha_poly1305_set_nonce` (*struct chacha_poly1305_ctx* ***ctx**, *const uint8_t* ***nonce**) [Function]

Initializes the per-message state, using the given nonce.

`void chacha_poly1305_update` (*struct chacha_poly1305_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]
Process associated data for authentication.

`void chacha_poly1305_encrypt` (*struct chacha_poly1305_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void chacha_poly1305_decrypt` (*struct chacha_poly1305_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Encrypts or decrypts the data of a message. All but the last call for each message *must* use a length that is a multiple of the block size.

`void chacha_poly1305_digest` (*struct chacha_poly1305_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]
Extracts the message digest (also known "authentication tag"). This is the final operation when processing a message. If *length* is smaller than `CHACHA_POLY1305_DIGEST_SIZE`, only the first *length* octets of the digest are written.

7.4.5 Synthetic Initialization Vector AEAD

SIV-CMAC mode is a combination of counter mode with message authentication based on CMAC. Unlike other counter AEAD modes, it provides protection against accidental nonce misuse, making it a good choice for stateless-servers that cannot ensure nonce uniqueness. It is constructed on top of a block cipher which must have a block size of 128 bits. Nettle's support for SIV-CMAC consists of a message encryption and authentication interface, for SIV-CMAC using AES as the underlying block cipher. When a nonce is re-used with this mode, message authenticity is retained however an attacker can determine whether the same plaintext was protected with the two messages sharing the nonce. These interfaces are defined in '`<nettle/siv-cmac.h>`'.

Unlike other AEAD mode in SIV-CMAC the initialization vector serves as the tag. That means that in the generated ciphertext the tag precedes the ciphertext.

Note also, that the SIV-CMAC algorithm, as specified in *RFC 5297*, introduces the notion of authenticated data which consist of multiple components. For example with SIV-CMAC the authentication tag of data `X` followed by `Y`, is different than the concatenated data `X || Y`. The interfaces described below follow the AEAD paradigm and do not allow access to this feature and also require the use of a non-empty nonce. In the terminology of the RFC, the input to the S2V function is always a vector of three elements, where S1 is the authenticated data, S2 is the nonce, and S3 is the plaintext.

7.4.5.1 General interface

`SIV_BLOCK_SIZE` [Constant]
SIV-CMAC's block size, 16.

`SIV_DIGEST_SIZE` [Constant]
Size of the SIV-CMAC digest or initialization vector, 16.

`SIV_MIN_NONCE_SIZE` [Constant]
The the minimum size for an SIV-CMAC nonce, 1.

7.4.5.2 SIV-CMAC-AES interface

The AES SIV-CMAC functions provide an API for using SIV-CMAC mode with the AES block ciphers. The parameters all have the same meaning as the general and message interfaces, except that the *cipher*, *f*, and *ctx* parameters are replaced with an AES context structure, and a set-key function must be called before using any of the other functions in this interface.

`struct siv_cmac_aes128_ctx` [Context struct]
Holds state corresponding to a particular message encrypted using the AES-128 block cipher.

`struct siv_cmac_aes256_ctx` [Context struct]
Holds state corresponding to a particular message encrypted using the AES-256 block cipher.

`void siv_cmac_aes128_set_key` (*struct siv_cmac_aes128_ctx* ***ctx***, *const uint8_t* ***key***) [Function]
`void siv_cmac_aes256_set_key` (*struct siv_cmac_aes256_ctx* ***ctx***, *const uint8_t* ***key***) [Function]
Initializes the encryption key for the AES block cipher. One of these functions must be called before any of the other functions in the AES SIV-CMAC interface.

`void siv_cmac_aes128_encrypt_message` (*struct siv_cmac_aes128_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***clength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`void siv_cmac_aes256_encrypt_message` (*struct siv_cmac_aes256_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***clength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Computes the message digest from the *adata* and *src* parameters, encrypts the plaintext from *src*, prepends the initialization vector to the ciphertext and outputs it to *dst*. The *clength* variable must be equal to the length of *src* plus `SIV_DIGEST_SIZE`.

`int siv_cmac_aes128_decrypt_message` (*struct siv_cmac_aes128_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***mlength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
`int siv_cmac_aes256_decrypt_message` (*struct siv_cmac_aes128_ctx* ***ctx***, *size_t* ***nlength***, *const uint8_t* ***nonce***, *size_t* ***alength***, *const uint8_t* ***adata***, *size_t* ***mlength***, *uint8_t* ***dst***, *const uint8_t* ***src***) [Function]
Decrypts the ciphertext from *src*, outputs the plaintext to *dst*, recalculates the initialization vector from *adata* and the plaintext. If the values of the received and calculated initialization vector are equal, this will return 1 indicating a valid and authenticated message. Otherwise, this function will return zero.

7.4.6 The `struct nettle_aead` abstraction

Nettle includes a struct including information about the supported hash functions. It is defined in '`<nettle/nettle-meta.h>`'.

`struct nettle_aead` *name context_size block_size key_size nonce_size digest_size set_encrypt_key set_decrypt_key set_nonce update encrypt decrypt digest* [Meta struct]

The last seven attributes are function pointers.

`struct nettle_aead nettle_gcm_aes128` [Constant Struct]
`struct nettle_aead nettle_gcm_aes192` [Constant Struct]
`struct nettle_aead nettle_gcm_aes256` [Constant Struct]
`struct nettle_aead nettle_gcm_camellia128` [Constant Struct]
`struct nettle_aead nettle_gcm_camellia256` [Constant Struct]
`struct nettle_aead nettle_eax_aes128` [Constant Struct]
`struct nettle_aead nettle_chacha_poly1305` [Constant Struct]

These are most of the AEAD constructions that Nettle implements. Note that CCM is missing; it requirement that the message size is specified in advance makes it incompatible with the `nettle_aead` abstraction.

Nettle also exports a list of all these constructions.

`const struct nettle_aead ** nettle_get_aeads` (*void*) [Function]

Returns a NULL-terminated list of pointers to supported algorithms.This list can be used to dynamically enumerate or search the supported algorithms.

`nettle_aeads` [Macro]

A macro expanding to a call to nettle_get_aeads. In earlier versions, this was not a macro but the actual array of pointers.

7.5 Keyed Hash Functions

A *keyed hash function*, or *Message Authentication Code* (MAC) is a function that takes a key and a message, and produces fixed size MAC. It should be hard to compute a message and a matching MAC without knowledge of the key. It should also be hard to compute the key given only messages and corresponding MACs.

Keyed hash functions are useful primarily for message authentication, when Alice and Bob shares a secret: The sender, Alice, computes the MAC and attaches it to the message. The receiver, Bob, also computes the MAC of the message, using the same key, and compares that to Alice's value. If they match, Bob can be assured that the message has not been modified on its way from Alice.

However, unlike digital signatures, this assurance is not transferable. Bob can't show the message and the MAC to a third party and prove that Alice sent that message. Not even if he gives away the key to the third party. The reason is that the *same* key is used on both sides, and anyone knowing the key can create a correct MAC for any message. If Bob believes that only he and Alice knows the key, and he knows that he didn't attach a MAC to a particular message, he knows it must be Alice who did it. However, the third party can't distinguish between a MAC created by Alice and one created by Bob.

Keyed hash functions are typically a lot faster than digital signatures as well.

7.5.1 HMAC

One can build keyed hash functions from ordinary hash functions. Older constructions simply concatenate secret key and message and hashes that, but such constructions have weaknesses. A better construction is HMAC, described in *RFC 2104*.

For an underlying hash function `H`, with digest size `l` and internal block size `b`, HMAC-H is constructed as follows: From a given key `k`, two distinct subkeys `k_i` and `k_o` are constructed, both of length `b`. The HMAC-H of a message `m` is then computed as `H(k_o | H(k_i | m))`, where `|` denotes string concatenation.

HMAC keys can be of any length, but it is recommended to use keys of length `l`, the digest size of the underlying hash function `H`. Keys that are longer than `b` are shortened to length `l` by hashing with `H`, so arbitrarily long keys aren't very useful.

Nettle's HMAC functions are defined in '`<nettle/hmac.h>`'. There are abstract functions that use a pointer to a `struct nettle_hash` to represent the underlying hash function and `void *` pointers that point to three different context structs for that hash function. There are also concrete functions for HMAC-MD5, HMAC-RIPEMD160 HMAC-SHA1, HMAC-SHA256, and HMAC-SHA512. First, the abstract functions:

`void hmac_set_key` (*void ***`outer`**, void ***`inner`**, void ***`state`**, const struct nettle_hash ***`H`**, size_t **`length`**, const uint8_t ***`key`**)* [Function]

Initializes the three context structs from the key. The *outer* and *inner* contexts corresponds to the subkeys `k_o` and `k_i`. *state* is used for hashing the message, and is initialized as a copy of the *inner* context.

`void hmac_update` (*void ***`state`**, const struct nettle_hash ***`H`**, size_t **`length`**, const uint8_t ***`data`**)* [Function]

This function is called zero or more times to process the message. Actually, `hmac_update(state, H, length, data)` is equivalent to `H->update(state, length, data)`, so if you wish you can use the ordinary update function of the underlying hash function instead.

`void hmac_digest` (*const void ***`outer`**, const void ***`inner`**, void *`*state`, const struct nettle_hash *`*H`, size_t **`length`**, uint8_t *`*digest`)* [Function]

Extracts the MAC of the message, writing it to *digest*. *outer* and *inner* are not modified. *length* is usually equal to `H->digest_size`, but if you provide a smaller value, only the first *length* octets of the MAC are written.

This function also resets the *state* context so that you can start over processing a new message (with the same key).

Like for CBC, there are some macros to help use these functions correctly.

`HMAC_CTX` (*type*) [Macro]

Expands to

```
{
   type outer;
   type inner;
   type state;
}
```

It can be used to define a HMAC context struct, either directly,

```
struct HMAC_CTX(struct md5_ctx) ctx;
```

or to give it a struct tag,

```
struct hmac_md5_ctx HMAC_CTX (struct md5_ctx);
```

`HMAC_SET_KEY` (*ctx*, *H*, *length*, *key*) [Macro]
: *ctx* is a pointer to a context struct as defined by `HMAC_CTX`, *H* is a pointer to a `const struct nettle_hash` describing the underlying hash function (so it must match the type of the components of *ctx*). The last two arguments specify the secret key.

`HMAC_DIGEST` (*ctx*, *H*, *length*, *digest*) [Macro]
: *ctx* is a pointer to a context struct as defined by `HMAC_CTX`, *H* is a pointer to a `const struct nettle_hash` describing the underlying hash function. The last two arguments specify where the digest is written.

Note that there is no `HMAC_UPDATE` macro; simply call `hmac_update` function directly, or the update function of the underlying hash function.

7.5.2 Concrete HMAC functions

Now we come to the specialized HMAC functions, which are easier to use than the general HMAC functions.

7.5.2.1 HMAC-MD5

`struct hmac_md5_ctx` [Context struct]

`void hmac_md5_set_key` (*struct hmac_md5_ctx *ctx*, *size_t key_length*, *const uint8_t *key*) [Function]
: Initializes the context with the key.

`void hmac_md5_update` (*struct hmac_md5_ctx *ctx*, *size_t length*, *const uint8_t *data*) [Function]
: Process some more data.

`void hmac_md5_digest` (*struct hmac_md5_ctx *ctx*, *size_t length*, *uint8_t *digest*) [Function]
: Extracts the MAC, writing it to *digest*. *length* may be smaller than `MD5_DIGEST_SIZE`, in which case only the first *length* octets of the MAC are written.

  This function also resets the context for processing new messages, with the same key.

7.5.2.2 HMAC-RIPEMD160

`struct hmac_ripemd160_ctx` [Context struct]

`void hmac_ripemd160_set_key` (*struct hmac_ripemd160_ctx *ctx*, *size_t key_length*, *const uint8_t *key*) [Function]
: Initializes the context with the key.

`void hmac_ripemd160_update` (*struct hmac_ripemd160_ctx *ctx*, *size_t length*, *const uint8_t *data*) [Function]
: Process some more data.

`void hmac_ripemd160_digest` (*struct hmac_ripemd160_ctx* ***ctx**, *size_t* ***length**, *uint8_t* ***digest**) [Function]

Extracts the MAC, writing it to *digest*. *length* may be smaller than `RIPEMD160_DIGEST_SIZE`, in which case only the first *length* octets of the MAC are written.

This function also resets the context for processing new messages, with the same key.

7.5.2.3 HMAC-SHA1

`struct hmac_sha1_ctx` [Context struct]

`void hmac_sha1_set_key` (*struct hmac_sha1_ctx* ***ctx**, *size_t* ***key_length**, *const uint8_t* ***key**) [Function]

Initializes the context with the key.

`void hmac_sha1_update` (*struct hmac_sha1_ctx* ***ctx**, *size_t* ***length**, *const uint8_t* ***data**) [Function]

Process some more data.

`void hmac_sha1_digest` (*struct hmac_sha1_ctx* ***ctx**, *size_t* ***length**, *uint8_t* ***digest**) [Function]

Extracts the MAC, writing it to *digest*. *length* may be smaller than `SHA1_DIGEST_SIZE`, in which case only the first *length* octets of the MAC are written.

This function also resets the context for processing new messages, with the same key.

7.5.2.4 HMAC-SHA256

`struct hmac_sha256_ctx` [Context struct]

`void hmac_sha256_set_key` (*struct hmac_sha256_ctx* ***ctx**, *size_t* ***key_length**, *const uint8_t* ***key**) [Function]

Initializes the context with the key.

`void hmac_sha256_update` (*struct hmac_sha256_ctx* ***ctx**, *size_t* ***length**, *const uint8_t* ***data**) [Function]

Process some more data.

`void hmac_sha256_digest` (*struct hmac_sha256_ctx* ***ctx**, *size_t* ***length**, *uint8_t* ***digest**) [Function]

Extracts the MAC, writing it to *digest*. *length* may be smaller than `SHA256_DIGEST_SIZE`, in which case only the first *length* octets of the MAC are written.

This function also resets the context for processing new messages, with the same key.

7.5.2.5 HMAC-SHA512

`struct hmac_sha512_ctx` [Context struct]

`void hmac_sha512_set_key` (*struct hmac_sha512_ctx* ***ctx**, *size_t* ***key_length**, *const uint8_t* ***key**) [Function]

Initializes the context with the key.

`void hmac_sha512_update` (*struct hmac_sha512_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]

Process some more data.

`void hmac_sha512_digest` (*struct hmac_sha512_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

Extracts the MAC, writing it to *digest*. *length* may be smaller than `SHA512_DIGEST_SIZE`, in which case only the first *length* octets of the MAC are written.

This function also resets the context for processing new messages, with the same key.

7.5.3 UMAC

UMAC is a message authentication code based on universal hashing, and designed for high performance on modern processors (in contrast to GCM, See Section 7.4.2 [GCM], page 47, which is designed primarily for hardware performance). On processors with good integer multiplication performance, it can be 10 times faster than SHA256 and SHA512. UMAC is specified in *RFC 4418*.

The secret key is always 128 bits (16 octets). The key is used as an encryption key for the AES block cipher. This cipher is used in counter mode to generate various internal subkeys needed in UMAC. Messages are of arbitrary size, and for each message, UMAC also needs a unique nonce. Nonce values must not be reused for two messages with the same key, but they need not be kept secret.

The nonce must be at least one octet, and at most 16; nonces shorter than 16 octets are zero-padded. Nettle's implementation of UMAC increments the nonce automatically for each message, so explicitly setting the nonce for each message is optional. This auto-increment uses network byte order and it takes the length of the nonce into account. E.g., if the initial nonce is "abc" (3 octets), this value is zero-padded to 16 octets for the first message. For the next message, the nonce is incremented to "abd", and this incremented value is zero-padded to 16 octets.

UMAC is defined in four variants, for different output sizes: 32 bits (4 octets), 64 bits (8 octets), 96 bits (12 octets) and 128 bits (16 octets), corresponding to different trade-offs between speed and security. Using a shorter output size sometimes (but not always!) gives the same result as using a longer output size and truncating the result. So it is important to use the right variant. For consistency with other hash and MAC functions, Nettle's `_digest` functions for UMAC accept a length parameter so that the output can be truncated to any desired size, but it is recommended to stick to the specified output size and select the umac variant corresponding to the desired size.

The internal block size of UMAC is 1024 octets, and it also generates more than 1024 bytes of subkeys. This makes the size of the context struct quite a bit larger than other hash functions and MAC algorithms in Nettle.

Nettle defines UMAC in '`<nettle/umac.h>`'.

`struct umac32_ctx` [Context struct]
`struct umac64_ctx` [Context struct]
`struct umac96_ctx` [Context struct]
`struct umac128_ctx` [Context struct]

Each UMAC variant uses its own context struct.

`UMAC_KEY_SIZE` [Constant]
The UMAC key size, 16.

`UMAC_MIN_NONCE_SIZE` [Constant]
`UMAC_MAX_NONCE_SIZE` [Constant]
The the minimum and maximum sizes for an UMAC nonce, 1 and 16, respectively.

`UMAC32_DIGEST_SIZE` [Constant]
The size of an UMAC32 digest, 4.

`UMAC64_DIGEST_SIZE` [Constant]
The size of an UMAC64 digest, 8.

`UMAC96_DIGEST_SIZE` [Constant]
The size of an UMAC96 digest, 12.

`UMAC128_DIGEST_SIZE` [Constant]
The size of an UMAC128 digest, 16.

`UMAC_BLOCK_SIZE` [Constant]
The internal block size of UMAC.

`void umac32_set_key` (*struct umac32_ctx* ***ctx**, *const uint8_t* ***key**) [Function]
`void umac64_set_key` (*struct umac64_ctx* ***ctx**, *const uint8_t* ***key**) [Function]
`void umac96_set_key` (*struct umac96_ctx* ***ctx**, *const uint8_t* ***key**) [Function]
`void umac128_set_key` (*struct umac128_ctx* ***ctx**, *const uint8_t* ***key**) [Function]
These functions initialize the UMAC context struct. They also initialize the nonce to zero (with length 16, for auto-increment).

`void umac32_set_nonce` (*struct umac32_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***nonce**) [Function]
`void umac64_set_nonce` (*struct umac64_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***nonce**) [Function]
`void umac96_set_nonce` (*struct umac96_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***nonce**) [Function]
`void umac128_set_nonce` (*struct umac128_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***nonce**) [Function]
Sets the nonce to be used for the next message. In general, nonces should be set before processing of the message. This is not strictly required for UMAC (the nonce only affects the final processing generating the digest), but it is nevertheless recommended that this function is called *before* the first `_update` call for the message.

`void umac32_update` (*struct umac32_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
`void umac64_update` (*struct umac64_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
`void umac96_update` (*struct umac96_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
`void umac128_update` (*struct umac128_ctx* ***ctx**, *size_t* **length**, *const uint8_t* ***data**) [Function]
These functions are called zero or more times to process the message.

`void umac32_digest` (*struct umac32_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

`void umac64_digest` (*struct umac64_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

`void umac96_digest` (*struct umac96_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

`void umac128_digest` (*struct umac128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

Extracts the MAC of the message, writing it to *digest*. *length* is usually equal to the specified output size, but if you provide a smaller value, only the first *length* octets of the MAC are written. These functions reset the context for processing of a new message with the same key. The nonce is incremented as described above, the new value is used unless you call the `_set_nonce` function explicitly for each message.

7.5.4 CMAC

CMAC is a message authentication code based on CBC encryption mode. It is suitable for systems where block ciphers are preferrable and perform better than hash functions. CMAC-128 is specified in *RFC4493*. The block size is always 128 bits (16 octets). CMAC-64 is specified by NIST Special Publication 800-38B (`https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-38B.pdf`). The block size is always 64 bits (8 octets).

Nettle provides helper functions for CMAC-128 with the AES block cipher and for CMAC-64 with the Tripple-DES block cipher.

Nettle defines CMAC in '`<nettle/cmac.h>`'.

`struct cmac_aes128_ctx` [Context struct]

`struct cmac_aes256_ctx` [Context struct]

`CMAC128_DIGEST_SIZE` [Constant]

The size of an CMAC-128 digest, 16.

`void cmac_aes128_set_key` (*struct cmac_aes128_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

This function initializes the CMAC context struct for AES-128.

`void cmac_aes128_update` (*struct cmac_aes128_ctx* ***ctx***, *size_t* ***length***, *const uint8_t* ***data***) [Function]

This function is called zero or more times to process the message.

`void cmac_aes128_digest` (*struct cmac_aes128_ctx* ***ctx***, *size_t* ***length***, *uint8_t* ***digest***) [Function]

Extracts the MAC of the message, writing it to *digest*. *length* is usually equal to the specified output size, but if you provide a smaller value, only the first *length* octets of the MAC are written. This function resets the context for processing of a new message with the same key.

`void cmac_aes256_set_key` (*struct cmac_aes256_ctx* ***ctx***, *const uint8_t* ***key***) [Function]

This function initializes the CMAC context struct for AES-256.

`void cmac_aes256_update` (*struct cmac_aes256_ctx* ***ctx**, *size_t* ***length**, *const uint8_t* ***data**) [Function]

This function is called zero or more times to process the message.

`void cmac_aes256_digest` (*struct cmac_aes256_ctx* ***ctx**, *size_t* ***length**, *uint8_t* ***digest**) [Function]

Extracts the MAC of the message, writing it to *digest*. *length* is usually equal to the specified output size, but if you provide a smaller value, only the first *length* octets of the MAC are written. This function resets the context for processing of a new message with the same key.

`struct cmac_des3_ctx` [Context struct]

`CMAC64_DIGEST_SIZE` [Constant]

The size of an CMAC-64 digest, 8.

`void cmac_des3_set_key` (*struct cmac_des3_ctx* ***ctx**, *const uint8_t* ***key**) [Function]

This function initializes the CMAC context struct for Tripple-DES.

`void cmac_des3_update` (*struct cmac_des3_ctx* ***ctx**,*size_t* ***length**, *const uint8_t* ***data**) [Function]

This function is called zero or more times to process the message.

`void cmac_des3_digest` (*struct cmac_des3_ctx* ***ctx**, *size_t* ***length**, *uint8_t* ***digest**) [Function]

Extracts the MAC of the message, writing it to *digest*. *length* is usually equal to the specified output size, but if you provide a smaller value, only the first *length* octets of the MAC are written. This function resets the context for processing of a new message with the same key.

7.5.5 Poly1305

Poly1305-AES is a message authentication code designed by D. J. Bernstein. It treats the message as a polynomial modulo the prime number $2^130 - 5$.

The key, 256 bits, consists of two parts, where the first half is an AES-128 key, and the second half specifies the point where the polynomial is evaluated. Of the latter half, 22 bits are set to zero, to enable high-performance implementation, leaving 106 bits for specifying an evaluation point `r`. For each message, one must also provide a 128-bit nonce. The nonce is encrypted using the AES key, and that's the only thing AES is used for.

The message is split into 128-bit chunks (with final chunk possibly being shorter), each read as a little-endian integer. Each chunk has a one-bit appended at the high end. The resulting integers are treated as polynomial coefficients modulo 2^130-5, and the polynomial is evaluated at the point `r`. Finally, this value is reduced modulo 2^128, and added (also modulo 2^128) to the encrypted nonce, to produce an 128-bit authenticator for the message. See `http://cr.yp.to/mac/poly1305-20050329.pdf` for further details.

Clearly, variants using a different cipher than AES could be defined. Another variant is the ChaCha-Poly1305 AEAD construction (see Section 7.4.4 [ChaCha-Poly1305], page 57). Nettle defines Poly1305-AES in '`nettle/poly1305.h`'.

`POLY1305_AES_KEY_SIZE` [Constant]
Key size, 32 octets.

`POLY1305_AES_DIGEST_SIZE` [Constant]
Size of the digest or "authenticator", 16 octets.

`POLY1305_AES_NONCE_SIZE` [Constant]
Nonce size, 16 octets.

`struct poly1305_aes_ctx` [Context struct]
The poly1305-aes context struct.

`void poly1305_aes_set_key (`*struct poly1305_aes_ctx* `*ctx`, *const uint8_t* `*key`) [Function]
Initialize the context struct. Also sets the nonce to zero.

`void poly1305_aes_set_nonce (`*struct poly1305_aes_ctx* `*ctx`, *const uint8_t* `*nonce`) [Function]
Sets the nonce. Calling this function is optional, since the nonce is incremented automatically for each message.

`void poly1305_aes_update (`*struct poly1305_aes_ctx* `*ctx`, *size_t* `length`, *const uint8_t* `*data`) [Function]
Process more data.

`void poly1305_aes_digest (`*struct poly1305_aes_ctx* `*ctx`, *size_t* `length`, *uint8_t* `*digest`) [Function]
Extracts the digest. If *length* is smaller than `POLY1305_AES_DIGEST_SIZE`, only the first *length* octets are written. Also increments the nonce, and prepares the context for processing a new message.

7.6 Key derivation Functions

A *key derivation function* (KDF) is a function that from a given symmetric key derives other symmetric keys. A sub-class of KDFs is the *password-based key derivation functions* (PBKDFs), which take as input a password or passphrase, and its purpose is typically to strengthen it and protect against certain pre-computation attacks by using salting and expensive computation.

7.6.1 HKDF: HMAC-based Extract-and-Expand

HKDF is a key derivation function used as a building block of higher-level protocols like TLS 1.3. It is a derivation function based on HMAC described in *RFC 5869*, and is split into two logical modules, called 'extract' and 'expand'. The extract module takes an initial secret and a random salt to `"extract"` a fixed-length pseudorandom key (PRK). The second stage takes as input the previous PRK and some informational data (e.g., text) and expands them into multiple keys.

Nettle's HKDF functions are defined in '`<nettle/hkdf.h>`'. There are two abstract functions for the extract and expand operations that operate on any HMAC implemented via the `nettle_hash_update_func`, and `nettle_hash_digest_func` interfaces.

`void hkdf_extract` (*void *mac_ctx, nettle_hash_update_func *update, nettle_hash_digest_func *digest, size_t digest_size,size_t secret_size, const uint8_t *secret, uint8_t *dst*) [Function]

Extract a Pseudorandom Key (PRK) from a secret and a salt according to HKDF. The HMAC must have been initialized, with its key being the salt for the Extract operation. This function will call the *update* and *digest* functions passing the *mac_ctx* context parameter as an argument in order to compute digest of size *digest_size*. Inputs are the secret *secret* of length *secret_length*. The output length is fixed to *digest_size* octets, thus the output buffer *dst* must have room for at least *digest_size* octets.

`void hkdf_expand` (*void *mac_ctx, nettle_hash_update_func *update, nettle_hash_digest_func *digest, size_t digest_size, size_t info_size, const uint8_t *info, size_t length, uint8_t *dst*) [Function]

Expand a Pseudorandom Key (PRK) to an arbitrary size according to HKDF. The HMAC must have been initialized, with its key being the PRK from the Extract operation. This function will call the *update* and *digest* functions passing the *mac_ctx* context parameter as an argument in order to compute digest of size *digest_size*. Inputs are the info *info* of length *info_length*, and the desired derived output length *length*. The output buffer is *dst* which must have room for at least *length* octets.

7.6.2 PBKDF2

The most well known PBKDF is the `PKCS #5 PBKDF2` described in *RFC 2898* which uses a pseudo-random function such as HMAC-SHA1.

Nettle's PBKDF2 functions are defined in '`<nettle/pbkdf2.h>`'. There is an abstract function that operate on any PRF implemented via the `nettle_hash_update_func`, `nettle_hash_digest_func` interfaces. There is also helper macros and concrete functions PBKDF2-HMAC-SHA1, PBKDF2-HMAC-SHA256, PBKDF2-HMAC-SHA384 and PBKDF2-HMAC-SHA512. First, the abstract function:

`void pbkdf2` (*void *mac_ctx, nettle_hash_update_func *update, nettle_hash_digest_func *digest, size_t digest_size, unsigned iterations, size_t salt_length, const uint8_t *salt, size_t length, uint8_t *dst*) [Function]

Derive symmetric key from a password according to PKCS #5 PBKDF2. The PRF is assumed to have been initialized and this function will call the *update* and *digest* functions passing the *mac_ctx* context parameter as an argument in order to compute digest of size *digest_size*. Inputs are the salt *salt* of length *salt_length*, the iteration counter *iterations* (> 0), and the desired derived output length *length*. The output buffer is *dst* which must have room for at least *length* octets.

Like for CBC and HMAC, there is a macro to help use the function correctly.

`PBKDF2` (*ctx*, *update*, *digest*, *digest_size*, *iterations*, *salt_length*, *salt*, *length*, *dst*) [Macro]

ctx is a pointer to a context struct passed to the *update* and *digest* functions (of the types `nettle_hash_update_func` and `nettle_hash_digest_func` respectively) to implement the underlying PRF with digest size of *digest_size*. Inputs are the salt *salt* of length *salt_length*, the iteration counter *iterations* (> 0), and the desired

derived output length *length*. The output buffer is *dst* which must have room for at least *length* octets.

7.6.3 Concrete PBKDF2 functions

Now we come to the specialized PBKDF2 functions, which are easier to use than the general PBKDF2 function.

7.6.3.1 PBKDF2-HMAC-SHA1

`void pbkdf2_hmac_sha1` (*size_t* **`key_length`**, *const uint8_t* ***`key`**, *unsigned* **`iterations`**, *size_t* **`salt_length`**, *const uint8_t* ***`salt`**, *size_t* **`length`**, *uint8_t* ***`dst`**) [Function]

PBKDF2 with HMAC-SHA1. Derive *length* bytes of key into buffer *dst* using the password *key* of length *key_length* and salt *salt* of length *salt_length*, with iteration counter *iterations* (> 0). The output buffer is *dst* which must have room for at least *length* octets.

7.6.3.2 PBKDF2-HMAC-SHA256

`void pbkdf2_hmac_sha256` (*size_t* **`key_length`**, *const uint8_t* ***`key`**, *unsigned* **`iterations`**, *size_t* **`salt_length`**, *const uint8_t* ***`salt`**, *size_t* **`length`**, *uint8_t* ***`dst`**) [Function]

PBKDF2 with HMAC-SHA256. Derive *length* bytes of key into buffer *dst* using the password *key* of length *key_length* and salt *salt* of length *salt_length*, with iteration counter *iterations* (> 0). The output buffer is *dst* which must have room for at least *length* octets.

7.6.3.3 PBKDF2-HMAC-SHA384

`void pbkdf2_hmac_sha384` (*size_t* **`key_length`**, *const uint8_t* ***`key`**, *unsigned* **`iterations`**, *size_t* **`salt_length`**, *const uint8_t* ***`salt`**, *size_t* **`length`**, *uint8_t* ***`dst`**) [Function]

PBKDF2 with HMAC-SHA384. Derive *length* bytes of key into buffer *dst* using the password *key* of length *key_length* and salt *salt* of length *salt_length*, with iteration counter *iterations* (> 0). The output buffer is *dst* which must have room for at least *length* octets.

7.6.3.4 PBKDF2-HMAC-SHA512

`void pbkdf2_hmac_sha512` (*size_t* **`key_length`**, *const uint8_t* ***`key`**, *unsigned* **`iterations`**, *size_t* **`salt_length`**, *const uint8_t* ***`salt`**, *size_t* **`length`**, *uint8_t* ***`dst`**) [Function]

PBKDF2 with HMAC-SHA512. Derive *length* bytes of key into buffer *dst* using the password *key* of length *key_length* and salt *salt* of length *salt_length*, with iteration counter *iterations* (> 0). The output buffer is *dst* which must have room for at least *length* octets.

7.7 Public-key algorithms

Nettle uses GMP, the GNU bignum library, for all calculations with large numbers. In order to use the public-key features of Nettle, you must install GMP, at least version 3.0, before compiling Nettle, and you need to link your programs with `-lhogweed -lnettle -lgmp`.

The concept of *Public-key* encryption and digital signatures was discovered by Whitfield Diffie and Martin E. Hellman and described in a paper 1976. In traditional, "symmetric", cryptography, sender and receiver share the same keys, and these keys must be distributed in a secure way. And if there are many users or entities that need to communicate, each *pair* needs a shared secret key known by nobody else.

Public-key cryptography uses trapdoor one-way functions. A *one-way function* is a function `F` such that it is easy to compute the value `F(x)` for any `x`, but given a value `y`, it is hard to compute a corresponding `x` such that `y = F(x)`. Two examples are cryptographic hash functions, and exponentiation in certain groups.

A *trapdoor one-way function* is a function `F` that is one-way, unless one knows some secret information about `F`. If one knows the secret, it is easy to compute both `F` and it's inverse. If this sounds strange, look at the RSA example below.

Two important uses for one-way functions with trapdoors are public-key encryption, and digital signatures. The public-key encryption functions in Nettle are not yet documented; the rest of this chapter is about digital signatures.

To use a digital signature algorithm, one must first create a *key-pair*: A public key and a corresponding private key. The private key is used to sign messages, while the public key is used for verifying that that signatures and messages match. Some care must be taken when distributing the public key; it need not be kept secret, but if a bad guy is able to replace it (in transit, or in some user's list of known public keys), bad things may happen.

There are two operations one can do with the keys. The signature operation takes a message and a private key, and creates a signature for the message. A signature is some string of bits, usually at most a few thousand bits or a few hundred octets. Unlike paper-and-ink signatures, the digital signature depends on the message, so one can't cut it out of context and glue it to a different message.

The verification operation takes a public key, a message, and a string that is claimed to be a signature on the message, and returns true or false. If it returns true, that means that the three input values matched, and the verifier can be sure that someone went through with the signature operation on that very message, and that the "someone" also knows the private key corresponding to the public key.

The desired properties of a digital signature algorithm are as follows: Given the public key and pairs of messages and valid signatures on them, it should be hard to compute the private key, and it should also be hard to create a new message and signature that is accepted by the verification operation.

Besides signing meaningful messages, digital signatures can be used for authorization. A server can be configured with a public key, such that any client that connects to the service is given a random nonce message. If the server gets a reply with a correct signature matching the nonce message and the configured public key, the client is granted access. So the configuration of the server can be understood as "grant access to whoever knows the private key corresponding to this particular public key, and to no others".

7.7.1 RSA

The RSA algorithm was the first practical digital signature algorithm that was constructed. It was described 1978 in a paper by Ronald Rivest, Adi Shamir and L.M. Adleman, and the technique was also patented in the USA in 1983. The patent expired on September 20, 2000, and since that day, RSA can be used freely, even in the USA.

It's remarkably simple to describe the trapdoor function behind RSA. The "one-way"-function used is

```
F(x) = x^e mod n
```

I.e. raise x to the `e`'th power, while discarding all multiples of `n`. The pair of numbers `n` and `e` is the public key. `e` can be quite small, even `e = 3` has been used, although slightly larger numbers are recommended. `n` should be about 2000 bits or larger.

If `n` is large enough, and properly chosen, the inverse of F, the computation of `e`'th roots modulo `n`, is very difficult. But, where's the trapdoor?

Let's first look at how RSA key-pairs are generated. First `n` is chosen as the product of two large prime numbers `p` and `q` of roughly the same size (so if `n` is 2000 bits, `p` and `q` are about 1000 bits each). One also computes the number `phi = (p-1)(q-1)`, in mathematical speak, `phi` is the order of the multiplicative group of integers modulo n.

Next, `e` is chosen. It must have no factors in common with `phi` (in particular, it must be odd), but can otherwise be chosen more or less randomly. `e = 65537` is a popular choice, because it makes raising to the `e`'th power particularly efficient, and being prime, it usually has no factors common with `phi`.

Finally, a number `d`, `d < n` is computed such that `e d mod phi = 1`. It can be shown that such a number exists (this is why `e` and `phi` must have no common factors), and that for all x,

```
(x^e)^d mod n = x^(ed) mod n = (x^d)^e mod n = x
```

Using Euclid's algorithm, `d` can be computed quite easily from `phi` and `e`. But it is still hard to get `d` without knowing `phi`, which depends on the factorization of `n`.

So `d` is the trapdoor, if we know `d` and `y = F(x)`, we can recover x as `y^d mod n`. `d` is also the private half of the RSA key-pair.

The most common signature operation for RSA is defined in *PKCS#1*, a specification by RSA Laboratories. The message to be signed is first hashed using a cryptographic hash function, e.g. MD5 or SHA1. Next, some padding, the ASN.1 "Algorithm Identifier" for the hash function, and the message digest itself, are concatenated and converted to a number `x`. The signature is computed from `x` and the private key as `s = x^d mod n`[1]. The signature, `s` is a number of about the same size of `n`, and it usually encoded as a sequence of octets, most significant octet first.

The verification operation is straight-forward, `x` is computed from the message in the same way as above. Then `s^e mod n` is computed, the operation returns true if and only if the result equals `x`.

The RSA algorithm can also be used for encryption. RSA encryption uses the public key `(n,e)` to compute the ciphertext `m^e mod n`. The *PKCS#1* padding scheme will use at

[1] Actually, the computation is not done like this, it is done more efficiently using `p`, `q` and the Chinese remainder theorem (CRT). But the result is the same.

least 8 random and non-zero octets, using *m* of the form `[00 02 padding 00 plaintext]`. It is required that `m < n`, and therefor the plaintext must be smaller than the octet size of the modulo `n`, with some margin.

To decrypt the message, one needs the private key to compute `m = c^e mod n` followed by checking and removing the padding.

7.7.1.1 Nettle's RSA support

Nettle represents RSA keys using two structures that contain large numbers (of type `mpz_t`).

`rsa_public_key` *size n e* [Context struct]
: `size` is the size, in octets, of the modulo, and is used internally. `n` and `e` is the public key.

`rsa_private_key` *size d p q a b c* [Context struct]
: `size` is the size, in octets, of the modulo, and is used internally. `d` is the secret exponent, but it is not actually used when signing. Instead, the factors `p` and `q`, and the parameters `a`, `b` and `c` are used. They are computed from `p`, `q` and `e` such that `a e mod (p - 1) = 1, b e mod (q - 1) = 1, c q mod p = 1`.

Before use, these structs must be initialized by calling one of

`void rsa_public_key_init` (*struct rsa_public_key *pub*) [Function]
`void rsa_private_key_init` (*struct rsa_private_key *key*) [Function]
: Calls `mpz_init` on all numbers in the key struct.

and when finished with them, the space for the numbers must be deallocated by calling one of

`void rsa_public_key_clear` (*struct rsa_public_key *pub*) [Function]
`void rsa_private_key_clear` (*struct rsa_private_key *key*) [Function]
: Calls `mpz_clear` on all numbers in the key struct.

In general, Nettle's RSA functions deviates from Nettle's "no memory allocation"-policy. Space for all the numbers, both in the key structs above, and temporaries, are allocated dynamically. For information on how to customize allocation, see See Section "GMP Allocation" in *GMP Manual*.

When you have assigned values to the attributes of a key, you must call

`int rsa_public_key_prepare` (*struct rsa_public_key *pub*) [Function]
`int rsa_private_key_prepare` (*struct rsa_private_key *key*) [Function]
: Computes the octet size of the key (stored in the `size` attribute, and may also do other basic sanity checks. Returns one if successful, or zero if the key can't be used, for instance if the modulo is smaller than the minimum size needed for RSA operations specified by PKCS#1.

For each operation using the private key, there are two variants, e.g., `rsa_sha256_sign` and `rsa_sha256_sign_tr`. The former function is older, and it should be avoided, because it provides no defenses against side-channel attacks. The latter function use randomized RSA blinding, which defends against timing attacks using chosen-ciphertext, and it also

checks the correctness of the private key computation using the public key, which defends against software or hardware errors which could leak the private key.

Before signing or verifying a message, you first hash it with the appropriate hash function. You pass the hash function's context struct to the RSA signature function, and it will extract the message digest and do the rest of the work. There are also alternative functions that take the hash digest as argument.

There is currently no support for using SHA224 or SHA384 with RSA signatures, since there's no gain in either computation time nor message size compared to using SHA256 and SHA512, respectively.

Creating an RSA signature is done with one of the following functions:

`int rsa_md5_sign_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *struct md5_ctx* `*hash`, *mpz_t* `signature`) [Function]

`int rsa_sha1_sign_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *struct sha1_ctx* `*hash`, *mpz_t* `signature`) [Function]

`int rsa_sha256_sign_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *struct sha256_ctx* `*hash`, *mpz_t* `signature`) [Function]

`int rsa_sha512_sign_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *struct sha512_ctx* `*hash`, *mpz_t* `signature`) [Function]

The signature is stored in *signature* (which must have been `mpz_init`'ed earlier). The hash context is reset so that it can be used for new messages. The *random_ctx* and *random* pointers are used to generate the RSA blinding. Returns one on success, or zero on failure. Signing fails if an error in the computation was detected, or if the key is too small for the given hash size, e.g., it's not possible to create a signature using SHA512 and a 512-bit RSA key.

`int rsa_md5_sign_digest_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *const uint8_t* `*digest`, *mpz_t* `signature`) [Function]

`int rsa_sha1_sign_digest_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *const uint8_t* `*digest`, *mpz_t* `signature`) [Function]

`int rsa_sha256_sign_digest_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *const uint8_t* `*digest`, *mpz_t* `signature`) [Function]

`int rsa_sha512_sign_digest_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *const uint8_t* `*digest`, *mpz_t* `signature`) [Function]

Creates a signature from the given hash digest. *digest* should point to a digest of size `MD5_DIGEST_SIZE`, `SHA1_DIGEST_SIZE`, `SHA256_DIGEST_SIZE`, or `SHA512_DIGEST_SIZE`respectively. The signature is stored in *signature* (which must have been `mpz_init`:ed earlier). Returns one on success, or zero on failure.

`int rsa_pkcs1_sign_tr(const` *struct rsa_public_key* ***pub***, *const struct rsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***length***, *const uint8_t* ***digest_info***, *mpz_t* ***signature***) [Function]

Similar to the above `_sign_digest_tr` functions, but the input is not the plain hash digest, but a PKCS#1 "DigestInfo", an ASN.1 DER-encoding of the digest together with an object identifier for the used hash algorithm.

`int rsa_md5_sign` (*const struct rsa_private_key* ***key***, *struct md5_ctx* ***hash***, *mpz_t* ***signature***) [Function]

`int rsa_sha1_sign` (*const struct rsa_private_key* ***key***, *struct sha1_ctx* ***hash***, *mpz_t* ***signature***) [Function]

`int rsa_sha256_sign` (*const struct rsa_private_key* ***key***, *struct sha256_ctx* ***hash***, *mpz_t* ***signature***) [Function]

`int rsa_sha512_sign` (*const struct rsa_private_key* ***key***, *struct sha512_ctx* ***hash***, *mpz_t* ***signature***) [Function]

The signature is stored in *signature* (which must have been `mpz_init`'ed earlier). The hash context is reset so that it can be used for new messages. Returns one on success, or zero on failure. Signing fails if the key is too small for the given hash size, e.g., it's not possible to create a signature using SHA512 and a 512-bit RSA key.

`int rsa_md5_sign_digest` (*const struct rsa_private_key* ***key***, *const uint8_t* ***digest***, *mpz_t* ***signature***) [Function]

`int rsa_sha1_sign_digest` (*const struct rsa_private_key* ***key***, *const uint8_t* ***digest***, *mpz_t* ***signature***); [Function]

`int rsa_sha256_sign_digest` (*const struct rsa_private_key* ***key***, *const uint8_t* ***digest***, *mpz_t* ***signature***); [Function]

`int rsa_sha512_sign_digest` (*const struct rsa_private_key* ***key***, *const uint8_t* ***digest***, *mpz_t* ***signature***); [Function]

Creates a signature from the given hash digest; otherwise analoguous to the above signing functions. *digest* should point to a digest of size `MD5_DIGEST_SIZE`, `SHA1_DIGEST_SIZE`, `SHA256_DIGEST_SIZE`, or `SHA512_DIGEST_SIZE`, respectively. The signature is stored in *signature* (which must have been `mpz_init`:ed earlier). Returns one on success, or zero on failure.

`int rsa_pkcs1_sign(const` *struct rsa_private_key* ***key***, *size_t* ***length***, *const uint8_t* ***digest_info***, *mpz_t* ***s***) [Function]

Similar to the above _sign_digest functions, but the input is not the plain hash digest, but a PKCS#1 "DigestInfo", an ASN.1 DER-encoding of the digest together with an object identifier for the used hash algorithm.

Verifying an RSA signature is done with one of the following functions:

`int rsa_md5_verify` (*const struct rsa_public_key* ***key***, *struct md5_ctx* ***hash***, *const mpz_t* ***signature***) [Function]

`int rsa_sha1_verify` (*const struct rsa_public_key* ***key***, *struct sha1_ctx* ***hash***, *const mpz_t* ***signature***) [Function]

`int rsa_sha256_verify` (*const struct rsa_public_key* ***key***, *struct sha256_ctx* ***hash***, *const mpz_t* ***signature***) [Function]

`int rsa_sha512_verify` (*const struct rsa_public_key* ***key***, *struct sha512_ctx* ***hash***, *const mpz_t* ***signature***) [Function]

Returns 1 if the signature is valid, or 0 if it isn't. In either case, the hash context is reset so that it can be used for new messages.

`int rsa_md5_verify_digest` (*const struct rsa_public_key* ***key***, *const uint8_t* ***digest***, *const mpz_t* ***signature***) [Function]

`int rsa_sha1_verify_digest` (*const struct rsa_public_key* ***key***, *const uint8_t* ***digest***, *const mpz_t* ***signature***) [Function]

`int rsa_sha256_verify_digest` (*const struct rsa_public_key* ***key***, *const uint8_t* ***digest***, *const mpz_t* ***signature***) [Function]

`int rsa_sha512_verify_digest` (*const struct rsa_public_key* ***key***, *const uint8_t* ***digest***, *const mpz_t* ***signature***) [Function]

Returns 1 if the signature is valid, or 0 if it isn't. *digest* should point to a digest of size `MD5_DIGEST_SIZE`, `SHA1_DIGEST_SIZE`, `SHA256_DIGEST_SIZE`, or `SHA512_DIGEST_SIZE` respectively.

`int rsa_pkcs1_verify(const` *struct rsa_public_key* ***key***, *size_t* ***length***, *const uint8_t* ***digest_info***, *const mpz_t* ***signature***) [Function]

Similar to the above _verify_digest functions, but the input is not the plain hash digest, but a PKCS#1 "DigestInfo", and ASN.1 DER-encoding of the digest together with an object identifier for the used hash algorithm.

While the above functions for the RSA signature operations use the *PKCS#1* padding scheme, Nettle also provides the variants based on the PSS padding scheme, specified in *RFC 3447*. These variants take advantage of a randomly choosen salt value, which could enhance the security by causing output to be different for equivalent inputs. However, assuming the same security level as inverting the RSA algorithm, a longer salt value does not always mean a better security `http://www.iacr.org/archive/eurocrypt2002/23320268/coron.pdf`. The typical choices of the length are between 0 and the digest size of the underlying hash function.

Creating an RSA signature with the PSS padding scheme is done with one of the following functions:

`int rsa_pss_sha256_sign_digest_tr(const` *struct rsa_public_key* ***pub***, *const struct rsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***salt_length***, *const uint8_t* ***salt***, *const uint8_t* ***digest***, *mpz_t* ***signature***) [Function]

`int rsa_pss_sha384_sign_digest_tr(const` *struct rsa_public_key* ***pub***, *const struct rsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***salt_length***, *const uint8_t* ***salt***, *const uint8_t* ***digest***, *mpz_t* ***signature***) [Function]

`int rsa_pss_sha512_sign_digest_tr(const` *struct rsa_public_key* ***pub***, *const struct rsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***salt_length***, *const uint8_t* ***salt***, *const uint8_t* ***digest***, *mpz_t* ***signature***) [Function]

Creates a signature using the PSS padding scheme. *salt* should point to a salt string of size *salt_length*. *digest* should point to a digest of size `SHA256_DIGEST_SIZE`,

`SHA384_DIGEST_SIZE`, or `SHA512_DIGEST_SIZE`respectively. The signature is stored in *signature* (which must have been `mpz_init`:ed earlier). Returns one on success, or zero on failure.

Verifying an RSA signature with the PSS padding scheme is done with one of the following functions:

`int rsa_pss_sha256_verify_digest (`*const struct rsa_public_key* `*key`, *size_t* `salt_length`, *const uint8_t* `*digest`, *const mpz_t* `signature``)` [Function]

`int rsa_pss_sha384_verify_digest (`*const struct rsa_public_key* `*key`, *size_t* `salt_length`, *const uint8_t* `*digest`, *const mpz_t* `signature``)` [Function]

`int rsa_pss_sha512_verify_digest (`*const struct rsa_public_key* `*key`, *size_t* `salt_length`, *const uint8_t* `*digest`, *const mpz_t* `signature``)` [Function]

Returns 1 if the signature is valid, or 0 if it isn't. *digest* should point to a digest of size `SHA256_DIGEST_SIZE`, `SHA384_DIGEST_SIZE`, or `SHA512_DIGEST_SIZE` respectively.

The following function is used to encrypt a clear text message using RSA.

`int rsa_encrypt (`*const struct rsa_public_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *size_t* `length`, *const uint8_t* `*cleartext`, *mpz_t* `ciphertext``)` [Function]

Returns 1 on success, 0 on failure. If the message is too long then this will lead to a failure.

The following function is used to decrypt a cipher text message using RSA.

`int rsa_decrypt (`*const struct rsa_private_key* `*key`, *size_t* `*length`, *uint8_t* `*cleartext`, *const mpz_t* `ciphertext``)` [Function]

Returns 1 on success, 0 on failure. Causes of failure include decryption failing or the resulting message being to large. The message buffer pointed to by *cleartext* must be of size **length*. After decryption, **length* will be updated with the size of the message.

There is also a timing resistant version of decryption that utilizes randomized RSA blinding.

`int rsa_decrypt_tr (`*const struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *size_t* `*length`, *uint8_t* `*message`, *const mpz_t* `ciphertext``)` [Function]

Returns 1 on success, 0 on failure.

If you need to use the RSA trapdoor, the private key, in a way that isn't supported by the above functions Nettle also includes a function that computes `x^d mod n` and nothing more, using the CRT optimization.

`int rsa_compute_root_tr(const` *struct rsa_public_key* `*pub`, *const struct rsa_private_key* `*key`, *void* `*random_ctx`, *nettle_random_func* `*random`, *mpz_t* `x`, *const mpz_t* `m``)` [Function]

Computes `x = m^d`. Returns one on success, or zero if a failure in the computation was detected.

`void rsa_compute_root` (*struct rsa_private_key* ***key***, *mpz_t* `x`, *const mpz_t* `m`) [Function]

Computes `x = m^d`.

At last, how do you create new keys?

`int rsa_generate_keypair` (*struct rsa_public_key* ***pub***, *struct rsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *void* ***progress_ctx***, *nettle_progress_func* ***progress***, *unsigned* ***n_size***, *unsigned* ***e_size***); [Function]

There are lots of parameters. *pub* and *key* is where the resulting key pair is stored. The structs should be initialized, but you don't need to call `rsa_public_key_prepare` or `rsa_private_key_prepare` after key generation.

random_ctx and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89.

progress and *progress_ctx* can be used to get callbacks during the key generation process, in order to uphold an illusion of progress. *progress* can be NULL, in that case there are no callbacks.

size_n is the desired size of the modulo, in bits. If *size_e* is non-zero, it is the desired size of the public exponent and a random exponent of that size is selected. But if *e_size* is zero, it is assumed that the caller has already chosen a value for `e`, and stored it in *pub*. Returns one on success, and zero on failure. The function can fail for example if if *n_size* is too small, or if *e_size* is zero and `pub->e` is an even number.

7.7.2 DSA

The DSA digital signature algorithm is more complex than RSA. It was specified during the early 1990s, and in 1994 NIST published FIPS 186 which is the authoritative specification. Sometimes DSA is referred to using the acronym DSS, for Digital Signature Standard. The most recent revision of the specification, FIPS186-3, was issued in 2009, and it adds support for larger hash functions than sha1.

For DSA, the underlying mathematical problem is the computation of discrete logarithms. The public key consists of a large prime `p`, a small prime `q` which is a factor of `p-1`, a number `g` which generates a subgroup of order `q` modulo `p`, and an element `y` in that subgroup.

In the original DSA, the size of `q` is fixed to 160 bits, to match with the SHA1 hash algorithm. The size of `p` is in principle unlimited, but the standard specifies only nine specific sizes: `512 + l*64`, where `l` is between 0 and 8. Thus, the maximum size of `p` is 1024 bits, and sizes less than 1024 bits are considered obsolete and not secure.

The subgroup requirement means that if you compute

```
g^t mod p
```

for all possible integers `t`, you will get precisely `q` distinct values.

The private key is a secret exponent `x`, such that

```
g^x = y mod p
```

In mathematical speak, `x` is the *discrete logarithm* of `y` mod `p`, with respect to the generator `g`. The size of `x` will also be about the same size as `q`. The security of the DSA

algorithm relies on the difficulty of the discrete logarithm problem. Current algorithms to compute discrete logarithms in this setting, and hence crack DSA, are of two types. The first type works directly in the (multiplicative) group of integers mod `p`. The best known algorithm of this type is the Number Field Sieve, and it's complexity is similar to the complexity of factoring numbers of the same size as `p`. The other type works in the smaller `q`-sized subgroup generated by `g`, which has a more difficult group structure. One good algorithm is Pollard-rho, which has complexity `sqrt(q)`.

The important point is that security depends on the size of *both* `p` and `q`, and they should be chosen so that the difficulty of both discrete logarithm methods are comparable. Today, the security margin of the original DSA may be uncomfortably small. Using a `p` of 1024 bits implies that cracking using the number field sieve is expected to take about the same time as factoring a 1024-bit RSA modulo, and using a `q` of size 160 bits implies that cracking using Pollard-rho will take roughly `2^80` group operations. With the size of `q` fixed, tied to the SHA1 digest size, it may be tempting to increase the size of `p` to, say, 4096 bits. This will provide excellent resistance against attacks like the number field sieve which works in the large group. But it will do very little to defend against Pollard-rho attacking the small subgroup; the attacker is slowed down at most by a single factor of 10 due to the more expensive group operation. And the attacker will surely choose the latter attack.

The signature generation algorithm is randomized; in order to create a DSA signature, you need a good source for random numbers (see Section 7.8 [Randomness], page 89). Let us describe the common case of a 160-bit `q`.

To create a signature, one starts with the hash digest of the message, `h`, which is a 160 bit number, and a random number `k, 0<k<q`, also 160 bits. Next, one computes

```
r = (g^k mod p) mod q
s = k^-1 (h + x r) mod q
```

The signature is the pair `(r, s)`, two 160 bit numbers. Note the two different mod operations when computing `r`, and the use of the secret exponent `x`.

To verify a signature, one first checks that `0 < r,s < q`, and then one computes backwards,

```
w = s^-1 mod q
v = (g^(w h) y^(w r) mod p) mod q
```

The signature is valid if `v = r`. This works out because `w = s^-1 mod q = k (h + x r)^-1 mod q`, so that

```
g^(w h) y^(w r) = g^(w h) (g^x)^(w r) = g^(w (h + x r)) = g^k
```

When reducing mod `q` this yields `r`. Note that when verifying a signature, we don't know either `k` or `x`: those numbers are secret.

If you can choose between RSA and DSA, which one is best? Both are believed to be secure. DSA gained popularity in the late 1990s, as a patent free alternative to RSA. Now that the RSA patents have expired, there's no compelling reason to want to use DSA. Today, the original DSA key size does not provide a large security margin, and it should probably be phased out together with RSA keys of 1024 bits. Using the revised DSA algorithm with a larger hash function, in particular, SHA256, a 256-bit `q`, and `p` of size 2048 bits or more, should provide for a more comfortable security margin, but these variants are not yet in wide use.

DSA signatures are smaller than RSA signatures, which is important for some specialized applications.

From a practical point of view, DSA's need for a good randomness source is a serious disadvantage. If you ever use the same `k` (and `r`) for two different message, you leak your private key.

7.7.2.1 Nettle's DSA support

Like for RSA, Nettle represents DSA keys using two structures, containing values of type `mpz_t`. For information on how to customize allocation, see See Section "GMP Allocation" in *GMP Manual*. Nettle's DSA interface is defined in '`<nettle/dsa.h>`'.

A DSA group is represented using the following struct.

`dsa_params` *p q g* [Context struct]
Parameters of the DSA group.

`void dsa_params_init` (*struct dsa_params* ***params**) [Function]
Calls `mpz_init` on all numbers in the struct.

`void dsa_params_clear` (*struct dsa_params* ***params** *params*) [Function]
Calls `mpz_clear` on all numbers in the struct.

`int dsa_generate_params` (*struct dsa_params* ***params**, *void* ***random_ctx**, *nettle_random_func* ***random**, *void* ***progress_ctx**, *nettle_progress_func* ***progress**, *unsigned* **p_bits**, *unsigned* **q_bits**) [Function]
Generates parameters of a new group. The *params* struct should be initialized before you call this function.

random_ctx and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89.

progress and *progress_ctx* can be used to get callbacks during the key generation process, in order to uphold an illusion of progress. *progress* can be NULL, in that case there are no callbacks.

p_bits and *q_bits* are the desired sizes of `p` and `q`. To generate keys that conform to the original DSA standard, you must use `q_bits = 160` and select *p_bits* of the form `p_bits = 512 + l*64`, for `0 <= l <= 8`, where the smaller sizes are no longer recommended, so you should most likely stick to `p_bits = 1024`. Non-standard sizes are possible, in particular `p_bits` larger than 1024, although DSA implementations can not in general be expected to support such keys. Also note that using very large *p_bits*, with *q_bits* fixed at 160, doesn't make much sense, because the security is also limited by the size of the smaller prime. To generate DSA keys for use with SHA256, use `q_bits = 256` and, e.g., `p_bits = 2048`.

Returns one on success, and zero on failure. The function will fail if *q_bits* is too small, or too close to *p_bits*.

Signatures are represented using the structure below.

`dsa_signature` *r s* [Context struct]

`void dsa_signature_init` (*struct dsa_signature* ***signature***) [Function]
`void dsa_signature_clear` (*struct dsa_signature* ***signature***) [Function]
You must call `dsa_signature_init` before creating or using a signature, and call `dsa_signature_clear` when you are finished with it.

Keys are represented as bignums, of type `mpz_t`. A public key represents a group element, and is of the same size as `p`, while a private key is an exponent, of the same size as `q`.

`int dsa_sign` (*const struct dsa_params* ***params***, *const mpz_t* ***x***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***digest_size***, *const uint8_t* ***digest***, *struct dsa_signature* ***signature***) [Function]
Creates a signature from the given hash digest, using the private key *x*. *random_ctx* and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89. Returns one on success, or zero on failure. Signing can fail only if the key is invalid, so that inversion modulo `q` fails.

`int dsa_verify` (*const struct dsa_params* ***params***, *const mpz_t* ***y***, *size_t* ***digest_size***, *const uint8_t* ***digest***, *const struct dsa_signature* ***signature***) [Function]
Verifies a signature, using the public key y. Returns 1 if the signature is valid, otherwise 0.

To generate a keypair, first generate a DSA group using `dsa_generate_params`. A keypair in this group is then created using

`void dsa_generate_keypair` (*const struct dsa_params* ***params***, *mpz_t* ***pub***, *mpz_t* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***) [Function]
Generates a new keypair, using the group *params*. The public key is stored in *pub*, and the private key in *key*. Both variables must be initialized using `mpz_init` before this call.

random_ctx and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89.

7.7.2.2 Old, deprecated, DSA interface

Versions before nettle-3.0 used a different interface for DSA signatures, where the group parameters and the public key was packed together as `struct dsa_public_key`. Most of this interface is kept for backwards compatibility, and declared in '`nettle/dsa-compat.h`'. Below is the old documentation. The old and new interface use distinct names and don't confict, with one exception: The key generation function. The '`nettle/dsa-compat.h`' redefines `dsa_generate_keypair` as an alias for `dsa_compat_generate_keypair`, compatible with the old interface and documented below.

The old DSA functions are very similar to the corresponding RSA functions, but there are a few differences pointed out below. For a start, there are no functions corresponding to `rsa_public_key_prepare` and `rsa_private_key_prepare`.

`dsa_public_key` *p q g y* [Context struct]
The public parameters described above.

`dsa_private_key` *x* [Context struct]
The private key `x`.

Before use, these structs must be initialized by calling one of

`void dsa_public_key_init` (*struct dsa_public_key* ***pub***) [Function]
`void dsa_private_key_init` (*struct dsa_private_key* ***key***) [Function]
Calls `mpz_init` on all numbers in the key struct.

When finished with them, the space for the numbers must be deallocated by calling one of

`void dsa_public_key_clear` (*struct dsa_public_key* ***pub***) [Function]
`void dsa_private_key_clear` (*struct dsa_private_key* ***key***) [Function]
Calls `mpz_clear` on all numbers in the key struct.

Signatures are represented using `struct dsa_signature`, described earlier.

For signing, you need to provide both the public and the private key (unlike RSA, where the private key struct includes all information needed for signing), and a source for random numbers. Signatures can use the SHA1 or the SHA256 hash function, although the implementation of DSA with SHA256 should be considered somewhat experimental due to lack of official test vectors and interoperability testing.

`int dsa_sha1_sign` (*const struct dsa_public_key* ***pub***, *const struct dsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *struct sha1_ctx* ***hash***, *struct dsa_signature* ***signature***) [Function]
`int dsa_sha1_sign_digest` (*const struct dsa_public_key* ***pub***, *const struct dsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *const uint8_t* ***digest***, *struct dsa_signature* ***signature***) [Function]
`int dsa_sha256_sign` (*const struct dsa_public_key* ***pub***, *const struct dsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *struct sha256_ctx* ***hash***, *struct dsa_signature* ***signature***) [Function]
`int dsa_sha256_sign_digest` (*const struct dsa_public_key* ***pub***, *const struct dsa_private_key* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *const uint8_t* ***digest***, *struct dsa_signature* ***signature***) [Function]
Creates a signature from the given hash context or digest. *random_ctx* and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89. Returns one on success, or zero on failure. Signing fails if the key size and the hash size don't match.

Verifying signatures is a little easier, since no randomness generator is needed. The functions are

`int dsa_sha1_verify` (*const struct dsa_public_key* ***key***, *struct sha1_ctx* ***hash***, *const struct dsa_signature* ***signature***) [Function]
`int dsa_sha1_verify_digest` (*const struct dsa_public_key* ***key***, *const uint8_t* ***digest***, *const struct dsa_signature* ***signature***) [Function]

`int dsa_sha256_verify` (*const struct dsa_public_key* ***key**, *struct sha256_ctx* ***hash**, *const struct dsa_signature* ***signature**) [Function]

`int dsa_sha256_verify_digest` (*const struct dsa_public_key* ***key**, *const uint8_t* ***digest**, *const struct dsa_signature* ***signature**) [Function]

Verifies a signature. Returns 1 if the signature is valid, otherwise 0.

Key generation uses mostly the same parameters as the corresponding RSA function.

`int dsa_compat_generate_keypair` (*struct dsa_public_key* ***pub**, *struct dsa_private_key* ***key**, *void* ***random_ctx**, *nettle_random_func* **random**, *void* ***progress_ctx**, *nettle_progress_func* **progress**, *unsigned* **p_bits**, *unsigned* **q_bits**) [Function]

pub and *key* is where the resulting key pair is stored. The structs should be initialized before you call this function.

random_ctx and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89.

progress and *progress_ctx* can be used to get callbacks during the key generation process, in order to uphold an illusion of progress. *progress* can be NULL, in that case there are no callbacks.

p_bits and *q_bits* are the desired sizes of `p` and `q`. See `dsa_generate_keypair` for details.

7.7.3 Elliptic curves

For cryptographic purposes, an elliptic curve is a mathematical group of points, and computing logarithms in this group is computationally difficult problem. Nettle uses additive notation for elliptic curve groups. If P and Q are two points, and k is an integer, the point sum, $P + Q$, and the multiple kP can be computed efficiently, but given only two points P and Q, finding an integer k such that $Q = kP$ is the elliptic curve discrete logarithm problem.

Nettle supports standard curves which are all of the form $y^2 = x^3 - 3x + b \pmod p$, i.e., the points have coordinates (x, y), both considered as integers modulo a specified prime p. Curves are represented as a `struct ecc_curve`. It also supports curve25519, which uses a different form of curve. Supported curves are declared in '`<nettle/ecc-curve.h>`', e.g., call `nettle_get_secp_256r1` for a standardized curve using the 256-bit prime $p = 2^{256} - 2^{224} + 2^{192} + 2^{96} - 1$. The contents of these structs is not visible to nettle users. The "bitsize of the curve" is used as a shorthand for the bitsize of the curve's prime p, e.g., 256 bits for the SECP 256R1 curve.

7.7.3.1 Side-channel silence

Nettle's implementation of the elliptic curve operations is intended to be side-channel silent. The side-channel attacks considered are:

- Timing attacks If the timing of operations depends on secret values, an attacker interacting with your system can measure the response time, and infer information about your secrets, e.g., a private signature key.

- Attacks using memory caches Assume you have some secret data on a multi-user system, and that this data is properly protected so that other users get no direct access to it. If you have a process operating on the secret data, and this process does memory accesses depending on the data, e.g, an internal lookup table in some cryptographic algorithm, an attacker running a separate process on the same system may use behavior of internal CPU caches to get information about your secrets. This type of attack can even cross virtual machine boundaries.

Nettle's ECC implementation is designed to be *side-channel silent*, and not leak any information to these attacks. Timing and memory accesses depend only on the size of the input data and its location in memory, not on the actual data bits. This implies a performance penalty in several of the building blocks.

7.7.3.2 ECDSA

ECDSA is a variant of the DSA digital signature scheme (see Section 7.7.2 [DSA], page 78), which works over an elliptic curve group rather than over a (subgroup of) integers modulo p. Like DSA, creating a signature requires a unique random nonce (repeating the nonce with two different messages reveals the private key, and any leak or bias in the generation of the nonce also leaks information about the key).

Unlike DSA, signatures are in general not tied to any particular hash function or even hash size. Any hash function can be used, and the hash value is truncated or padded as needed to get a size matching the curve being used. It is recommended to use a strong cryptographic hash function with digest size close to the bit size of the curve, e.g., SHA256 is a reasonable choice when using ECDSA signature over the curve secp256r1. A protocol or application using ECDSA has to specify which curve and which hash function to use, or provide some mechanism for negotiating.

Nettle defines ECDSA in '`<nettle/ecdsa.h>`'. We first need to define the data types used to represent public and private keys.

`struct ecc_point` [struct]
Represents a point on an elliptic curve. In particular, it is used to represent an ECDSA public key.

`void ecc_point_init` (*struct ecc_point* `*p`, *const struct ecc_curve* `*ecc`) [Function]
Initializes p to represent points on the given curve *ecc*. Allocates storage for the coordinates, using the same allocation functions as GMP.

`void ecc_point_clear` (*struct ecc_point* `*p`) [Function]
Deallocate storage.

`int ecc_point_set` (*struct ecc_point* `*p`, *const mpz_t* `x`, *const mpz_t* `y`) [Function]
Check that the given coordinates represent a point on the curve. If so, the coordinates are copied and converted to internal representation, and the function returns 1. Otherwise, it returns 0. Currently, the infinity point (or zero point, with additive notation) is not allowed.

`void ecc_point_get` (*const struct ecc_point* `*p`, *mpz_t* `x`, *mpz_t* `y`) [Function]
Extracts the coordinate of the point p. The output parameters x or y may be NULL if the caller doesn't want that coordinate.

`struct ecc_scalar` [struct]
Represents an integer in the range $0 < x < grouporder$, where the "group order" refers to the order of an ECC group. In particular, it is used to represent an ECDSA private key.

`void ecc_scalar_init` (*struct ecc_scalar* ***s***, *const struct ecc_curve* ***ecc***) [Function]
Initializes *s* to represent a scalar suitable for the given curve *ecc*. Allocates storage using the same allocation functions as GMP.

`void ecc_scalar_clear` (*struct ecc_scalar* ***s***) [Function]
Deallocate storage.

`int ecc_scalar_set` (*struct ecc_scalar* ***s***, *const mpz_t* ***z***) [Function]
Check that *z* is in the correct range. If so, copies the value to *s* and returns 1, otherwise returns 0.

`void ecc_scalar_get` (*const struct ecc_scalar* ***s***, *mpz_t* ***z***) [Function]
Extracts the scalar, in GMP `mpz_t` representation.

To create and verify ECDSA signatures, the following functions are used.

`void ecdsa_sign` (*const struct ecc_scalar* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***digest_length***, *const uint8_t* ***digest***, *struct dsa_signature* ***signature***) [Function]
Uses the private key *key* to create a signature on *digest*. *random_ctx* and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. The signature is stored in *signature*, in the same was as for plain DSA.

`int ecdsa_verify` (*const struct ecc_point* ***pub***, *size_t* ***length***, *const uint8_t* ***digest***, *const struct dsa_signature* ***signature***) [Function]
Uses the public key *pub* to verify that *signature* is a valid signature for the message digest *digest* (of *length* octets). Returns 1 if the signature is valid, otherwise 0.

Finally, generating a new ECDSA key pair:

`void ecdsa_generate_keypair` (*struct ecc_point* ***pub***, *struct ecc_scalar* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***); [Function]
pub and *key* is where the resulting key pair is stored. The structs should be initialized, for the desired ECC curve, before you call this function.

random_ctx and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. For advice, see See Section 7.8 [Randomness], page 89.

7.7.3.3 GOSTDSA

GOSTDSA (GOST R 34.10-2001, GOST R 34.10-2012) is a variant of the DSA (see Section 7.7.2 [DSA], page 78) and ECDSA (see Section 7.7.3.2 [ECDSA], page 84) digital signature schemes, which works over an elliptic curve group. Original documents are written in

Russian. English translations are provided in *RFC 5832* and *RFC 7091*. While technically nothing stops one from using GOSTDSA over any curve, it is defined only over several 256 and 512-bit curves. Like DSA and ECDSA, creating a signature requires a unique random nonce (repeating the nonce with two different messages reveals the private key, and any leak or bias in the generation of the nonce also leaks information about the key).

GOST R 34.10-2001 was defined to use GOST R 34.11-94 hash function (GOSTHASH94 and GOSTHASH94CP, *RFC 5831*). GOST R 34.10-2012 is defined to use GOST R 34.11-2012 hash function (Streebog, *RFC 6986*) of corresponding size (256 or 512) depending on curve size.

Nettle defines GOSTDSA in '`<nettle/gostdsa.h>`'. GOSTDSA reuses ECDSA data types (`struct ecc_point`, `struct ecc_scalar`) to represent public and private keys. Also to generate a new GOSTDSA key pair one has to use `ecdsa_generate_keypair()` function.

To create and verify GOSTDSA signatures, the following functions are used.

`void gostdsa_sign` (*const struct ecc_scalar* ***key***, *void* ***random_ctx***, *nettle_random_func* ***random***, *size_t* ***digest_length***, *const uint8_t* ***digest***, *struct dsa_signature* ***signature***) [Function]

Uses the private key *key* to create a signature on *digest*. *random_ctx* and *random* is a randomness generator. `random(random_ctx, length, dst)` should generate `length` random octets and store them at `dst`. The signature is stored in *signature*, in the same was as for plain DSA.

`int gostdsa_verify` (*const struct ecc_point* ***pub***, *size_t* ***length***, *const uint8_t* ***digest***, *const struct dsa_signature* ***signature***) [Function]

Uses the public key *pub* to verify that *signature* is a valid signature for the message digest *digest* (of *length* octets). Returns 1 if the signature is valid, otherwise 0.

For historical reason several curve IDs (OIDs) may correspond to a single curve/generator combination. Following list defines correspondence between nettle's view on curves and actual identifiers defined in *RFC 4357* and *RFC 7836*.

`const struct ecc_curve nettle_get_gost_gc256b(void)` [Function]

Returns curve corresponding to following identifiers:

- id-GostR3410-2001-CryptoPro-A-ParamSet (*RFC 4357*)
- id-GostR3410-2001-CryptoPro-XchA-ParamSet (*RFC 4357*)
- id-tc26-gost-3410-12-256-paramSetB

`const struct ecc_curve nettle_get_gost_gc512a(void)` [Function]

Returns curve corresponding to following identifiers:

- id-tc26-gost-3410-12-512-paramSetA (*RFC 7836*)

For GOST key pairs key derivation/key agreement function (VKO) is defined in *RFC 4357* and *RFC 7836*. Basically shared key is equal to hash(cofactor * ukm * priv * pub). Nettle library provides a function that does multiplication. Caller should do hashing on his own (it will be either GOST R 34.11-94 (see [GOSTHASH94CP], page 19) or GOST R 34.11-2012, Streebog, which nor part of the library yet).

`void gostdsa_vko` (*const struct ecc_scalar* ***priv***, *const struct ecc_point* ***pub***, *size_t* ***ukm_length***, *const uint8_t* ***ukm***, *uint8_t* ***out***) [Function]

Uses private key *priv*, public ket *pub* and shared key material *ukm* to generate shared secret, written to buffer *out*. The buffer should be of the size equal to 2 private key lengths: 64 bytes for 256 bit curves and 128 bytes for 512 bit ones. UKM is a shared key material, usually transferred in cleartext. It does not have to be secret.

7.7.3.4 Curve25519 and Curve448

Curve25519 is an elliptic curve of Montgomery type, $y^2 = x^3 + 486662x^2 + x \pmod p$, with $p = 2^255 - 19$. Montgomery curves have the advantage of simple and efficient point addition based on the x-coordinate only. This particular curve was proposed by D. J. Bernstein in 2006, for fast Diffie-Hellman key exchange, and is also described in *RFC 7748*. The group generator is defined by $x = 9$ (there are actually two points with $x = 9$, differing by the sign of the y-coordinate, but that doesn't matter for the curve25519 operations which work with the x-coordinate only).

The curve25519 functions are defined as operations on octet strings, representing 255-bit scalars or x-coordinates, in little-endian byte order. The most significant input bit, i.e, the most significant bit of the last octet, is always ignored.

For scalars, in addition, the least significant three bits are ignored, and treated as zero, and the second most significant bit is ignored too, and treated as one. Then the scalar input string always represents 8 times a number in the range $2^251 <= s < 2^252$.

Of all the possible input strings, only about half correspond to x-coordinates of points on curve25519, i.e., a value x for which the the curve equation can be solved for y. The other half correspond to points on a related "twist curve". The function `curve25519_mul` uses a Montgomery ladder for the scalar multiplication, as suggested in the curve25519 literature, and required by *RFC 7748*. The output is therefore well defined for *all* possible inputs, no matter if the input string represents a valid point on the curve or not.

Note that the curve25519 implementation in earlier versions of Nettle deviates slightly from *RFC 7748*, in that bit 255 of the x coordinate of the point input to curve25519_mul was not ignored. The '`nette/curve25519.h`' defines a preprocessor symbol `NETTLE_CURVE25519_RFC7748` to indicate conformance with the standard.

Nettle defines Curve 25519 in '`<nettle/curve25519.h>`'.

`NETTLE_CURVE25519_RFC7748` [Constant]

Defined to 1 in Nettle versions conforming to RFC 7748. Undefined in earlier versions.

`CURVE25519_SIZE` [Constant]

The size of the strings representing curve25519 points and scalars, 32.

`void curve25519_mul_g` (*uint8_t* ***q***, *const uint8_t* ***n***) [Function]

Computes $Q = NG$, where G is the group generator and N is an integer. The input argument n and the output argument q use a little-endian representation of the scalar and the x-coordinate, respectively. They are both of size `CURVE25519_SIZE`.

This function is intended to be compatible with the function `crypto_scalar_mult_base` in the NaCl library.

`void curve25519_mul (uint8_t *q, const uint8_t *n, const uint8_t *p)` [Function]
Computes $Q = NP$, where P is an input point and N is an integer. The input arguments n and p and the output argument q use a little-endian representation of the scalar and the x-coordinates, respectively. They are all of size `CURVE25519_SIZE`.

This function is intended to be compatible with the function `crypto_scalar_mult` in the NaCl library.

Similarly, Nettle also implements Curve448, an elliptic curve of Montgomery type, $y^2 = x^3 + 156326x^2 + x \pmod p$, with $p = 2^448 - 2^224 - 1$. This particular curve was proposed by Mike Hamburg in 2015, for fast Diffie-Hellman key exchange, and is also described in *RFC 7748*.

Nettle defines Curve 448 in '`<nettle/curve448.h>`'.

`CURVE448_SIZE` [Constant]
The octet length of the strings representing curve448 points and scalars, 56.

`void curve448_mul_g (uint8_t *q, const uint8_t *n)` [Function]
Computes $Q = NG$, where G is the group generator and N is an integer. The input argument n and the output argument q use a little-endian representation of the scalar and the x-coordinate, respectively. They are both of size `CURVE448_SIZE`.

This function is intended to be compatible with the function `crypto_scalar_mult_base` in the NaCl library.

`void curve448_mul (uint8_t *q, const uint8_t *n, const uint8_t *p)` [Function]
Computes $Q = NP$, where P is an input point and N is an integer. The input arguments n and p and the output argument q use a little-endian representation of the scalar and the x-coordinates, respectively. They are all of size `CURVE448_SIZE`.

This function is intended to be compatible with the function `crypto_scalar_mult` in the NaCl library.

7.7.3.5 EdDSA

EdDSA is a signature scheme proposed by D. J. Bernstein et al. in 2011. It is defined using a "Twisted Edwards curve", of the form $-x^2 + y^2 = 1 + dx^2y^2$. The specific signature scheme Ed25519 uses a curve which is equivalent to curve25519: The two groups used differ only by a simple change of coordinates, so that the discrete logarithm problem is of equal difficulty in both groups.

Unlike other signature schemes in Nettle, the input to the EdDSA sign and verify functions is the possibly large message itself, not a hash digest. EdDSA is a variant of Schnorr signatures, where the message is hashed together with other data during the signature process, providing resilience to hash-collisions: A successful attack finding collisions in the hash function does not automatically translate into an attack to forge signatures. EdDSA also avoids the use of a randomness source by generating the needed signature nonce from a hash of the private key and the message, which means that the message is actually hashed twice when creating a signature. If signing huge messages, it is possible to hash the message first and pass the short message digest as input to the sign and verify functions, however, the resilience to hash collision is then lost.

`ED25519_KEY_SIZE` [Constant]
The size of a private or public Ed25519 key, 32 octets.

`ED25519_SIGNATURE_SIZE` [Constant]
The size of an Ed25519 signature, 64 octets.

`void ed25519_sha512_public_key (`*uint8_t* ***pub***, *const uint8_t* ***priv***`)` [Function]
Computes the public key corresponding to the given private key. Both input and output are of size `ED25519_KEY_SIZE`.

`void ed25519_sha512_sign (`*const uint8_t* ***pub***, *const uint8_t* ***priv***, *size_t* ***length***, *const uint8_t* ***msg***, *uint8_t* ***signature***`)` [Function]
Signs a message using the provided key pair.

`int ed25519_sha512_verify (`*const uint8_t* ***pub***, *size_t* ***length***, *const uint8_t* ***msg***, *const uint8_t* ***signature***`)` [Function]
Verifies a message using the provided public key. Returns 1 if the signature is valid, otherwise 0.

Nettle also provides Ed448, an EdDSA signature scheme based on an Edwards curve equivalent to curve448.

`ED448_KEY_SIZE` [Constant]
The size of a private or public Ed448 key, 57 octets.

`ED448_SIGNATURE_SIZE` [Constant]
The size of an Ed448 signature, 114 octets.

`void ed448_shake256_public_key (`*uint8_t* ***pub***, *const uint8_t* ***priv***`)` [Function]
Computes the public key corresponding to the given private key. Both input and output are of size `ED448_KEY_SIZE`.

`void ed448_shake256_sign (`*const uint8_t* ***pub***, *const uint8_t* ***priv***, *size_t* ***length***, *const uint8_t* ***msg***, *uint8_t* ***signature***`)` [Function]
Signs a message using the provided key pair.

`int ed448_shake256_verify (`*const uint8_t* ***pub***, *size_t* ***length***, *const uint8_t* ***msg***, *const uint8_t* ***signature***`)` [Function]
Verifies a message using the provided public key. Returns 1 if the signature is valid, otherwise 0.

7.8 Randomness

A crucial ingredient in many cryptographic contexts is randomness: Let `p` be a random prime, choose a random initialization vector `iv`, a random key `k` and a random exponent `e`, etc. In the theories, it is assumed that you have plenty of randomness around. If this assumption is not true in practice, systems that are otherwise perfectly secure, can be broken. Randomness has often turned out to be the weakest link in the chain.

In non-cryptographic applications, such as games as well as scientific simulation, a good randomness generator usually means a generator that has good statistical properties, and is seeded by some simple function of things like the current time, process id, and host name.

However, such a generator is inadequate for cryptography, for at least two reasons:

- It's too easy for an attacker to guess the initial seed. Even if it will take some 2^32 tries before he guesses right, that's far too easy. For example, if the process id is 16 bits, the resolution of "current time" is one second, and the attacker knows what day the generator was seeded, there are only about 2^32 possibilities to try if all possible values for the process id and time-of-day are tried.
- The generator output reveals too much. By observing only a small segment of the generator's output, its internal state can be recovered, and from there, all previous output and all future output can be computed by the attacker.

A randomness generator that is used for cryptographic purposes must have better properties. Let's first look at the seeding, as the issues here are mostly independent of the rest of the generator. The initial state of the generator (its seed) must be unguessable by the attacker. So what's unguessable? It depends on what the attacker already knows. The concept used in information theory to reason about such things is called "entropy", or "conditional entropy" (not to be confused with the thermodynamic concept with the same name). A reasonable requirement is that the seed contains a conditional entropy of at least some 80-100 bits. This property can be explained as follows: Allow the attacker to ask `n` yes-no-questions, of his own choice, about the seed. If the attacker, using this question-and-answer session, as well as any other information he knows about the seeding process, still can't guess the seed correctly, then the conditional entropy is more than `n` bits.

Let's look at an example. Say information about timing of received network packets is used in the seeding process. If there is some random network traffic going on, this will contribute some bits of entropy or "unguessability" to the seed. However, if the attacker can listen in to the local network, or if all but a small number of the packets were transmitted by machines that the attacker can monitor, this additional information makes the seed easier for the attacker to figure out. Even if the information is exactly the same, the conditional entropy, or unguessability, is smaller for an attacker that knows some of it already before the hypothetical question-and-answer session.

Seeding of good generators is usually based on several sources. The key point here is that the amount of unguessability that each source contributes, depends on who the attacker is. Some sources that have been used are:

High resolution timing of i/o activities
: Such as completed blocks from spinning hard disks, network packets, etc. Getting access to such information is quite system dependent, and not all systems include suitable hardware. If available, it's one of the better randomness source one can find in a digital, mostly predictable, computer.

User activity
: Timing and contents of user interaction events is another popular source that is available for interactive programs (even if I suspect that it is sometimes used in order to make the user feel good, not because the quality of the input is needed or used properly). Obviously, not available when a machine is unattended. Also

beware of networks: User interaction that happens across a long serial cable, TELNET session, or even SSH session may be visible to an attacker, in full or partially.

Audio input
: Any room, or even a microphone input that's left unconnected, is a source of some random background noise, which can be fed into the seeding process.

Specialized hardware
: Hardware devices with the sole purpose of generating random data have been designed. They range from radioactive samples with an attached Geiger counter, to amplification of the inherent noise in electronic components such as diodes and resistors, to low-frequency sampling of chaotic systems. Hashing successive images of a Lava lamp is a spectacular example of the latter type.

Secret information
: Secret information, such as user passwords or keys, or private files stored on disk, can provide some unguessability. A problem is that if the information is revealed at a later time, the unguessability vanishes. Another problem is that this kind of information tends to be fairly constant, so if you rely on it and seed your generator regularly, you risk constructing almost similar seeds or even constructing the same seed more than once.

For all practical sources, it's difficult but important to provide a reliable lower bound on the amount of unguessability that it provides. Two important points are to make sure that the attacker can't observe your sources (so if you like the Lava lamp idea, remember that you have to get your own lamp, and not put it by a window or anywhere else where strangers can see it), and that hardware failures are detected. What if the bulb in the Lava lamp, which you keep locked into a cupboard following the above advice, breaks after a few months?

So let's assume that we have been able to find an unguessable seed, which contains at least 80 bits of conditional entropy, relative to all attackers that we care about (typically, we must at the very least assume that no attacker has root privileges on our machine).

How do we generate output from this seed, and how much can we get? Some generators (notably the Linux '`/dev/random`' generator) tries to estimate available entropy and restrict the amount of output. The goal is that if you read 128 bits from '`/dev/random`', you should get 128 "truly random" bits. This is a property that is useful in some specialized circumstances, for instance when generating key material for a one time pad, or when working with unconditional blinding, but in most cases, it doesn't matter much. For most application, there's no limit on the amount of useful "random" data that we can generate from a small seed; what matters is that the seed is unguessable and that the generator has good cryptographic properties.

At the heart of all generators lies its internal state. Future output is determined by the internal state alone. Let's call it the generator's key. The key is initialized from the unguessable seed. Important properties of a generator are:

Key-hiding
: An attacker observing the output should not be able to recover the generator's key.

Independence of outputs
: Observing some of the output should not help the attacker to guess previous or future output.

Forward secrecy
: Even if an attacker compromises the generator's key, he should not be able to guess the generator output *before* the key compromise.

Recovery from key compromise
: If an attacker compromises the generator's key, he can compute *all* future output. This is inevitable if the generator is seeded only once, at startup. However, the generator can provide a reseeding mechanism, to achieve recovery from key compromise. More precisely: If the attacker compromises the key at a particular time `t_1`, there is another later time `t_2`, such that if the attacker observes all output generated between `t_1` and `t_2`, he still can't guess what output is generated after `t_2`.

Nettle includes one randomness generator that is believed to have all the above properties, and two simpler ones.

ARCFOUR, like any stream cipher, can be used as a randomness generator. Its output should be of reasonable quality, if the seed is hashed properly before it is used with `arcfour_set_key`. There's no single natural way to reseed it, but if you need reseeding, you should be using Yarrow instead.

The "lagged Fibonacci" generator in '`<nettle/knuth-lfib.h>`' is a fast generator with good statistical properties, but is **not** for cryptographic use, and therefore not documented here. It is included mostly because the Nettle test suite needs to generate some test data from a small seed.

The recommended generator to use is Yarrow, described below.

7.8.1 Yarrow

Yarrow is a family of pseudo-randomness generators, designed for cryptographic use, by John Kelsey, Bruce Schneier and Niels Ferguson. Yarrow-160 is described in a paper at `http://www.counterpane.com/yarrow.html`, and it uses SHA1 and triple-DES, and has a 160-bit internal state. Nettle implements Yarrow-256, which is similar, but uses SHA256 and AES to get an internal state of 256 bits.

Yarrow was an almost finished project, the paper mentioned above is the closest thing to a specification for it, but some smaller details are left out. There is no official reference implementation or test cases. This section includes an overview of Yarrow, but for the details of Yarrow-256, as implemented by Nettle, you have to consult the source code. Maybe a complete specification can be written later.

Yarrow can use many sources (at least two are needed for proper reseeding), and two randomness "pools", referred to as the "slow pool" and the "fast pool". Input from the sources is fed alternatingly into the two pools. When one of the sources has contributed 100 bits of entropy to the fast pool, a "fast reseed" happens and the fast pool is mixed into the internal state. When at least two of the sources have contributed at least 160 bits each to the slow pool, a "slow reseed" takes place. The contents of both pools are mixed into the internal state. These procedures should ensure that the generator will eventually recover after a key compromise.

The output is generated by using AES to encrypt a counter, using the generator's current key. After each request for output, another 256 bits are generated which replace the key. This ensures forward secrecy.

Yarrow can also use a *seed file* to save state across restarts. Yarrow is seeded by either feeding it the contents of the previous seed file, or feeding it input from its sources until a slow reseed happens.

Nettle defines Yarrow-256 in '`<nettle/yarrow.h>`'.

`struct yarrow256_ctx` [Context struct]

`struct yarrow_source` [Context struct]
Information about a single source.

`YARROW256_SEED_FILE_SIZE` [Constant]
Recommended size of the Yarrow-256 seed file.

`void yarrow256_init` (*struct yarrow256_ctx* ***ctx**, *unsigned* **nsources**, *struct yarrow_source* ***sources**) [Function]
Initializes the yarrow context, and its *nsources* sources. It's possible to call it with *nsources*=0 and *sources*=NULL, if you don't need the update features.

`void yarrow256_seed` (*struct yarrow256_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***seed_file**) [Function]
Seeds Yarrow-256 from a previous seed file. *length* should be at least `YARROW256_SEED_FILE_SIZE`, but it can be larger.

The generator will trust you that the *seed_file* data really is unguessable. After calling this function, you *must* overwrite the old seed file with newly generated data from `yarrow256_random`. If it's possible for several processes to read the seed file at about the same time, access must be coordinated using some locking mechanism.

`int yarrow256_update` (*struct yarrow256_ctx* ***ctx**, *unsigned* **source**, *unsigned* **entropy**, *size_t* **length**, *const uint8_t* ***data**) [Function]
Updates the generator with data from source *SOURCE* (an index that must be smaller than the number of sources). *entropy* is your estimated lower bound for the entropy in the data, measured in bits. Calling update with zero *entropy* is always safe, no matter if the data is random or not.

Returns 1 if a reseed happened, in which case an application using a seed file may want to generate new seed data with `yarrow256_random` and overwrite the seed file. Otherwise, the function returns 0.

`void yarrow256_random` (*struct yarrow256_ctx* ***ctx**, *size_t* **length**, *uint8_t* ***dst**) [Function]
Generates *length* octets of output. The generator must be seeded before you call this function.

If you don't need forward secrecy, e.g. if you need non-secret randomness for initialization vectors or padding, you can gain some efficiency by buffering, calling this function for reasonably large blocks of data, say 100-1000 octets at a time.

`int yarrow256_is_seeded` (*struct yarrow256_ctx* ***ctx**) [Function]
Returns 1 if the generator is seeded and ready to generate output, otherwise 0.

`unsigned yarrow256_needed_sources` (*struct yarrow256_ctx* ***ctx**) [Function]
Returns the number of sources that must reach the threshold before a slow reseed will happen. Useful primarily when the generator is unseeded.

`void yarrow256_fast_reseed` (*struct yarrow256_ctx* ***ctx**) [Function]
`void yarrow256_slow_reseed` (*struct yarrow256_ctx* ***ctx**) [Function]
Causes a fast or slow reseed to take place immediately, regardless of the current entropy estimates of the two pools. Use with care.

Nettle includes an entropy estimator for one kind of input source: User keyboard input.

`struct yarrow_key_event_ctx` [Context struct]
Information about recent key events.

`void yarrow_key_event_init` (*struct yarrow_key_event_ctx* ***ctx**) [Function]
Initializes the context.

`unsigned yarrow_key_event_estimate` (*struct yarrow_key_event_ctx* ***ctx**, *unsigned* **key**, *unsigned* **time**) [Function]
key is the id of the key (ASCII value, hardware key code, X keysym, ..., it doesn't matter), and *time* is the timestamp of the event. The time must be given in units matching the resolution by which you read the clock. If you read the clock with microsecond precision, *time* should be provided in units of microseconds. But if you use `gettimeofday` on a typical Unix system where the clock ticks 10 or so microseconds at a time, *time* should be given in units of 10 microseconds.

Returns an entropy estimate, in bits, suitable for calling `yarrow256_update`. Usually, 0, 1 or 2 bits.

7.9 ASCII encoding

Encryption will transform your data from text into binary format, and that may be a problem if, for example, you want to send the data as if it was plain text in an email, or store it along with descriptive text in a file. You may then use an encoding from binary to text: each binary byte is translated into a number of bytes of plain text.

A base-N encoding of data is one representation of data that only uses N different symbols (instead of the 256 possible values of a byte).

The base64 encoding will always use alphanumeric (upper and lower case) characters and the '+', '/' and '=' symbols to represent the data. Four output characters are generated for each three bytes of input. In case the length of the input is not a multiple of three, padding characters are added at the end. There's also a "URL safe" variant, which is useful for encoding binary data into URLs and filenames. See *RFC 4648*.

The base16 encoding, also known as "hexadecimal", uses the decimal digits and the letters from A to F. Two hexadecimal digits are generated for each input byte.

Nettle supports both base64 and base16 encoding and decoding.

Encoding and decoding uses a context struct to maintain its state (with the exception of base16 encoding, which doesn't need any). To encode or decode the data, first initialize the context, then call the update function as many times as necessary, and complete the operation by calling the final function.

The following functions can be used to perform base64 encoding and decoding. They are defined in '`<nettle/base64.h>`'.

`struct base64_encode_ctx` [Context struct]

`void base64_encode_init` (*struct base64_encode_ctx* ***ctx**) [Function]
`void base64url_encode_init` (*struct base64_encode_ctx* ***ctx**) [Function]
Initializes a base64 context. This is necessary before starting an encoding session. `base64_encode_init` selects the standard base64 alphabet, while `base64url_encode_init` selects the URL safe alphabet.

`size_t base64_encode_single` (*struct base64_encode_ctx* ***ctx**, *uint8_t* ***dst**, *uint8_t* **src**) [Function]
Encodes a single byte. Returns amount of output (always 1 or 2).

`BASE64_ENCODE_LENGTH` (*length*) [Macro]
The maximum number of output bytes when passing *length* input bytes to `base64_encode_update`.

`size_t base64_encode_update` (*struct base64_encode_ctx* ***ctx**, *uint8_t* ***dst**, *size_t* **length**, *const uint8_t* ***src**) [Function]
After *ctx* is initialized, this function may be called to encode *length* bytes from *src*. The result will be placed in *dst*, and the return value will be the number of bytes generated. Note that *dst* must be at least of size BASE64_ENCODE_LENGTH(*length*).

`BASE64_ENCODE_FINAL_LENGTH` [Constant]
The maximum amount of output from `base64_encode_final`.

`size_t base64_encode_final` (*struct base64_encode_ctx* ***ctx**, *uint8_t* ***dst**) [Function]
After calling base64_encode_update one or more times, this function should be called to generate the final output bytes, including any needed paddding. The return value is the number of output bytes generated.

`struct base64_decode_ctx` [Context struct]

`void base64_decode_init` (*struct base64_decode_ctx* ***ctx**) [Function]
`void base64url_decode_init` (*struct base64_decode_ctx* ***ctx**) [Function]
Initializes a base64 decoding context. This is necessary before starting a decoding session. `base64_decode_init` selects the standard base64 alphabet, while `base64url_decode_init` selects the URL safe alphabet.

`int base64_decode_single` (*struct base64_decode_ctx* ***ctx**, *uint8_t* ***dst**, *uint8_t* **src**) [Function]
Decodes a single byte (*src*) and stores the result in *dst*. Returns amount of output (0 or 1), or -1 on errors.

`BASE64_DECODE_LENGTH (length)` [Macro]
The maximum number of output bytes when passing *length* input bytes to `base64_decode_update`.

`void base64_decode_update (struct base64_decode_ctx *ctx, size_t *dst_length, uint8_t *dst, size_t src_length, const uint8_t *src)` [Function]
After *ctx* is initialized, this function may be called to decode *src_length* bytes from *src*. *dst* should point to an area of size at least BASE64_DECODE_LENGTH(*src_length*). The amount of data generated is returned in **dst_length*. Returns 1 on success and 0 on error.

`int base64_decode_final (struct base64_decode_ctx *ctx)` [Function]
Check that final padding is correct. Returns 1 on success, and 0 on error.

Similarly to the base64 functions, the following functions perform base16 encoding, and are defined in '`<nettle/base16.h>`'. Note that there is no encoding context necessary for doing base16 encoding.

`void base16_encode_single (uint8_t *dst, uint8_t src)` [Function]
Encodes a single byte. Always stores two digits in *dst*[0] and *dst*[1].

`BASE16_ENCODE_LENGTH (length)` [Macro]
The number of output bytes when passing *length* input bytes to `base16_encode_update`.

`void base16_encode_update (uint8_t *dst, size_t length, const uint8_t *src)` [Function]
Always stores BASE16_ENCODE_LENGTH(*length*) digits in *dst*.

`struct base16_decode_ctx` [Context struct]

`void base16_decode_init (struct base16_decode_ctx *ctx)` [Function]
Initializes a base16 decoding context. This is necessary before starting a decoding session.

`int base16_decode_single (struct base16_decode_ctx *ctx, uint8_t *dst, uint8_t src)` [Function]
Decodes a single byte from *src* into *dst*. Returns amount of output (0 or 1), or -1 on errors.

`BASE16_DECODE_LENGTH (length)` [Macro]
The maximum number of output bytes when passing *length* input bytes to `base16_decode_update`.

`int base16_decode_update (struct base16_decode_ctx *ctx, size_t *dst_length, uint8_t *dst, size_t src_length, const uint8_t *src)` [Function]
After *ctx* is initialized, this function may be called to decode *src_length* bytes from *src*. *dst* should point to an area of size at least BASE16_DECODE_LENGTH(*src_length*). The amount of data generated is returned in **dst_length*. Returns 1 on success and 0 on error.

`int base16_decode_final` (*struct base16_decode_ctx* *`ctx`) [Function]
Checks that the end of data is correct (i.e., an even number of hexadecimal digits have been seen). Returns 1 on success, and 0 on error.

7.10 Miscellaneous functions

`void * memxor` (*void* *`dst`, *const void* *`src`, *size_t* `n`) [Function]
XORs the source area on top of the destination area. The interface doesn't follow the Nettle conventions, because it is intended to be similar to the ANSI-C `memcpy` function.

`void * memxor3` (*void* *`dst`, *const void* *`a`, *const void* *`b`, *size_t* `n`) [Function]
Like `memxor`, but takes two source areas and separate destination area.

`int memeql_sec` (*const void* *`a`, *const void* *`b`, *size_t* `n`) [Function]
Side-channel silent comparison of the n bytes at a and b. I.e., instructions executed and memory accesses are identical no matter where the areas differ, see Section 7.7.3.1 [Side-channel silence], page 83. Return non-zero if the areas are equal, and zero if they differ.

These functions are declared in '`<nettle/memops.h>`'. For compatibility with earlier versions of Nettle, `memxor` and `memxor3` are also declared in '`<nettle/memxor.h>`'.

7.11 Compatibility functions

For convenience, Nettle includes alternative interfaces to some algorithms, for compatibility with some other popular crypto toolkits. These are not fully documented here; refer to the source or to the documentation for the original implementation.

MD5 is defined in [RFC 1321], which includes a reference implementation. Nettle defines a compatible interface to MD5 in '`<nettle/md5-compat.h>`'. This file defines the typedef `MD5_CTX`, and declares the functions `MD5Init`, `MD5Update` and `MD5Final`.

8 Traditional Nettle Soup

For the serious nettle hacker, here is a recipe for nettle soup. 4 servings.

1 liter fresh nettles (urtica dioica)

2 tablespoons butter

3 tablespoons flour

1 liter stock (meat or vegetable)

1/2 teaspoon salt

a tad white pepper

some cream or milk

Gather 1 liter fresh nettles. Use gloves! Small, tender shoots are preferable but the tops of larger nettles can also be used.

Rinse the nettles very well. Boil them for 10 minutes in lightly salted water. Strain the nettles and save the water. Hack the nettles. Melt the butter and mix in the flour. Dilute with stock and the nettle-water you saved earlier. Add the hacked nettles. If you wish you can add some milk or cream at this stage. Bring to a boil and let boil for a few minutes. Season with salt and pepper.

Serve with boiled egg-halves.

9 Installation

Nettle uses `autoconf`. To build it, unpack the source and run

```
./configure
make
make check
make install
```

to install it under the default prefix, '`/usr/local`'. Using GNU make is strongly recommended. By default, both static and shared libraries are built and installed.

To get a list of configure options, use `./configure --help`. Some of the more interesting are:

'`--enable-fat`'
: Include multiple versions of certain functions in the library, and select the ones to use at run-time, depending on available processor features. Supported for ARM and x86_64.

'`--enable-mini-gmp`'
: Use the smaller and slower "mini-gmp" implementation of the bignum functions needed for public-key cryptography, instead of the real GNU GMP library. This option is intended primarily for smaller embedded systems. Note that builds using mini-gmp are **not** binary compatible with regular builds of Nettle, and more likely to leak side-channel information.

'`--disable-shared`'
: Omit building the shared libraries.

'`--disable-dependency-tracking`'
: Disable the automatic dependency tracking. You will likely need this option to be able to build with BSD make.

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