

Programming with GNU Crypto

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1 Introduction

GNU Crypto is a free, high-quality, versatile, and provably correct implementation of a wide array of cryptographic primitives and tools written in the Java programming language. It provides an application programmer's interface (API) to a number of cryptographic algorithms, a variety of end-user tools, and a full Java cryptography architecture (JCA) provider.

The algorithms implemented by GNU Crypto include symmetric key ciphers for protecting data, message digests and message authentication codes for proving the integrity of data, digital signature schemes for proving the authenticity of data, and algorithms for generating unguessable pseudo-random numbers. The API is deliberately designed to be low-level, with access to the bare innards of the cryptographic algorithms involved, so more complex libraries and programs can be built.

GNU Crypto does not implement any algorithms that are encumbered by patents, and does not rely on any non-free code or documentation. GNU Crypto is designed to run in any Java environment that is compatible with Sun's Java runtime version 1.2 or later. This includes GNU Classpath, a free software implementation of the Java class libraries, and free virtual machines such as Kissme, Japhar, Kaffe, and the Jikes RVM.

This manual covers the basics for using the GNU Crypto API in new Java programs. It describes the public API for all the implemented algorithms, describes which algorithms are implemented, and provides simple examples of each. The reader is assumed to have some knowledge about cryptography and the Java programming language.

This is not a reference about cryptography, the Java programming language, or the Java cryptography architecture API. For an introduction to cryptography, we recommend the following books:

- Bruce Schneier, *Applied Cryptography: Protocols, Algorithms, and Source Code in C, Second Edition* [Sch95].
- Alfred J. Menezes, Paul C. Van Oorschot, and Scott A. Vanstone, *Handbook of Applied Cryptography* [MOV96].

The JCA API documentation is available on-line from either Sun Microsystems (<http://java.sun.com/products/jce/doc/apidoc/>) or the Legion of the Bouncy Castle (<http://www.bouncycastle.org/docs/index.html>). There are copious references about the Java programming language available (although, as far as the author is aware, no free manuals are available at the time of writing).

GNU Crypto is always available on the web from <http://www.gnu.org/software/gnu-crypto/>, via anonymous FTP from <ftp://ftp.gnupg.org/gcrypt/gnu-crypto/>. The mailing list for bugs, help, and discussion is gnu-crypto-discuss@gnu.org, and additional information about the project is available on Savannah at <http://savannah.gnu.org/projects/gnu-crypto/>.

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Part 1: The GNU Crypto API

2 Ciphers

This chapter describes the symmetric ciphers implemented by GNU Crypto, and how to create and use them. The package name for all GNU Crypto ciphers is `gnu.crypto.cipher`. The ciphers implemented by GNU Crypto are:

- The **Advanced Encryption Standard**, or the **AES**. The AES is a symmetric block cipher with a 128 bit block size and a key size of 128, 192, or 256 bits. The AES was adopted as US FIPS PUB 197 [NIST01] by the National Institute of Standards and Technology (NIST) in November 2001 after a five-year process of standarization and public comment. The AES was written by Joan Daemen and Vincent Rijmen for the AES process, and is derived from the Rijndael cipher.
- **Anubis**. The Anubis cipher is a symmetric block cipher with a 128 bit block size and a key size from 128 to 320 bits, with increments of 32 bits. Anubis was designed by Paulo Barreto and Vincent Rijmen, and has been submitted as a candidate cipher to the New European Schemes for Signatures, Integrity, and Encryption (NESSIE) process.
- **Blowfish**. The Blowfish symmetric block cipher was designed by Bruce Schneier. It has a 64 bit block size and a key size of up to 448 bits. Blowfish encryption and decryption are very fast in software, especially on 32 bit microprocessor architectures.
- **DES**. DES is the Data encryption standard, a 64-bit cipher with a 56-bit key. DES was developed by IBM in the 1970's for a standardization process begun by the National Bureau of Standards (now NIST). DES should not be used in new applications in favor of the new standard, AES, except for compatibility.
- **Identity cipher**. The identity, or null cipher, is not a true cipher as it does not transform the data input, but rather copies it directly to the output.
- **Khazad**. The Khazad cipher is a symmetric block cipher with a 64 bit block size and a 128 bit key size. Khazad was designed by Paulo Barreto and Vincent Rijmen, and has been submitted as a candidate cipher to the New European Schemes for Signatures, Integrity, and Encryption (NESSIE) process.
- **Rijndael**. Rijndael is a symmetric block cipher written by Joan Daemen and Vincent Rijmen as a candidate to the Advanced Encryption Standard process, and was adopted as the AES. Rijndael additionally has a 192 and 256 bit block size.
- **Serpent**. The Serpent cipher was designed by Ross Anderson, Eli Biham, and Lars Knudsen as a proposed cipher for the Advanced Encryption Standard. Serpent has a 128 bit block size, and a key size of 128, 192, or 256 bits.
- **Square**. The Square cipher was designed by Joan Daemen and Vincent Rijmen and was cryptanalyzed by Lars Knudsen. It has a 128 bit block size and a 128 bit key size.
- **Triple-DES**, or DESede, is a combined cipher based on the Data Encryption Standard. It is the iteration of three separte instances of DES with three independent keys, and therefore has a 64 bit block size and a key size of 168 bits.
- **Twofish**. The Twofish cipher was designed by Bruce Schneier, John Kelsey, Doug Whiting, David Wagner, Chris Hall, and Niels Ferguson as a proposed cipher for the Advanced Encryption Standard. Twofish has a 128 bit block size, and a key size of 128, 192, or 256 bits.

2.1 The IBlockCipher Interface

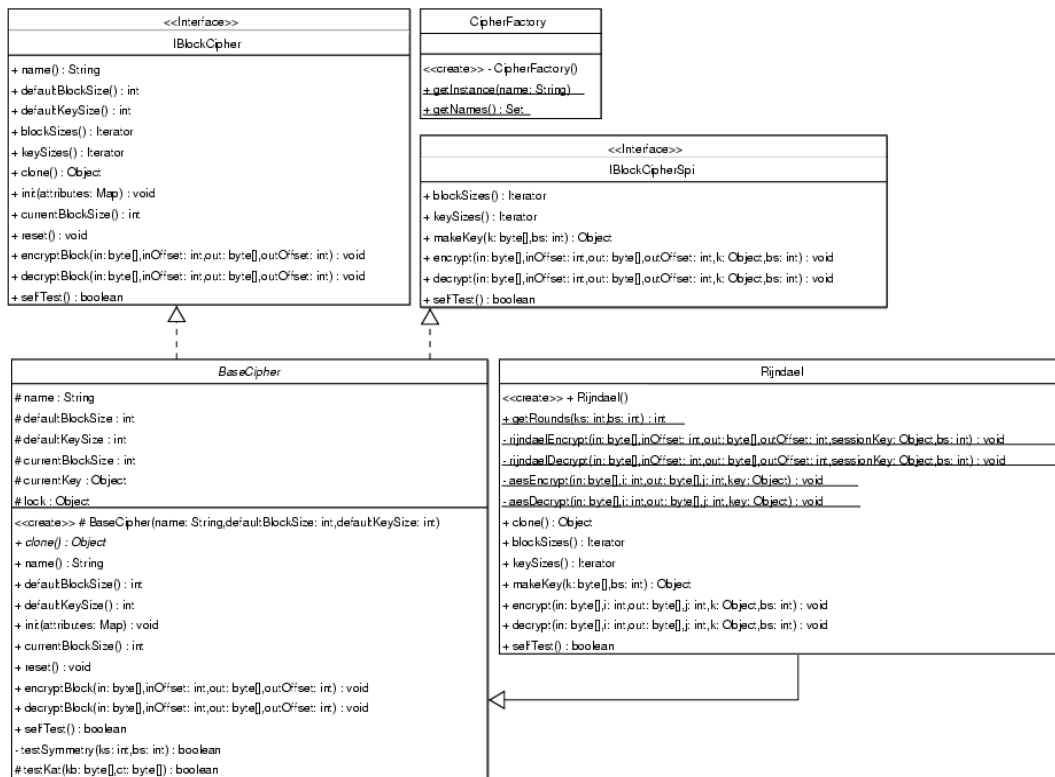


Figure 1: overview of the ciphers API

All ciphers in GNU Crypto implement the **IBlockCipher** interface, and support all the methods listed in this section.

java.lang.String CIPHER_BLOCK_SIZE [Variable]

A property name in the attributes map that is passed to the **init** method, representing the cipher's desired block size. The mapped value should be a **java.lang.Integer** of the cipher's block size, in bytes. If this attribute is omitted, the cipher's default block size is used.

java.lang.String KEY_MATERIAL [Variable]

A property name in the attributes map that is passed to the **init** method, representing the bytes that are to compose the cipher's key. The mapped value must be a byte array, and its length must be one of the cipher's supported key sizes.

void init (java.util.Map *attributes*) throws [Function]
java.security.InvalidKeyException, java.lang.IllegalStateException
Initializes the cipher for transforming data. The *attributes* parameter must be a java.util.Map that has, at least, a mapping between the **KEY_MATERIAL** property name to a byte array containing the key. Ciphers *may* define other property names. If the supplied byte array is not an acceptable key, this method throws a java.security.InvalidKeyException. If this instance has already been initialized, this method throws a java.lang.IllegalStateException.

java.lang.String name () [Function]
Returns the cipher's canonical name.

int defaultBlockSize () [Function]
Returns the default block size, in bytes.

int defaultKeySize () [Function]
Returns the default key size, in bytes.

java.util.Iterator blockSizes () [Function]
Returns a java.util.Iterator of the cipher's supported block sizes. Each element of the iterator is a java.lang.Integer.

java.util.Iterator keySizes () [Function]
Returns a java.util.Iterator of the cipher's supported key sizes. Each element of the iterator is a java.lang.Integer.

java.lang.Object clone () [Function]
Returns a clone of this cipher. The cloned instance must be initialized, as this method will not clone the cipher's internal key.

int currentBlockSize () throws java.lang.IllegalStateException [Function]
Returns the cipher's current block size, in bytes, or will throw a java.lang.IllegalStateException if this instance has not been initialized.

void reset () [Function]
Resets this instance, which may then be re-initialized.

void encryptBlock (byte[] *plaintext*, int *inOffset*, byte[] *ciphertext*, int *outOffset*) throws java.lang.IllegalStateException [Function]

Encrypts a block of bytes from *plaintext* starting at *inOffset*, storing the encrypted bytes in *ciphertext*, starting at *outOffset*. It is up to the programmer to ensure that there is at least one full block in *plaintext* from *inOffset* and space for one full block in *ciphertext* from *outOffset*. A `java.lang.IllegalStateException` will be thrown if the cipher has not been initialized.

void decryptBlock (byte[] *ciphertext*, int *inOffset*, byte[] *plaintext*, int *outOffset*) throws java.lang.IllegalStateException [Function]

Decrypts a block of bytes from *ciphertext* starting at *inOffset*, storing the encrypted bytes in *plaintext*, starting at *outOffset*. It is up to the programmer to ensure that there is at least one full block in *ciphertext* from *inOffset* and space for one full block in *plaintext* from *outOffset*. A `java.lang.IllegalStateException` will be thrown if the cipher has not been initialized.

boolean selfTest () [Function]

Performs a simple test of conformance, to ensure that there are no implementation or system errors. This method returns `true` if the test succeeds; `false` otherwise.

2.2 The CipherFactory Class

The ciphers in GNU Crypto can usually be initialized directly through their constructors, but the preferred way is to use the `CipherFactory` class, with the following method:

static IBlockCipher getInstance (java.lang.String *name*) [Function]

Returns a new cipher instance for the cipher named *name*, or `null` if no such cipher exists. This method will throw a `java.lang.InternalError` if the new instance's self-test fails.

The class also defines this method:

static java.util.Set getNames () [Function]

This method returns a `java.util.Set` of the names (each element of type `java.lang.String`) of all supported ciphers.

2.3 Example

The following example transforms the plaintext to the ciphertext, and the ciphertext back to the plaintext, using the AES in electronic codebook mode with no padding. Note also the classes for cipher modes and padding schemes for more complex constructions.

```
IBlockCipher cipher = CipherFactory.getInstance("AES");
Map attributes = new HashMap();
attributes.put(IBlockCipher.CIPHER_BLOCK_SIZE, new Integer(16));
attributes.put(IBlockCipher.KEY_MATERIAL, key_bytes);
cipher.init(attributes);
int bs = cipher.currentBlockSize();

for (int i = 0; i + bs < pt.length; i += bs)
{
    cipher.encryptBlock(pt, i, ct, i);
}

for (int i = 0; i + bs < cpt.length; i += bs)
{
    cipher.decryptBlock(ct, i, cpt, i);
}
```

3 Modes

Cipher modes operate on the next level up from the underlying block cipher. They transform the blocks going in and out of the cipher in ways to give them desirable properties in certain circumstances. The cipher modes implemented by GNU Crypto, which is contained in the `gnu.crypto.mode` package and are referenced herein by their three-letter abbreviations described below, are:

- **Cipher block chaining mode.** The “CBC” mode makes every block of the ciphertext depend upon all previous blocks by adding *feedback* to the transformation. This is done by XORing the plaintext with the previous ciphertext (or, with the first block, an initialization vector) before it is transformed. That is, encryption looks like: $C_i = E_k(P_i \oplus C_{i-1})$; and decryption is $P_i = C_{i-1} \oplus E_k^{-1}(C_i)$.
- **Counter mode.** Counter mode, referred to as “CTR” mode, is one of a class of sequenced cipher modes that turn the underlying cipher into a *keystream*. Counter mode relies on a simple counter register that is updated for every block processed. For plaintexts $P_1 \dots P_n$, ciphertexts $C_1 \dots C_n$, counter elements $T_1 \dots T_n$, and an encryption function E_k , encryption is defined as $C_i = P_i \oplus E_k(T_i)$ and decryption as $P_i = C_i \oplus E_k(T_i)$.
- **Electronic codebook mode.** Or “ECB” mode, is the most obvious cipher mode: the cipher block is the direct output of the forward function, and the plain block is the direct output of the inverse function. That is, encryption is $C_i = E_k(P_i)$ and decryption is $P_i = E_k^{-1}(C_i)$.
- **Integer counter mode.** “ICM” mode has features in common with counter mode described above. The counter, T_i , is computed by $T_i = (T_0 + i) \bmod 256^b$, where b is the cipher’s block size. T_0 is initialized to the integer representation of some initialization vector. The keystream bytes are then $E_k(T_i)$. Encryption and decryption are then $C_i = P_i \oplus E_k(T_i)$ and $P_i = C_i \oplus E_k(T_i)$, respectively.
- **Output feedback mode.** “OFB” mode creates a keystream by repeatedly iterating the underlying block cipher over an initialization vector. That is, the i th keystream block is $X_i = E(X_{i-1})$ for $1 < i \leq n$, and $X_1 = IV$. Like the other stream modes, the input block i is transformed by the exclusive-or of the block with X_i .

3.1 The IMode Interface

The `IMode` interface is similar to the `IBlockCipher` interface, except modes have a *state* associated with them, e.g. whether the instance is used for encryption or decryption. The `IMode` interface is usually the one that is used when encrypting or decrypting; `IBlockCipher` is used when the lowest level—the cipher function itself—needs to be accessed. `IMode` extends `IBlockCipher` interface, and thus all methods specified in that interface are implemented in modes, and have the same meaning. The properties passed to the `init` method of `IBlockCipher` may also be passed to the `init` method of `IMode`, along with the following property names.

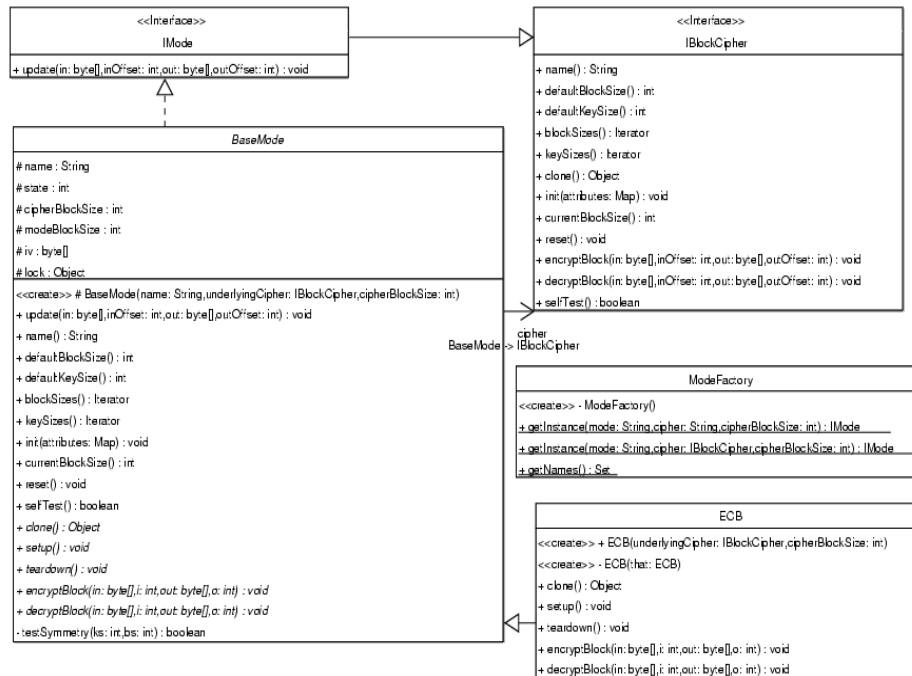


Figure 2: overview of the modes API

`java.lang.String` **STATE** [Variable]

The property name for the mode's state, as passed to the `init` method. Values for this property are an `java.lang.Integer` containing either the `ENCRYPTION` constant or the `DECRYPTION` constant.

`int` **ENCRYPTION** [Variable]

The value passed for the `STATE` property, wrapped in a `java.lang.Integer`, which indicates that the instance is to be used for encryption.

`int` **DECRYPTION** [Variable]

The value passed for the `STATE` property, wrapped in a `java.lang.Integer`, which indicates that the instance is to be used for decryption.

`java.lang.String` **MODE_BLOCK_SIZE** [Variable]

The property name for the block size of this mode. The value for this property should be a `java.lang.Integer` of the block size. If omitted, the underlying cipher's block size is used.

`java.lang.String` **IV** [Variable]

The property name for the initialization vector to initialize this mode with, if required. The value should be a byte array equal in size to the `MODE_BLOCK_SIZE` property. If omitted a byte array consisting of zeros is used.

void update (byte[] *in*, int *inOffset*, byte[] *out*, int *outOffset*) [Function]
 throws java.lang.IllegalStateException

Transforms the block in *in* starting at *inOffset* into the block in *out* starting at *outOffset*. Encryption or decryption is performed depending upon the value passed along with the **state** property given to the **init** method. A **java.lang.IllegalStateException** is thrown if this instance has not been initialized, and it is up to the programmer to ensure that there is one full block in *in* starting at *inOffset*, and enough space for one full block in *out* starting at *outOffset*. Since modes can have states, and may require that they be used in a particular sequence, using this method is preferred over the **encryptBlock** and **decryptBlock** methods of **IBlockCipher**.

3.2 The ModeFactory Class

The preferred way to get mode instances is through the **ModeFactory** class, from one of the following methods:

static IMode getInstance (java.lang.String *mode*, [Function]
 java.lang.String *cipher*, int *cipherBlockSize*)

Returns an instance of *cipher* wrapped in an instance of *mode*, initialized to a block size of *cipherBlockSize*, or returns **null** if no appropriate cipher or mode is available. The *mode* argument is one of the names described above, and *cipher* is one of the names described in the Ciphers chapter.

static IMode getInstance (java.lang.String *mode*, IBlockCipher [Function]
 cipher, int *cipherBlockSize*)

Returns an instance of *mode* using the already-initialized *cipher*, initializing the mode with a block size of *cipherBlockSize*, or returns **null** if no appropriate mode is available.

Additionally the following method is defined:

static java.util.Set getNames () [Function]

This method returns a **java.util.Set** of the names (each element of type **java.lang.String**) of all supported modes.

3.3 Example

The following example encrypts and decrypts a byte array with the AES in CFB mode. See the next chapter on padding for instances where the input is not a multiple of the cipher or mode's block size.

```
IMode mode = ModeFactory.getInstance("CFB", "AES", 16);
Map attributes = new HashMap();

// These attributes are defined in gnu.crypto.cipher.IBlockCipher.
attributes.put(IMode.KEY_MATERIAL, key_bytes);
attributes.put(IMode.CIPHER_BLOCK_SIZE, new Integer(16));

// These attributes are defined in IMode.
attributes.put(IMode.STATE, new Integer(IMode.ENCRIPTION));
attributes.put(IMode.IV, iv_bytes);
mode.init(attributes);
int bs = mode.currentBlockSize();

for (int i = 0; i + bs < pt.length; i += bs)
{
    mode.update(pt, i, ct, i);
}

mode.reset();
attributes.put(IMode.STATE, new Integer(IMode.DECRYPTION));
mode.init(attributes);

for (int i = 0; i + bs < ct.length; i += bs)
{
    mode.update(ct, i, cpt, i);
}
```


4 Padding

A padding scheme is merely a standard method of ensuring that the input to be encrypted is a multiple of the cipher’s block size. The padding schemes of GNU Crypto are in package `gnu.crypto.pad` and include:

- **PKCS #7.** PKCS #7 (referred to as “PKCS7” in GNU Crypto) pads the input P with the quantity $w = b - (|P| \bmod b)$, where b is the cipher’s block size, encoded as w bytes. That is, if the input is 5 bytes shorter than the required length, then the input is padded with the byte equal to 5 five times. This padding scheme supports block sizes of $2 \leq b \leq 256$ bytes.
- **Trailing bit complement.** The “TBC” pad appends the complement of the last bit in the input until the input is the desired length. That is, if the last bit is 1, then the input is padded with 0, and if the last bit is 0, then the input is padded with 1. This padding scheme supports block sizes up to 256 bytes.

4.1 The IPad Interface

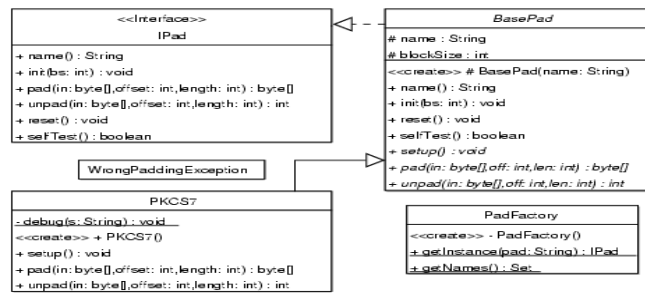


Figure 3: overview of the padding API

The IPad interface is used separately from ciphers and modes. The methods defined by padding schemes are:

```
void init (int bs) throws java.lang.IllegalStateException, [Function]
                        java.lang.IllegalArgumentException
```

Initializes this padding scheme for the specified block size. This method throws a `java.lang.IllegalStateException` if this instance has already been initialized but not reset, and will throw a `java.lang.IllegalArgumentException` if `bs` is not a supported block size.

```
void reset ( ) [Function]
```

Resets this instance, which may then be re-initialized later.

```
byte[] pad (byte[] input, int offset, int length) [Function]
```

Examines the bytes in `input` as the plaintext, starting at `offset` and considering `length` bytes, and returns the appropriate, possibly empty, byte array containing the padding.

int unpad (byte[] *input*, int *offset*, int *length*) throws WrongPaddingException [Function]

Examines the bytes in *input* as the plaintext, starting at *offset* and considering *length* bytes, and returns the number of bytes that should be trimmed off the end of *input* to unpad the plaintext. Throws a **WrongPaddingException** if the padding bytes to not correspond to the bytes expected by this padding scheme.

java.lang.String name () [Function]
Returns the canonical name of this instance.

boolean selfTest () [Function]
Performs a simple conformance test on the padding scheme, to avoid implementation or run time errors.

4.2 The PadFactory Class

Padding instances are created with the following method in the **PadFactory** class:

static IPad getInstance (String *pad*) [Function]
Gets an instance of the padding scheme with name *pad*, or null if no such padding scheme is available.

This class also defines this method:

static java.util.Set getNames () [Function]
Returns a set of strings with the names of all padding schemes implemented by GNU Crypto.

4.3 Example

The following example pads an input buffer, transforms the padded buffer with already-initialized **IMode** instances, then un pads the output buffer.

```
IPad padding = IPad.getInstance("PKCS7");
padding.init(blockSize);
byte[] pad = padding.pad(input, 0, input.length);
byte[] pt = new byte[input.length + pad.length];
byte[] ct = new byte[pt.length];
byte[] cpt = new byte[pt.length];
System.arraycopy(input, 0, pt, 0, input.length);
System.arraycopy(pad, 0, pt, input.length, pad.length);

for (int i = 0; i + blockSize < pt.length; i += blockSize)
{
    enc.update(pt, i, ct, i);
}
```

```
for (int i = 0; i + blockSize < ct.length; i += blockSize)
{
    dec.update(ct, i, cpt, i);
}

int unpad = padding.unpad(cpt, 0, cpt.length);
byte[] output = new byte[cpt.length - unpad];
System.arraycopy(cpt, 0, output, 0, output.length);
```

5 Cascades and Assemblies

This chapter describes two patterns implemented by the GNU Crypto library that allow users to combine the basic cipher (and other) primitives into higher level components in order to offer more flexible functionalities. These two patterns are: Cascade and Assembly.

The **Cascade** is a means of assembling block cipher Modes of Operations into an ordered sequence of *stages*. A *stage* is a representation of a Mode (of Operations) wired in a designated *direction*: FORWARD or REVERSED. A Mode staged in the FORWARD direction would encrypt input blocks, producing ciphertext, while the same Mode, wired in the REVERSED direction would do the opposite; i.e. decrypt an input text producing a plaintext.

In the simplest case, all stages in a Cascade have k -bit keys, and the stage inputs and outputs are all n -bit quantities. The stage ciphers may differ (general cascade of ciphers), or all be identical (cascade of identical ciphers).

An **Assembly** is a construction of an ordered set of **Transformer** objects. Each **Transformer** is wired to operate in PRE_PROCESSING or POST_PROCESSING mode –the Transformer’s **Operation**. In PRE_PROCESSING, the input is first processed by the Transformer before being passed to the rest of the chain, while in POST_PROCESSING state, the Transformer first passes the input to the rest of the chain and only processes the output of the returned data.

5.4 Cascades

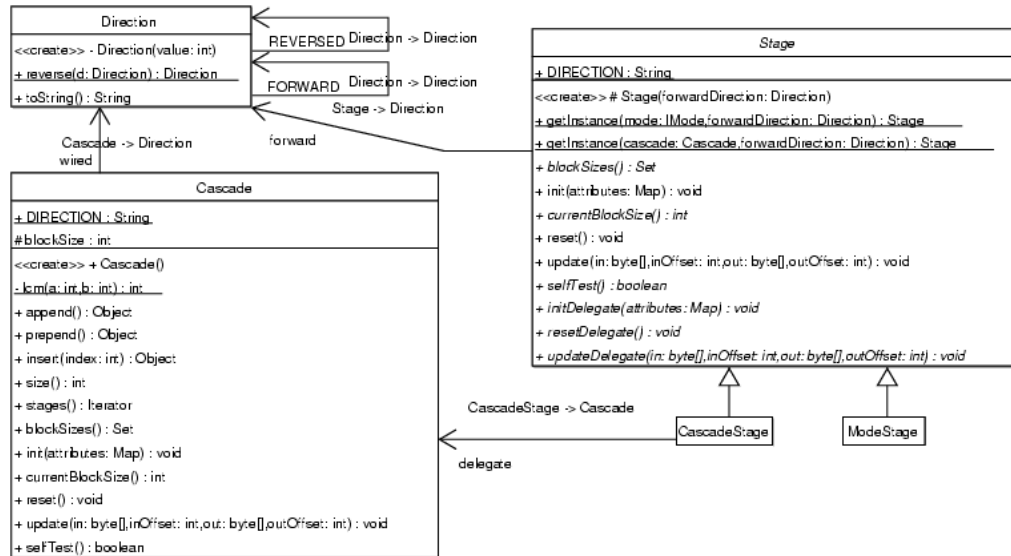


Figure 1: overview of the Cascade classes

5.5 Direction

An enumeration type for wiring **Stage** instances into **Cascade** chains, as well as for operating a **Cascade** in a given direction.

This class cannot be instantiated; but its (only) two possible values can be used for constructing **Stage** elements, and initializing **Cascade** instances:

- **FORWARD**: equivalent to `gnu.crypto.mode.IMode#ENCRYPTION`; and its inverse value
- **REVERSED**: equivalent to `gnu.crypto.mode.IMode#DECRYPTION`.

This class offers a *Factory* method to return the inverse of a designated **Direction** instance:

Direction `reverse` (**Direction** *d*)

[Function]

5.6 Stage

This class represents a **Stage** in a **Cascade** cipher.

Each stage may be either an implementation of a Block Cipher Mode of Operation (an instance of `gnu.crypto.mode.IMode`) or another **Cascade** cipher (an instance of **Cascade**). Each **Stage** has also a *natural* operational direction when constructed for inclusion within a **Cascade**. This *natural* direction dictates how data flows from one *Stage* into another when stages are chained together in a **Cascade**. One can think of a **Stage** and its natural direction as the specification of how to wire the **Stage** into the chain.

The following diagrams may help understand the paradigm. The first shows two stages chained together, each wired in the same direction (**Direction#FORWARD**).

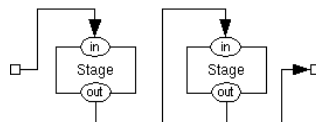


Figure 2: Two Stages wired in same direction

The second diagram shows two stages, one in a **Direction#FORWARD** direction, while the other is wired in a **Direction#REVERSED** direction.

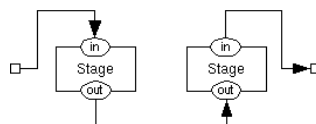


Figure 3: Two Stages wired in different directions

gnu.crypto.assembly.Stage **DIRECTION**

[Variable]

A property name in the attributes map that is passed to the `init` method, representing the stage's desired wiring direction. The mapped value should be a valid `gnu.crypto.assembly.Direction` value. If this attribute is omitted, `Direction.FORWARD` is used.

The following *Factory* methods, allow instantiation of concrete **Stage** class instances that adapt instances of either `gnu.crypto.mode.IMode` or (other) **Cascade** classes to operate as a **Stage** in a **Cascade**:

Stage getInstance (`IMode mode`, `Direction forwardDirection`) [Function]

Given a designated *mode* (an instance of `gnu.crypto.mode.IMode`, and a **Direction**, this method returns a **Stage** instance that adapts this designated *mode* to operate as a **Stage** in a **Cascade**.

Stage getInstance (`Cascade cascade`, `Direction forwardDirection`) [Function]

Given a designated *cascade* (an instance of `gnu.crypto.assembly.Cascade`, and a **Direction**, this method returns a **Stage** instance that adapts this designated *cascade* to operate as a **Stage** in another **Cascade**.

The following instance methods are also available:

`java.util.Set` **blockSizes** () [Function]

Returns the **Set** of supported block sizes for this **Stage**. Each element in the returned **Set** is an instance of `Integer`.

`void` **init** (`java.util.Map attributes`) throws [Function]

`java.security.InvalidKeyException`

Initializes the stage for operation with specific characteristics. Those characteristics are defined in *attributes*: a set of name-value pairs that describes the desired future behavior of this instance. This method throws an `IllegalStateException` if the instance is already initialized. It throws an `java.security.InvalidKeyException` if the key data (used to initialize the underlying Mode or Cascade) is invalid.

`int` **currentBlockSize** () throws `IllegalStateException` [Function]

Returns the current block size for this stage. This method throws an `IllegalStateException` if the instance is not yet initialized.

`void` **reset** () [Function]

Resets the stage for re-initialization and use with other characteristics. This method always succeeds.

`void` **update** (`byte[] in`, `int inOffset`, `byte[] out`, `int outOffset`) [Function]

Processes exactly one block of *plaintext* (if wired in the `Direction#FORWARD` direction) or *ciphertext* (if wired in the `Direction#REVERSED` direction), from *in* starting at *inOffset*, and storing the resulting bytes in *out*, starting at *outOffset*. An `IllegalStateException` will be thrown if the stage has not yet been initialized.

boolean selfTest () [Function]
 Conducts a simple *correctness* test that consists of basic symmetric encryption / decryption test(s) for all supported block and key sizes of underlying block cipher(s) wrapped by Mode leafs. The test also includes one (1) variable key Known Answer Test (KAT) for each block cipher. It returns **true** if the tests succeed, and **false** otherwise.

5.7 Cascade

A **Cascade** Cipher is the concatenation of two or more block ciphers each with independent keys. Plaintext is input to the first stage; the output stage *i* is input to stage *i + 1*; and the output of the last stage is the **Cascade**'s ciphertext output.

In the simplest case, all stages in a **Cascade** have *k*-bit keys, and the stage inputs and outputs are all *n*-bit quantities. The stage ciphers may differ (general cascade of ciphers), or all be identical (cascade of identical ciphers).

The term *block ciphers* used above refers to implementations of `gnu.crypto.mode.IMode`, including the `gnu.crypto.mode.ECB` mode which basically exposes a symmetric-key block cipher algorithm as a *Mode* of Operations.

String DIRECTION [Variable]
 The name of a property in the attributes map that is passed to the `init` method, representing the cascade's desired wiring direction. The mapped value should be a valid `gnu.crypto.assembly.Direction` value. If this attribute is omitted, `gnu.crypto.assembly.Direction.FORWARD` is used.

Object append (Stage stage) throws IllegalArgumentException [Function]
 Adds to the end of the current chain, a designated *stage*. Returns a unique identifier for this added stage, within this cascade. An `IllegalArgumentException` is thrown if *stage* is already in the chain, or it has incompatible characteristics with the current elements already in the chain. On the other hand, an `IllegalStateException` will be thrown if the cascade has already been initialized, or if the designated *stage* is null.

Object prepend (Stage stage) throws IllegalArgumentException [Function]
 Adds to the beginning of the current chain, a designated *stage*. Returns a unique identifier for this added stage, within this cascade. An `IllegalArgumentException` is thrown if *stage* is already in the chain, or it has incompatible characteristics with the current elements already in the chain. On the other hand, an `IllegalStateException` will be thrown if the cascade has already been initialized, or if the designated *stage* is null.

Object **insert** (int *index*, Stage *stage*) throws [Function]

IllegalArgumentException, **IndexOutOfBoundsException**

Inserts a designate *stage* **Stage** into the current **Cascade**, at the specified *index* (zero-based) position. Returns a unique identifier for this added stage, within this cascade. Throws an **IllegalArgumentException** if *stage* is already in the chain, or it has incompatible characteristics with the current elements already in the chain. Throws an **IllegalStateException** if the instance is already initialized. Finally, this method throws an **IndexOutOfBoundsException** if *index* is less than 0 or greater than the current size of this cascade.

int **size** () [Function]

Returns the current number of stages in this chain.

java.util.Iterator **stages** () [Function]

Returns an **java.util.Iterator** over the stages contained in this instance. Each element of this iterator is a concrete implementation of a **gnu.crypto.assembly.Stage**.

java.util.Set **blockSizes** () [Function]

Returns a **java.util.Set** of supported block sizes for this **Cascade** that are common to all of its chained stages. Each element in the returned set is an instance of **Integer**.

void **init** (java.util.Map *attributes*) throws **InvalidKeyException** [Function]

Initializes the chain for operation with specific characteristics, as specified by the contents of *attributes* –a set of name-value pairs that describes the desired future behavior of this instance. Throws an **IllegalStateException** if the chain, or any of its stages, is already initialized. Throws an **InvalidKeyException** if the initialization data provided with the stage is incorrect or causes an invalid key to be generated.

int **currentBlockSize** () [Function]

Returns the currently set block size for the chain. Throws an **IllegalStateException** if the instance is not yet initialized.

void **reset** () [Function]

Resets the chain for re-initialization and use with other characteristics. This method always succeeds.

void **update** (byte[] *in*, int *inOffset*, byte[] *out*, int *outOffset*) [Function]

Processes exactly one block of *plaintext* (if initialized in the **gnu.crypto.assembly.Direction#FORWARD** direction) or *ciphertext* (if initialised in the **gnu.crypto.assembly.Direction#REVERSED** direction), from *in*, starting at index position *inOffset*, returning the result in *out*, starting at index position *outOffset*. Throws an **IllegalStateException** if the instance is not yet initialized.

boolean selfTest () [Function]

Conducts a simple *correctness* test that consists of basic symmetric encryption / decryption test(s) for all supported block and key sizes of underlying block cipher(s) wrapped by Mode leafs. The test also includes one (1) variable key Known Answer Test (KAT) for each block cipher. Returns **true** if the implementation passes the tests. Returns **false** otherwise.

5.8 Example

The following example demonstrates how a DES-EDE block cipher can be constructed as a Cascade of three DES Stages.

```

HashMap map = new HashMap();
HashMap map1 = new HashMap();
HashMap map2 = new HashMap();
HashMap map3 = new HashMap();

Cascade new3DES = new Cascade();
Object des1 = new3DES.append(
    Stage.getInstance(
        ModeFactory.getInstance(Registry.ECB_MODE, new DES(), 8),
        Direction.FORWARD));
Object des2 = new3DES.append(
    Stage.getInstance(
        ModeFactory.getInstance(Registry.ECB_MODE, new DES(), 8),
        Direction.REVERSED));
Object des3 = new3DES.append(
    Stage.getInstance(
        ModeFactory.getInstance(Registry.ECB_MODE, new DES(), 8),
        Direction.FORWARD));

map.put(des1, map1);
map.put(des2, map2);
map.put(des3, map3);

map1.put(IBlockCipher.KEY_MATERIAL, key1material);
map2.put(IBlockCipher.KEY_MATERIAL, key2material);
map3.put(IBlockCipher.KEY_MATERIAL, key3material);

// encryption
map.put(Cascade.DIRECTION, Direction.FORWARD);
byte[] pt = ...; // some plaintext to encrypt
byte[] ct = new byte[pt.length]; // where ciphertext is returned

try
{
    new3DES.init(map);
    new3DES.update(pt, 0, ct, 0);
}

```

```

    }
    catch (InvalidKeyException x)
    {
        x.printStackTrace(System.err);
    }
}

```

5.9 Assemblies

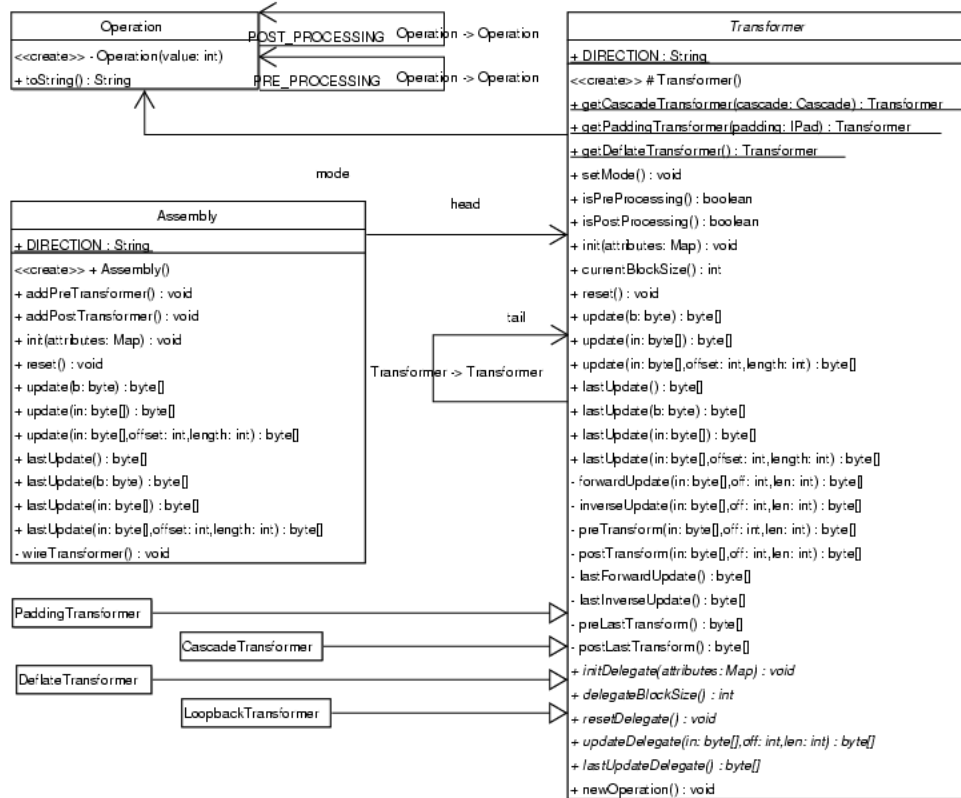


Figure 1: overview of the Assembly classes

5.10 Operation

An enumeration type for specifying the mode of operation of a **Transformer** instance, when wired into an **Assembly**.

This class cannot be instantiated; but its (only) two possible values can be used for constructing **Transformer** elements:

- **PRE_PROCESSING**: to mean that the input data is first processed by the current **Transformer** before being passed to the rest of the chain; and
- **POST_PROCESSING**: to mean that the input data is first passed to the rest of the chain, and the resulting bytes are then processed by the current **Transformer**.

5.11 Transformer

A **Transformer** is an abstract representation of a two-way *transformation* that can be chained together with other instances of this type. Examples of such transformations in this library are:

- **CascadeTransformer** that adapts an instance of a `gnu.crypto.assembly.Cascade`,
- **PaddingTransformer** that adapts an instance of `gnu.crypto.pad.IPad`, and finally
- **DeflateTransformer** that adapts a ZLib-based deflater/inflater algorithm implementation.

The special type **LoopbackTransformer** is also available and is implicitly (and silently) added to each instance of an **Assembly**.

A **Transformer** is characterized by the followings:

- It can be chained to other instances, to form an **Assembly**.
- When configured in an **Assembly**, it can be set to apply its internal transformation on the input data stream before (pre-processing) or after (post-processing) passing the input data to the next element in the chain. Note that the same type **Transformer** can be used in either pre-processing, or post-processing modes.
- A special transformer –**LoopbackTransformer**– is used to close the chain.
- A useful type of **Transformer** –one we’re interested in– has internal buffers. The distinction between a casual push (update) operation, and the last one, allows to correctly flush any intermediate bytes that may exist in those buffers.

To allow wiring **Transformer** instances together, a *minimal output size* in bytes is necessary. The trivial case of a value of 1 for such attribute practically means that no output buffering, from the previous element, is needed –which is independent of buffering the input if the **Transformer** implementation itself is block-based.

This class exposes one class attribute and three Factory methods. They are:

String DIRECTION [Variable]
 The name of a property in the attributes map that is passed to the `init` method, representing the transformation’s desired wiring direction. The mapped value should be a valid `gnu.crypto.assembly.Direction` value. If this attribute is omitted, `gnu.crypto.assembly.Direction.FORWARD` is used.

Transformer getCascadeTransformer (`Cascade cascade`) [Function]
 Returns the designated *cascade* instance wrapped in an Adapter for use as a **Transformer**.

Transformer getPaddingTransformer (`IPad padding`) [Function]
 Returns the designated *padding* instance wrapped in an Adapter for use as a **Transformer**.

Transformer **getDeflateTransformer** () [Function]

Returns a **Transformer** that underlies an implementation of the ZLib algorithm, able to deflate (compress) and inflate (decompress) data.

Concrete class instances of this abstract class, also expose the following instance methods:

void setMode (final *Operation mode*) [Function]

Sets the operational mode of this **Transformer** to the designated *mode* value. Throws **IllegalStateException** if this instance has already been assigned an operational mode.

boolean isPreProcessing () [Function]

Returns **true** if this **Transformer** has been wired in pre-processing mode; returns **false** otherwise. Throws an **IllegalStateException** if this instance has not yet been assigned an operational mode.

boolean isPostProcessing () [Function]

Returns **true** if this **Transformer** has been wired in post-processing mode; returns **false** otherwise. Throws an **IllegalStateException** if this instance has not yet been assigned an operational mode.

void init (java.util.Map *attributes*) throws **TransformerException** [Function]

Initializes the **Transformer** for operation with specific characteristics, indicated by the designated *attributes*. The latter being a set of name-value pairs that describes the desired future behavior of this instance. Throws an **IllegalStateException** if the instance is already initialized.

int currentBlockSize () [Function]

Returns the block-size of this **Transformer**. A value of 1 indicates that this instance is block-agnostic.

void reset () [Function]

Resets the **Transformer** for re-initialization and use with other characteristics. This method always succeeds.

byte[] update (byte *b*) throws **TransformerException** [Function]

Convenience method that calls the method with same name and three arguments, using a byte array of length 1 whose contents are the designated byte *b*. Returns the result of transformation. Throws an **IllegalStateException** if the instance is not yet initialized. Throws an **TransformerException** if a transformation-related exception occurs during the operation.

byte[] update (byte[] in) throws TransformerException [Function]

Convenience method that calls the same method with three arguments. All bytes in *in*, starting from index position 0 are considered. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws a `TransformerException` if a transformation-related exception occurs during the operation.

byte[] update (byte[] in, int offset, int length) throws TransformerException [Function]

Returns the result of processing a designated *length* bytes from a given *in* byte array, starting at position *offset*. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate () throws TransformerException [Function]

Convenience method that calls the same method with three arguments. A zero-long byte array is used. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate (byte b) throws TransformerException [Function]

Convenience method that calls the method with same name and three arguments, using a byte array of length 1 whose contents are the designated byte *b*. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate (byte[] in) throws TransformerException [Function]

Convenience method that calls the same method with three arguments. All bytes in *in*, starting from index position 0 are considered. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate (byte[] in, int offset, int length) throws TransformerException [Function]

Returns the result of processing a designated *length* bytes from the given *in* byte array, starting at index position *offset* and signals, at the same time, that this is the last *push* operation on this **Transformer**. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

5.12 Assembly

An **Assembly** is a construction consisting of a chain of **Transformer** elements; each wired in pre- or post- operational mode. This chain is (always) terminated by one **LoopbackTransformer** element.

Once constructed, and correctly initialized, the bulk of the methods available on the **Assembly** are delegated to the *head* of the **Transformer** chain of the **Assembly**.

String DIRECTION [Variable]

The name of a property in the attributes map that is passed to the **init** method, representing the assembly's desired wiring direction. The mapped value should be a valid `gnu.crypto.assembly.Direction` value. If this attribute is omitted, `gnu.crypto.assembly.Direction.FORWARD` is used.

boolean addPreTransformer (Transformer t) [Function]

Adds the designated **Transformer** *t*, to the head of the current chain, and signals that it should operate in pre-processing mode; i.e. it should apply its internal transformation algorithm on the input data stream, **before** it passes that stream to the next element in the *chain*. Throws an **IllegalArgumentException** if the designated **Transformer** has a non-null tail; i.e. it is already an element of a chain.

boolean addPostTransformer (Transformer t) [Function]

Adds the designated **Transformer** *t*, to the head of the current chain, and signals that it should operate in post-processing mode; i.e. it should apply its internal transformation algorithm on the input data stream, **after** it passes that stream to the next element in the *chain*. Throws an **IllegalArgumentException** if the designated **Transformer** has a non-null tail; i.e. it is already an element of a chain.

void init (java.util.Map attributes) throws TransformerException [Function]

Initializes the **Assembly** for operation with specific characteristics, indicated by the designated *attributes*. The latter being a set of name-value pairs that describes the desired future behavior of this instance. Throws an **IllegalStateException** if the instance is already initialized.

void reset () [Function]

Resets the **Assembly** for re-initialization and use with other characteristics. This method always succeeds.

byte[] update (byte b) throws TransformerException [Function]

Convenience method that calls the method with same name and three arguments, using a byte array of length 1 whose contents are the designated byte *b*. Returns the result of transformation. Throws an **IllegalStateException** if the instance is not yet initialized. Throws an **TransformerException** if a transformation-related exception occurs during the operation.

byte[] update (byte[] in) throws TransformerException [Function]

Convenience method that calls the same method with three arguments. All bytes in *in*, starting from index position 0 are considered. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws a `TransformerException` if a transformation-related exception occurs during the operation.

byte[] update (byte[] in, int offset, int length) throws TransformerException [Function]

Returns the result of processing a designated *length* bytes from a given *in* byte array, starting at position *offset*. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate () throws TransformerException [Function]

Convenience method that calls the same method with three arguments. A zero-long byte array is used. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate (byte b) throws TransformerException [Function]

Convenience method that calls the method with same name and three arguments, using a byte array of length 1 whose contents are the designated byte *b*. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate (byte[] in) throws TransformerException [Function]

Convenience method that calls the same method with three arguments. All bytes in *in*, starting from index position 0 are considered. Returns the result of transformation. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

byte[] lastUpdate (byte[] in, int offset, int length) throws TransformerException [Function]

Returns the result of processing a designated *length* bytes from the given *in* byte array, starting at index position *offset* and signals, at the same time, that this is the last *push* operation on this **Transformer**. Throws an `IllegalStateException` if the instance is not yet initialized. Throws an `TransformerException` if a transformation-related exception occurs during the operation.

5.13 Example

The following example shows an **Assembly** that compresses its input data, before encrypting it with a Blowfish algorithm, in OFB mode, with PKCS7 padding.

```
import gnu.crypto.Registry;
import gnu.crypto.util.Util;
import gnu.crypto.assembly.Assembly;
import gnu.crypto.assembly.Cascade;
import gnu.crypto.assembly.Direction;
import gnu.crypto.assembly.Stage;
import gnu.crypto.assembly.Transformer;
import gnu.crypto.assembly.TransformerException;
import gnu.crypto.cipher.Blowfish;
import gnu.crypto.cipher.IBlockCipher;
import gnu.crypto.mode.IMode;
import gnu.crypto.mode.ModeFactory;
import gnu.crypto.pad.IPad;
import gnu.crypto.pad.PadFactory;

HashMap attributes = new HashMap();
HashMap modeAttributes = new HashMap();

Cascade ofbBlowfish = new Cascade();
Object modeNdx = ofbBlowfish.append(
    Stage.getInstance(
        ModeFactory.getInstance(Registry.OFB_MODE, new Blowfish(), 8),
        Direction.FORWARD));

attributes.put(modeNdx, modeAttributes);
IPad pkcs7 = PadFactory.getInstance(Registry.PKCS7_PAD);

Assembly asm = new Assembly();
asm.addPreTransformer(Transformer.getCascadeTransformer(ofbBlowfish));
asm.addPreTransformer(Transformer.getPaddingTransformer(pkcs7));
asm.addPreTransformer(Transformer.getDeflateTransformer());

// plaintext and key material
byte[] km = new byte[] { 0, 1, 2, 3, 4, 5, 6, 7, 8};
byte[] iv = new byte[] {-1, -2, -3, -4, -5, -6, -7, -8, -9};
byte[] pt = new byte[] { 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11};
byte[] tpt = new byte[11 * pt.length];

// forward transformation
modeAttributes.put(IBlockCipher.KEY_MATERIAL, km);
modeAttributes.put(IMode.IV, iv);
attributes.put(Assembly.DIRECTION, Direction.FORWARD);
```



```

    try
    {
        asm.init(attributes);
    }
    catch (TransformerException x)
    {
        x.printStackTrace(System.err);
    }

    byte[] ct = null;
    ByteArrayOutputStream baos = new ByteArrayOutputStream();
    try
    {
        for (int i = 0; i < 10; i++)
        { // transform in parts of 12-byte a time
            System.arraycopy(pt, 0, tpt, i * pt.length, pt.length);
            ct = asm.update(pt);
            baos.write(ct, 0, ct.length);
        }
    }
    catch (TransformerException x)
    {
        x.printStackTrace(System.err);
    }

    try
    {
        System.arraycopy(pt, 0, tpt, 10 * pt.length, pt.length);
        ct = asm.lastUpdate(pt);
    }
    catch (TransformerException x)
    {
        x.printStackTrace(System.err);
    }

    baos.write(ct, 0, ct.length);
    ct = baos.toByteArray();

    // reversed transformation
    attributes.put(Assembly.DIRECTION, Direction.REVERSED);
    try
    {
        asm.init(attributes);
    }
    catch (TransformerException x)
    {
        x.printStackTrace(System.err);
    }

```

```
byte[] ot = null;
try
{
    ot = asm.lastUpdate(ct); // transform the lot in one go
}
catch (TransformerException x)
{
    x.printStackTrace(System.err);
}
```

6 Message Digests

Message digests, or one-way hash functions, generate fixed-sized signatures from variable-sized texts, in such a way that it is computationally infeasible to determine the source text from the signature or to find a different text that hashes to the same signature. Hash functions in GNU Crypto are in the `gnu.crypto.hash` package, and are:

- **MD2.** MD2 is an early-generation hash function with an 128 bit output size, developed by Ron Rivest at RSA Data Security, Inc., and described by Burton Kaliski in RFC 1319 [Kal92]. No significant cryptanalysis has been published about MD2, but it is still recommended that new applications use a different message digest algorithm.
- **MD4.** MD4 was also developed by Ron Rivest at RSA Data Security, Inc. and is described by Rivest in RFC 1320 [Riv92a]. MD4 has a 128 bit output size. It is not recommended that MD4 be used in new applications.
- **MD5.** MD5 is a successor to MD4, developed by Ron Rivest and described in RFC 1321 [Riv92b], and has a 128 bit output size. MD5 is not widely considered secure any longer, and using other message digests with longer output sizes is recommended.
- **RIPEMD.** RIPEMD-128 and RIPEMD-160 have 128 bit and 160 bit output sizes, and were developed by Hans Dobbertin, Antoon Bosselaers, and Bart Preneel as successors to the RIPEMD hash.
- **The Secure Hash Algorithm, SHA-1.** The secure hash algorithm was developed by the National Institute for Standards and Technology, published in FIPS 180-1. SHA-1 has a 160 bit output length.
- **Tiger** is a hash function created by Lars Anderson and Eli Biham, optimized for 64-bit architectures. It can produce a 192, 160, or 128 bit hash. [AnB96]
- **Whirlpool.** Whirlpool was designed by Paulo S. L. M. Barreto and Vincent Rijmen, and has a 512 bit output length.

6.1 IMessageDigest Interface

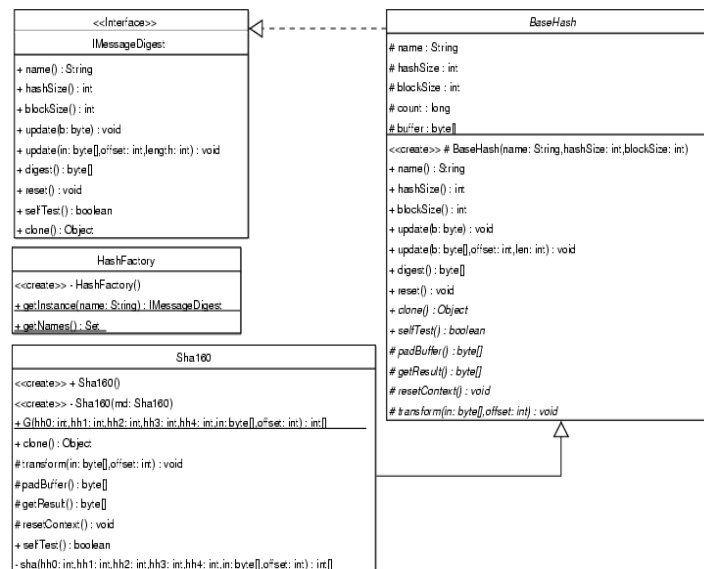


Figure 4: overview of the message digest API

void update (byte b) [Function]
 Updates the hash being computed with a single byte.

void update (byte[] buf, int offset, int length) [Function]
 Update the hash being computed with *length* of the bytes in *buf* starting at *offset*.
 The programmer should ensure that *buf* is at least *offset + length* bytes long.

byte[] digest () [Function]
 Finishes the computation of the hash and returns the result as a byte array. The input read thusfar may be padded first (depending on the algorithm), and the instance is reset.

java.lang.String name () [Function]
 Returns the canonical name of this message digest.

int hashSize () [Function]
 Returns the size of the final hash (the byte array returned by **digest()**) in bytes.

int blockSize () [Function]
 Returns the algorithm's internal block size, in bytes.

void reset () [Function]
Resets the internal state of the hash, making its state equivalent to that of a newly-created instance.

boolean selfTest () [Function]
Performs a simple conformance test of the underlying implementation, to guard against implementation or environment errors. Returns **true** if the test succeeds, **false** if it fails.

java.lang.Object clone () [Function]
Copies the state of this instance into a new instance, returning the copy. This copy can then be used in the same way as the original instance.

6.2 HashFactory Class

Message digest instances are created with the static factory method:

IMessageDigest getInstance (java.lang.String name) [Function]
Creates a message digest instance for the algorithm *name*, or **null** if there is no such algorithm.

The HashFactory class also defines the method:

java.util.Set getNames () [Function]
Returns a set of the names (strings) of all available message digest implementations.

6.3 Example

```
IMessageDigest md = HashFactory.getInstance("SHA-1");
md.update(input, 0, input.length);

byte[] digest = md.digest();
```

7 Message Authentication Codes

A message authentication code, or MAC, is akin to a *keyed hash function*, in that it produces a fixed-length identifier for variable-length data along with a key. The purpose of a MAC is to guarantee the integrity and authenticity of data, as it is computationally infeasible to fake a MAC without knowledge of the key. MAC algorithms in GNU Crypto are in the `gnu.crypto.mac` package, and include:

- **Hash-based MAC.** Hash-based MACs, also called HMACs, use a normal message digest algorithm to compute the code based on input data and the key. GNU Crypto therefore implements an HMAC for every message digest it supports, and the name of a HMAC is usually “HMAC-” concatenated with the message digest’s name; see the previous chapter on message digests for further discussion.
- The **Truncated Multi-Modular Hash** function, **TMMH**. TMMH/16 and TMMH/32 are universal hash functions; GNU Crypto implements TMMH/16. TMMH/16 has a variety of parameters, which are described later in this chapter. TMMH is described in [McG02].
- **UHASH-32.** UHASH-32 is a keyed hash function that outputs a hash of 8 bytes. The key supplied to this MAC must be 16 bytes long. UHASH is described in [Kro00].
- **UMAC-32.** The UMAC family of algorithms are parameterized, meaning that low-level choices such as endianness and the underlying cryptographic primitive are not fixed. The UMAC algorithms are described in [Kro00]. GNU Crypto implements UMAC-32, which performs well on 32- and 64-bit architectures, and has a key length of 16 bytes and an output length of 8 bytes. See the section on UMAC-32 for further discussion.

7.1 IMac Interface

`java.lang.String` **MAC_KEY_MATERIAL** [Variable]

A key in the attributes map passed to the `init` method. The value is taken to be a byte array, which contains the key as raw bytes. The length of the key must be at least the length of the computed hash in the case of hash-based MACs.

`java.lang.String` **TRUNCATED_SIZE** [Variable]

The actual size of the returned hash, taken from the first bytes of the raw result. The value must be a `java.lang.Integer` containing the desired length, which should not be smaller than 80 bits or one half the MAC’s usual output length, whichever is larger.

`void` **init** (`java.util.Map` *attributes*) throws [Function]

`java.security.InvalidKeyException`, `java.lang.IllegalStateException`
 Initializes this MAC instance with a specified attributes map, which maps keys (such as `MAC_KEY_MATERIAL`) to parameters (such as the key bytes). Throws a `java.security.InvalidKeyException` if the key is unacceptable or omitted, and throws a `java.lang.IllegalStateException` if this instance has already been initialized.

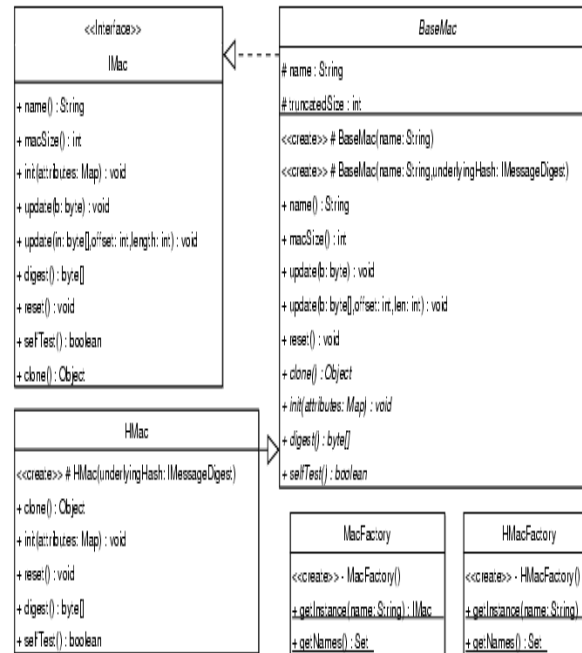


Figure 5: overview of the MAC API

void update (byte b) [Function]

Continues the computation of the MAC with a single input byte, *b*.

void update (byte[] in, int offset, int length) [Function]

Continues the computation of the MAC with a portion of the byte array *in*, starting at *offset* and considering *length* bytes.

byte[] digest () [Function]

Finishes the computation of the MAC and returns it in a new byte array. The instance is reset after this method returns.

void reset () [Function]

Resets the internal state of this instance, which may then be re-initialized.

int macSize () [Function]

Returns the size of the final MAC, in bytes.

java.lang.String name () [Function]

Returns the canonical name of this algorithm.

java.lang.Object clone () [Function]

Returns a copy of this instance, which may be used the same way as the original.

boolean selfTest () [Function]
 Performs a simple conformance test on this implementation; returns **true** if the test is successful, **false** if not.

7.2 MacFactory Class

MAC instances are created with the following factory method:

IMac getInstance (java.lang.String name) [Function]
 Returns an instance of the MAC algorithm named *name*, or **null** if no such algorithm exists.

Additionally the **MacFactory** class defines the following method:

java.util.Set getNames () [Function]
 Returns a **java.util.Set** of the names of all available MAC algorithms.

7.3 TMMH/16

In addition to the key, the TMMH/16 requires three more parameters passed to its **init** method, using the following three keys:

java.lang.String TAG_LENGTH [Variable]
 The output length, in bytes, represented as a **java.lang.Integer**. This value must be an even integer between 2 and 64.

java.lang.String KEYSTREAM [Variable]
 An instance of **gnu.crypto.prng.IRandom**, which is to serve as the source of random bytes for this instance.

java.lang.String PREFIX [Variable]
 A byte array of **TAG_LENGTH** bytes. If this parameter is omitted an all-zero byte array will be used. This value is XORed with the digest just before it is returned.

7.4 UMAC-32

The UMAC-32 algorithm requires, in addition to the key, a *nonce* byte array. The byte array must be 1–16 bytes of random data, which is passed to the **init** method of **IMac** in the attributes map. **UMac32** defined an additional key for this map:

java.lang.String NONCE_MATERIAL [Variable]
 The key for the *nonce* material for the attributes map. The value mapped must be a byte array of size 1–16 bytes.

7.5 Example

```
IMac mac = MacFactory.getInstance("HMAC-SHA-160");
HashMap attributes = new HashMap();
attributes.put(IMac.MAC_KEY_MATERIAL, key_bytes);
attributes.put(IMac.TRUNCATED_SIZE, new Integer(12));
mac.init(attributes);

mac.update(input, 0, input.length);

byte[] result = mac.digest();
```

8 Signatures

This chapter describes the digital signature schemes implemented in GNU Crypto. The package for all signature and related classes is `gnu.crypto.sig`. The following signature schemes are implemented:

- **DSS**, the Digital Signature Standard, was standardized in 1994 by the National Institute of Standards and Technology in the Federal Information Processing Standards (FIPS) Publication 186 [FIPS186]. DSS uses the secure hash algorithm (SHA-1) internally, and produces a 160 bit signature.
- **RSA-PSS**. This is a digital signature scheme based on the combination of the RSA algorithm with the Probabilistic Signature Scheme (PSS) encoding scheme. RSA was invented by Ron Rivest, Adi Shamir, and Leonard Adleman; the PSS encoding was developed by Mihir Bellare and Phillip Rogaway. During efforts to adopt RSA-PSS into the IEEE P1363a standards effort, certain adaptations to the original version of RSA-PSS were made by Mihir Bellare and Phillip Rogaway and also by Burt Kaliski (the editor of IEEE P1363a) to facilitate implementation and integration into existing protocols. [JoK00]

8.1 The ISignature Interface

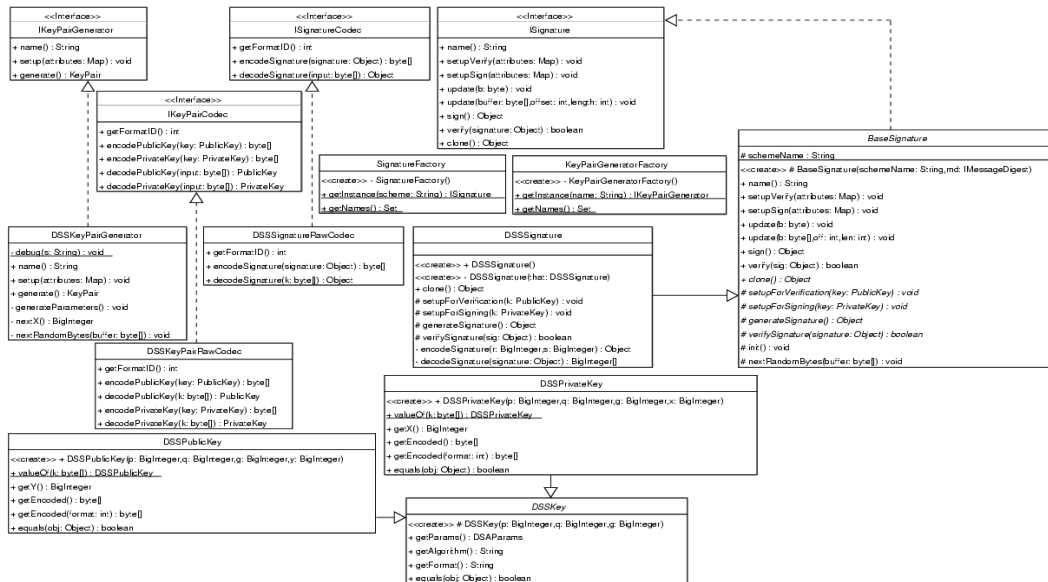


Figure 1: overview of the signature API

All digital signature schemes implement the `ISignature` interface, and support the following methods:

`java.lang.String SIGNER_KEY` [Variable]

A property name in the attributes map that is passed to instances being prepared for signing. The value mapped by this key must be a `java.security.PrivateKey` that is appropriate for the instance's algorithm (e.g. an instance of DSS would require a subclass of `java.security.interfaces.DSAPrivateKey`).

`java.lang.String` **VERIFIER_KEY** [Variable]

A property name in the attributes map that is passed to instances being prepared for verifying a signature. The value mapped by this key must be a `java.security.PublicKey` that is appropriate for the instance's algorithm, just as is the case with the signing key.

`java.lang.String` **SOURCE_OF_RANDOMNESS** [Variable]

A property name in the attributes map that is passed to instances being prepared for use as either signers or verifiers. The value mapped must be an already-initialized instance of `gnu.crypto.prng.IRandom`.

`void` **init** (`java.util.Map` *attributes*) throws [Function]

`java.lang.IllegalArgumentException`

Initializes this instance for signing. The *attributes* parameter must be a `java.util.Map` that has, at least, a mapping between the **SIGNER_KEY** property and the appropriate private key.

`void` **init** (`java.util.Map` *attributes*) throws [Function]

`java.lang.IllegalArgumentException`

Initializes this instance for verifying a signature. The *attributes* parameter must be a `java.util.Map` that has, at least, a mapping between the **VERIFIER_KEY** property and the appropriate public key.

`void` **update** (`byte` *b*) throws `java.lang.IllegalStateException` [Function]

Update either the signing or verifying operation with the next byte in the message. This method will throw a `java.lang.IllegalStateException` if this instance has not been initialized for either signing or verifying.

`void` **update** (`byte[]` *buf*, `int` *off*, `int` *len*) throws [Function]

`java.lang.IllegalStateException`

Update either the signing or verifying operation with the next *len* bytes of *buf*, starting at *offset*. This method will throw a `java.lang.IllegalStateException` if this instance has not been initialized for either signing or verifying.

`java.lang.Object` **sign** () throws `java.lang.IllegalStateException` [Function]

Finishes a signing operation and returns the final signature. This method will throw a `java.lang.IllegalStateException` if this instance has not been initialized for signing.

boolean verify (`java.lang.Object signature`) throws `java.lang.IllegalStateException` [Function]

Finishes a verifying operation by checking if the argument, a native signature object, matches the expected signature. This method returns `true` if the signature is valid, `false` otherwise. This method will throw a `java.lang.IllegalStateException` if this instance has not been initialized for verifying.

java.lang.String name () [Function]

Returns the canonical name of this instance's signature algorithm.

java.lang.Object clone () [Function]

Returns a copy of this signature object.

8.2 The SignatureFactory Class

Instances of `ISignature` can be retrieved with the class methods of the `SignatureFactory` class:

ISignature getInstance (`java.lang.String name`) [Function]

Creates an instance of the signature scheme for *name*, or `null` if there is no such algorithm.

java.util.Set getNames () [Function]

Returns a set of the names (`java.lang.String`) of all available signature schemes.

8.3 The ISignatureCodec Interface

The `ISignatureCodec` interface defines methods for externalizing and de-externalizing native signature results, as would be returned by the `ISignature.sign()` method, or passed to `ISignature.verify()` method. The only format currently supported is the "RAW" codec, which is specific to GNU Crypto.

Each signature scheme implements its own raw codec. There is no factory for codecs, but rather you should create instances of

- `gnu.crypto.sig.dss.DSSSignatureRawCodec` if you are reading or writing DSS signatures, or
- `gnu.crypto.sig.rsa.RSAPSSSignatureRawCodec` if you are reading or writing RSA-PSS signatures.

Each of these classes has a zero-argument constructor, needs no initialization, and defines these methods:

java.lang.Object decodeSignature (`byte[] encoded`) [Function]

Decodes a signature from the byte representation *encoded*, and returns the signature in the signature algorithm's native form. Implementations may throw an unchecked exception (such as `java.lang.IllegalArgumentException`) if the argument is improperly formatted.

byte[] encodeSignature (`java.lang.Object signature`) [Function]
 Encodes a native signature to an external byte representation. Implementations may throw an unchecked exception (such as `java.lang.IllegalArgumentException`) if the argument is not of the algorithm's native signature type.

int getFormatID () [Function]
 Returns the format identifier for this codec, such as `RAW_FORMAT`.

int RAW_FORMAT [Variable]
 Format identifier for GNU's "raw" codec.

8.4 The IKeyPairGenerator Interface

All signature algorithms in GNU Crypto have their corresponding key pair generators, which implement this interface and provide the following methods:

void setup (`java.util.Map attributes`) throws `java.lang.IllegalArgumentException` [Function]
 Initializes this key pair generator with the given attributes. The property names used are algorithm-dependent, and are described in the next section. This method throws a `java.lang.IllegalArgumentException` if the given attributes are incorrect or incomplete.

java.security.KeyPair generate () [Function]
 Generates and returns a new key pair based on the attributes used to configure this instance.

java.lang.String name () [Function]
 Returns the canonical name of the algorithm this class generates key pairs for.

8.5 Algorithm-Specific Attributes

8.5.1 DSS

Each of these constants are defined in the `gnu.crypto.sig.dss.DSSKeyPairGenerator` class.

java.lang.String MODULUS_LENGTH [Variable]
 Property name for the modulus length, in bits. The value mapped by this property must be of type `java.lang.Integer`.

java.lang.String SOURCE_OF_RANDOMNESS [Variable]
 Property name for the source of random bits to use when generating keys. The value mapped by this property must be of type `gnu.crypto.prng.IRandom`.

8.5.2 RSA-PSS

Each of these constants are defined in the `gnu.crypto.sig.rsa.RSAPSSKeyPairGenerator` class.

`java.lang.String` **MODULUS_LENGTH** [Variable]
Property name for the length, in bits, of the modulus. The value mapped by this property must be of type `java.lang.Integer`.

`java.lang.String` **SOURCE_OF_RANDOMNESS** [Variable]
Property name for the source of random bits to use. The value mapped by this property must be of type `gnu.crypto.prng.IRandom`, which must have been previously initialized.

`java.lang.String` **RSA_PARAMETERS** [Variable]
Property name for the optional values of *e* and *n*. The value mapped by this property must be of type `java.security.spec.RSAKeyGenParameterSpec`. Random or default values will be used instead if this parameter is not specified.

8.6 The KeyPairGeneratorFactory Class

`IKeyPairGenerator` **getInstance** (`java.lang.String algorithm`) [Function]
Returns an instance of a key pair generator for *algorithm*, or `null` if no such generator is available.

`java.util.Set` **getNames** () [Function]
Returns an unmodifiable set of all available key pair generator algorithms, each entry a `java.lang.String`.

8.7 The IKeyPairCodec Interface

A key pair codec is used to externalize and de-externalize the key pairs used in GNU Crypto. There is no factory class, but rather the implementations have public, zero-argument constructors. The available codecs are:

- `gnu.crypto.sig.dss.DSSKeyPairRawCodec`, for encoding and decoding DSS key pairs.
- `gnu.crypto.sig.rsa.RSAKeyPairRawCodec`, for encoding and decoding RSA key pairs.

`int` **RAW_FORMAT** [Variable]
Constant identifying the “raw” format used by GNU Crypto.

`java.security.PrivateKey` **decodePrivateKey** (`byte[] encoded`) [Function]
Decodes a private key from its external representation, returning it as an appropriate instance of `java.security.PrivateKey`. This function will throw a `java.lang.IllegalArgumentException` if the encoded bytes cannot be decoded or are incorrect.

java.security.PublicKey decodePublicKey (byte[] encoded) [Function]
Decodes a public key from its external representation, returning it as an appropriate instance of `java.security.PublicKey`. This function will throw a `java.lang.IllegalArgumentException` if the encoded bytes cannot be decoded or are incorrect.

byte[] encodePrivateKey (java.security.PrivateKey key) [Function]
Encodes a private key to its external representation, returning the encoded bytes. This function will throw a `java.lang.IllegalArgumentException` if the key cannot be encoded by this instance.

byte[] encodePublicKey (java.security.PublicKey key) [Function]
Encodes a public key to its external representation, returning the encoded bytes. This function will throw a `java.lang.IllegalArgumentException` if the key cannot be encoded by this instance.

int getFormatID () [Function]
Returns the format identifier of this codec, such as `RAW_FORMAT`.

8.8 Signature Example

```
ISignature dss = SignatureFactory.getInstance("DSS");
Map attrib = new HashMap();
attrib.put(ISignature.SIGNER_KEY, privateDsaKey);
dss.setupSign(attrib);

dss.update(message, 0, message.length);
Object sig = dss.sign();

ISignatureCodec codec = new DSSSignatureRawCodec();
byte[] encoded = codec.encodeSignature(sig);

Object sig2 = codec.decodeSignature(encoded);

attrib.clear();
attrib.put(ISignature.VERIFIER_KEY, publicDsaKey);
dss.setupVerify(attrib);

dss.update(message, 0, message.length);
```

```
boolean valid = dss.verify(sig);
```

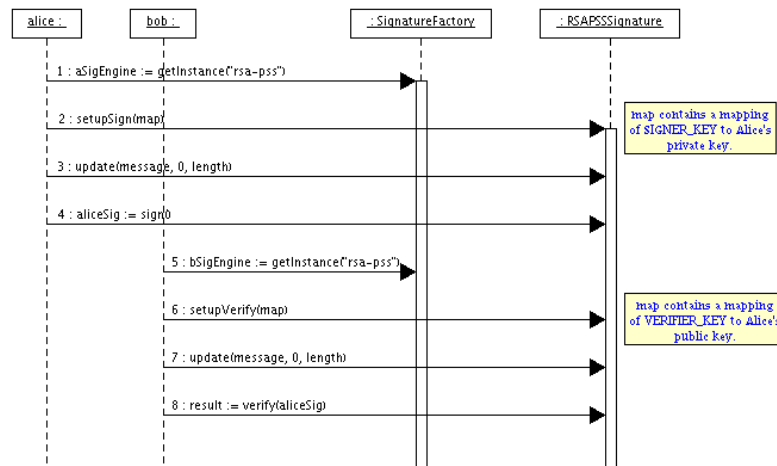


Figure 3: using signatures

9 Random Numbers

The pseudo-random number generator (PRNG) classes of GNU Crypto are used to generate streams of cryptographically secure pseudo-random bytes.

- **ARCFOUR** is an implementation of the ARCFOUR stream cipher's keystream generator. ARCFOUR is the name of a stream cipher that is believed to be compatible with RSA Data Security, Inc.'s RC4 stream cipher, and is a decendent of an algorithm that was posted anonymously to a mailing list in 1994.
- **ICM**, or the Integer Counter Mode PRNG, is an algorithm that creates a PRNG around a block cipher. The default cipher used in this implementation is Rijndael, the AES. ICM is described in [McG01].
- **MD**, or PRNGs based around a cryptographic hash function.
- **UMAC-KDF** is a PRNG based on the UMAC key derivation function.

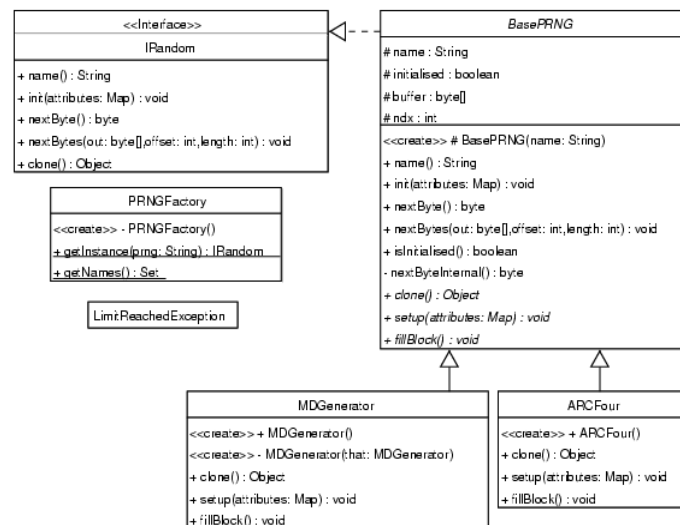


Figure 1: overview of the PRNG API

9.1 The IRandom Interface

void init (java.util.Map attributes) [Function]

Initializes this PRNG, preparing it for use. Throws an `IllegalArgumentException` if the given attributes are not appropriate for this PRNG algorithm.

byte nextByte () throws `LimitReachedException` [Function]

Returns the next pseudo-random byte in this generator's sequence. Throws a `LimitReachedException` if this generator cannot produce any more bytes of any quality.

`void nextBytes (byte[] out, int off, int len) throws` [Function]
`LimitReachedException`

Fills the buffer *out* with the next *len* bytes in this generator's sequence, storing the bytes beginning at *off*. Throws a `LimitReachedException` if this generator cannot produce any more bytes of any quality.

`java.lang.String name ()` [Function]
Returns the canonical name of this PRNG algorithm.

`java.lang.Object clone ()` [Function]
Returns a copy of this instance. The copy will be in the exact same state as this instance, and will be independent of this instance.

9.2 The PRNGFactory Class

`IRandom getInstance (java.lang.String name)` [Function]
Returns an instance of the named PRNG algorithm, or null if no such named algorithm exists.

`java.util.Set names ()` [Function]
Returns a `java.util.Set` of the names (`java.lang.String`) of all available PRNG algorithms.

9.3 ARCFour

The ARCFour keystream is implemented in the class `ARCFour`, which defines the following additional constant:

`java.lang.String ARCFOUR_KEY_MATERIAL` [Variable]
A property name in the attributes map used to initialize instances of `ARCFour`. The value mapped must be a byte array of the secret key, which can be up to 256 bytes long.

Also note that using the ARCFour PRNG as a stream cipher is as simple as:

```
IRandom arcfour; // initialized elsewhere.  
byte in, out;  
  
out = in ^ arcfour.next();
```

9.4 MDGenerator

Generic message digest-based PRNGs are implemented via the `MDGenerator` class, which defines the following additional constants:

`java.lang.String MD_NAME` [Variable]
A property name in the attributes map used to initialize instances of `MDGenerator`. The value mapped must be a `String` representing the name of the hash function to use, such as “MD5”. If this attribute is omitted the secure hash algorithm, SHA-1, is used.

`java.lang.String SEED` [Variable]
A property name in the attributes map used to initialize instances of `MDGenerator`. The value mapped must be a byte array carrying the seed, with which to seed the PRNG. This attribute is optional.

9.5 ICMGenerator

The ICM generator accepts a number of additional parameters, all contained in the following constants of the `ICMGenerator` class. The appropriate values, including the limits of the integral types, are specific to the ICM generator algorithm.

`java.lang.String BLOCK_INDEX_LENGTH` [Variable]
A property name in the attributes map used to initialize instances of `ICMGenerator`. The value mapped must be a `java.lang.Integer`.

`java.lang.String CIPHER` [Variable]
A property name in the attributes map used to initialize instances of `ICMGenerator`. The value mapped must be a `gnu.crypto.cipher.IBlockCipher`, and is the underlying cipher used in the algorithm.

`java.lang.String OFFSET` [Variable]
A property name in the attributes map used to initialize instances of `ICMGenerator`. The value mapped must be a `java.math.BigInteger` or a byte array of the same length of the underlying cipher’s block size.

`java.lang.String SEGMENT_INDEX` [Variable]
A property name in the attributes map used to initialize instances of `ICMGenerator`. The value mapped must be a `java.math.BigInteger`.

`java.lang.String SEGMENT_INDEX_LENGTH` [Variable]
A property name in the attributes map used to initialize instances of `ICMGenerator`. The value mapped must be a `java.lang.Integer`.

9.6 UMacGenerator

The UMac KDF generator accepts the following additional parameters, which are contained in the `UMacGenerator` class.

`java.lang.String CIPHER` [Variable]
A property name in the attributes map used to initialize instances of `UMacGenerator`.
The value mapped must be of type `gnu.crypto.cipher.IBlockCipher`.

`java.lang.String INDEX` [Variable]
A property name in the attributes map used to initialize instances of `UMacGenerator`.
The value mapped must be of type `java.lang.Integer`.

9.7 PRNG Example

```
Map attrib = ...;
IRandom rand = PRNGFactory.getInstance("MD");

attrib.put(MDGenerator.MD_NAME, "MD5");
attrib.put(MDGenerator.SEEED, seedBytes);

random.init(attrib);

for (int i = 0; i < bytes.length; i++)
{
    in[i] ^= random.nextByte();
}

random.nextBytes(bytes, 0, bytes.length);
```

Part 2: External API Support

10 JCE Support

GNU Crypto provides a full JCE (Java Cryptography Environment) provider for all its algorithms. This chapter briefly describes these classes and how to use them.

10.1 Installing the JCE Classes

Java runtimes such as those based around Classpath, Kaffe, and JREs from Sun and IBM up to version 1.4 do not include the JCE classes, encompassed by the `javax.crypto` package and its subpackages. Furthermore, many commercial Java 1.4 and later runtime environments do not allow providers to be installed if they are not digitally signed by an authority. The GNU Crypto developers do not agree with this practice and are not seeking to have GNU Crypto's provider signed.

To overcome this GNU Crypto includes a clean-room implementation of the `javax.crypto` packages, which is a modified version of the clean-room JCE distributed by the Legion of the Bouncy Castle <http://bouncycastle.org/>. If building these classes is enabled at compile-time, a Java archive file `javax-crypto.jar` will be built, along with the appropriate shared native libraries if you are using GCJ. Simply adding it to your system classpath should suffice, possibly replacing or superceding the `jce.jar` file that came with your virtual machine.

The JCE included mirrors most of the features of the reference JCE, except the `ExemptionMechanism` classes are omitted. U.S. export rules as of January 2000 no longer apply to open source software that is freely available on the Internet, so these classes have no practical use in GNU Crypto.

10.2 Installing the GNU Crypto Provider

The GNU Crypto provider is implemented in the class `gnu.crypto.jce.GnuCrypto`, and is available by the name "GNU Crypto". You can install this provider at run-time by including in your program a statement such as:

```
java.security.Security.addProvider(new gnu.crypto.jce.GnuCrypto());
```

Or by putting the following in your security properties file, usually located at `${JRE_HOME}/lib/security/${VM_NAME}.security`:

```
security.provider.N=gnu.crypto.jce.GnuCrypto
```

Where 'N' is the appropriate preference number. Doing this, and asserting that the `gnu-crypto.jar` file is in your classpath, will complete the installation of the provider.

10.3 List of Available Algorithms

The algorithms available through the GNU Crypto provider are, grouped by type, with alternate names in parentheses:

Cipher: AES, ANUBIS, ARCFOUR (RC4), BLOWFISH, DES, KHAZAD, RIJNDAEL, SERPENT, SQUARE, TRIPLEDES, TWOFISH.

Ciphers may, of course, be appended with any of the modes and paddings available in GNU Crypto, such as “AES/CBC/TBC”.

KeyPairGenerator: DSS (DSA), RSA.

MAC: HMAC-MD2, HMAC-MD4, HMAC-MD5, HMAC-RIPEMD128 (HMAC-RIPEMD-128), HMAC-RIPEMD160 (HMAC-RIPEMD-160), HMAC-SHA160 (HMAC-SHA, HMAC-SHA1, HMAC-SHA-160, HMAC-SHS), HMAC-TIGER, HMAC-WHIRLPOOL, TMMH16, UHASH32, UMAC32.

MessageDigest: MD2, MD4, MD5, RIPEMD128 (RIPEMD-128), RIPEMD-160 (RIPEMD-160), SHA-160 (SHA, SHA1, SHA-1, SHS), TIGER, WHIRLPOOL.

SecureRandom: ARCFOUR (RC4), ICM, MD2PRNG, MD4PRNG, MD5PRNG, RIPEMD128PRNG, RIPEMD160PRNG, SHA-160PRNG (SHAPRNG, SHA-1PRNG, SHA1PRNG), TIGERPRNG, WHIRLPOOLPRNG, UMAC-KDF.

Signature: DSS/RAW (SHA/DSA, SHA1/DSA, SHA-1/DSA, SHA-160/DSA, DSAwithSHA, DSAwithSHA1, DSAwithSHA160), RSA-PSS/RAW (RSA-PSS, RSAPSS).

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