PGPainless

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OpenPGP (RFC 4480[1]) is an Internet Standard mostly used for email encryption. It provides mechanisms to ensure *confidentiality*, *integrity* and *authenticity* of messages. However, OpenPGP can also be used for other purposes, such as secure messaging or as a signature mechanism for software distribution.

PGPainless strives to improve the (currently pretty dire) state of the ecosystem of Java libraries and tooling for OpenPGP.

The library focuses on being easy and intuitive to use without getting into your way. Common functions such as creating keys, encrypting data, and so on are implemented using a builder structure that guides you through the necessary steps.

Internally, it is based on Bouncy Castles[2] mighty, but low-level `bcpg` OpenPGP API. PGPainless' goal is to empower you to use OpenPGP without needing to write all the boilerplate code required by Bouncy Castle. It aims to be secure by default while allowing customization if required.

From its inception in 2018 as part of a Google Summer of Code project[3], the library was steadily advanced. Since 2020, FlowCrypt is the primary sponsor of its development. In 2022, PGPainless received a grant from NLnet for creating a Web-of-Trust implementation[4] as part of NGI Assure.

[1] https://datatracker.ietf.org/doc/rfc4880/
[2] https://www.bouncycastle.org/java.html
[3] https://summerofcode.withgoogle.com/archive/2018/projects/6037508810866688
[4] https://nlnet.nl/project/PGPainless/

CHAPTER ONE

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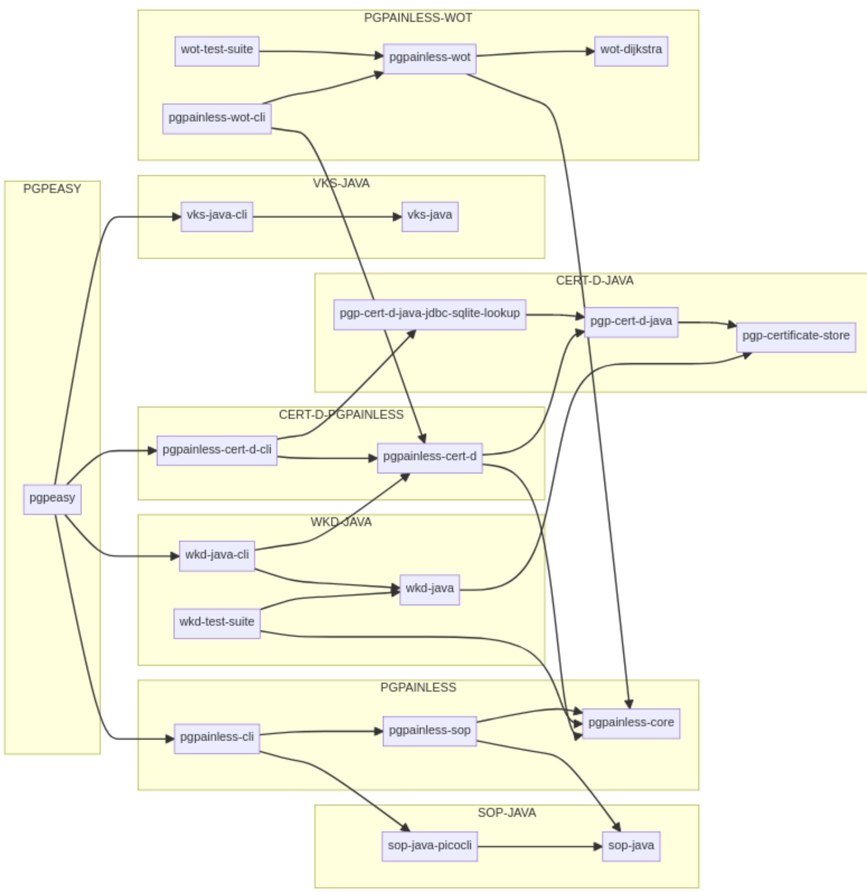
1.1 The PGPainless Ecosystem

PGPainless consists of an ecosystem of different libraries and projects.

The diagram below shows, how the different projects relate to one another.



1.1.1 Libraries and Tools

- PGPainless[5]

  The main repository contains the following components:

  - `pgpainless-core` - core implementation - powerful, yet easy to use OpenPGP API
  - `pgpainless-sop` - super simple OpenPGP implementation. Drop-in for `sop-java`
  - `pgpainless-cli` - SOP CLI implementation using PGPainless

- SOP-Java[6]

  An API definition and CLI implementation of the Stateless OpenPGP Protocol[7] (SOP). Consumers of the SOP API can simply depend on `sop-java` and then switch out the backend as they wish. Read more about the *SOP* protocol here.

  - `sop-java` - generic OpenPGP API definition
  - `sop-java-picocli` - CLI frontend for `sop-java`

- WKD-Java[8]

  Implementation of the Web Key Directory[9].

  - `wkd-java` - generic WKD discovery implementation
  - `wkd-java-cli` - CLI frontend for WKD discovery using PGPainless
  - `wkd-test-suite` - Generator for test vectors for testing WKD implementations

- VKS-Java[10]

  Client-side API for communicating with Verifying Key Servers, such as https://keys.openpgp.org/.

  - `vks-java` - VKS client implementation
  - `vks-java-cli` - CLI frontend for `vks-java`

- Cert-D-Java[11]

  Implementations of the Shared OpenPGP Certificate Directory specification[12].

  - `pgp-certificate-store` - abstract definitions of OpenPGP certificate stores
  - `pgp-cert-d-java` - implementation of `pgp-certificate-store` following the PGP-CERT-D spec
  - `pgp-cert-d-java-jdbc-sqlite-lookup` - subkey lookup using sqlite database

- Cert-D-PGPainless[13]

  Implementation of the Shared OpenPGP Certificate Directory specification[14] using PGPainless.

  - `pgpainless-cert-d` - PGPainless-based implementation of `pgp-cert-d-java`
  - `pgpainless-cert-d-cli` - CLI frontend for `pgpainless-cert-d`

[5] https://codeberg.org/pgpainless/pgpainless
[6] https://codeberg.org/pgpainless/sop-java
[7] https://datatracker.ietf.org/doc/draft-dkg-openpgp-stateless-cli/
[8] https://codeberg.org/pgpainless/wkd-java
[9] https://www.ietf.org/archive/id/draft-koch-openpgp-webkey-service-13.html
[10] https://codeberg.org/pgpainless/vks-java
[11] https://codeberg.org/pgpainless/cert-d-java
[12] https://sequoia-pgp.gitlab.io/pgp-cert-d/
[13] https://codeberg.org/pgpainless/cert-d-pgpainless
[14] https://sequoia-pgp.gitlab.io/pgp-cert-d/

- PGPainless-WOT[15]

  Implementation of the OpenPGP Web of Trust specification[16] using PGPainless.

  - `pgpainless-wot` - Parse OpenPGP keyrings into a generic `Network` object
  - `wot-dijkstra` - Perform queries to find paths inside a `Network` object
  - `pgpainless-wot-cli` - CLI frontend for `pgpainless-wot` and `wot-dijkstra`
  - `wot-test-suite` - Test vectors ported from Sequoia-PGPs WoT implementation[17]

- PGPeasy[18]

  Prototypical, comprehensive OpenPGP CLI application

  - `pgpeasy` - CLI application

1.2 Quickstart Guide

In this guide, we will get you started with OpenPGP using PGPainless as quickly as possible.

At first though, you need to decide which API you want to use;

- PGPainless' core API is powerful and heavily customizable
- The SOP API is a bit less powerful, but *dead* simple to use

The SOP API is the recommended way to go if you just want to get started already.

In case you need more technical documentation, Javadoc can be found in the following places:

- For the core API: pgpainless-core[19]
- For the SOP API: pgpainless-sop[20]

1.2.1 SOP API with pgpainless-sop

The Stateless OpenPGP Protocol (SOP) defines a simplistic interface for the most important OpenPGP operations. It allows you to encrypt, decrypt, sign and verify messages, generate keys and add/remove ASCII armor from data. However, it does not yet provide tools for key management. Furthermore, the implementation is deciding for you, which (secure) algorithms to use, and it doesn't let you change those.

If you want to read more about the background of the SOP protocol, there is a *whole chapter* dedicated to it.

[15] https://codeberg.org/pgpainless/pgpainless-wot
[16] https://sequoia-pgp.gitlab.io/sequoia-wot/
[17] https://gitlab.com/sequoia-pgp/sequoia-wot/-/tree/main/tests/data
[18] https://codeberg.org/pgpainless/pgpeasy
[19] https://javadoc.io/doc/org.pgpainless/pgpainless-core//index.html
[20] https://javadoc.io/doc/org.pgpainless/pgpainless-sop//index.html

Setup

PGPainless' releases are published to and can be fetched from Maven Central. To get started, you first need to include `pgpainless-sop` in your projects build script.

```
// If you use Gradle
...
dependencies {
    ...
    implementation "org.pgpainless:pgpainless-sop:XYZ"
    ...
}

// If you use Maven
...
<dependencies>
    ...
    <dependency>
        <groupId>org.pgpainless</groupId>
        <artifactId>pgpainless-sop</artifactId>
        <version>XYZ</version>
    </dependency>
    ...
</dependencies>
```

Important

Replace `XYZ` with the current version, in this case !

The entry point to the API is the `SOP` interface, for which `pgpainless-sop` provides a concrete implementation `SOPImpl`.

```
// Instantiate the API
SOP sop = new SOPImpl();
```

Now you are ready to go!

Generate a Key

To generate a new OpenPGP key, the method `SOP.generateKey()` is your friend:

```
// generate key
byte[] keyBytes = sop.generateKey()
        .userId("John Doe <john.doe@pgpainless.org>")
        .withKeyPassword("f00b4r")
        .generate()
        .getBytes();
```

The call `userId(String userId)` can be called multiple times to add multiple user-ids to the key, but it MUST be called at least once. The argument given in the first invocation will become the keys primary user-id.

Optionally, the key can be protected with a password by calling `withKeyPassword(String password)`. If this method is not called, the key will be unprotected.

The generate() method call generates the key and returns a Ready object. This in turn can be used to write the result to a stream via writeTo(OutputStream out), or to get the result as bytes via getBytes(). In both cases, the resulting output will be the UTF8 encoded, ASCII armored OpenPGP secret key.

To disable ASCII armoring, call noArmor() before calling generate().

Revision 05 of the Stateless OpenPGP Protocol specification introduced the concept of profiles for certain operations. The key generation feature is the first operation to make use of profiles to specify different key algorithms. To set a profile, simply call profile(String profileName) and pass in one of the available profile identifiers.

To explore, which profiles are available, refer to the dedicated *section*.

The default profile used by pgpainless-sop is called draft-koch-eddsa-for-openpgp-00. If this profile is used, the resulting OpenPGP secret key will consist of a certification-capable 256-bits ed25519 EdDSA primary key, a 256-bits ed25519 EdDSA subkey used for signing, as well as a 256-bits X25519 ECDH subkey for encryption.

Another profile defined by pgpainless-sop is rfc4880, which changes the key generation behaviour such that the resulting key is a single 4096-bit RSA key capable of certifying, signing and encrypting.

The whole key does not have an expiration date set.

Extract a Certificate

Now that you generated your secret key, you probably want to share the public key with your contacts. To extract the OpenPGP public key (which we will call *certificate* from now on) from the secret key, use the SOP.extractCert() method call:

```
// extract certificate
byte[] certificateBytes = sop.extractCert()
        .key(keyBytes)
        .getBytes();
```

The key(_) method either takes a byte array (like in the example), or an InputStream. In both cases it returns another Ready object from which the certificate can be accessed, either via writeTo(OutputStream out) or getBytes().

By default, the resulting certificate will be ASCII armored, regardless of whether the input key was armored or not. To disable ASCII armoring, call noArmor() before calling key(_).

In our example, certificateBytes can now safely be shared with anyone.

Change Key Password

OpenPGP keys can (but don't need to) be password protected. The changeKeyPassword() API can be used to add, change or remove password protection from OpenPGP keys. While the input to this operation can be keys with different per-subkey passwords, the output will use at most one password.

Via oldKeyPassphrase(), multiple decryption passphrase candidates can be provided. These are tried one after another to unlock protected subkeys.

In order to successfully change the passphrase of an OpenPGP key, all of its subkeys needs to be successfully decrypted. If one or more subkeys cannot be decrypted, the operation fails with a KeyIsProtected exception. The result is either fully encrypted for a single passphrase (passed via newKeyPassphrase()), or unprotected if the new key passphrase is omitted.

```
byte[] keyBefore = ...
byte[] keyAfter = sop.changeKeyPassword()
        // Provide old passphrases - all subkeys need to be decryptable,
```

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```
        //  otherwise KeyIsProtected exception will be thrown
        .oldKeyPassphrase("4d4m5m1th")
        .oldKeyPassphrase("d4v1dR1c4rd0")
        // Provide the new passphrase - if omitted, key will be unprotected
        .newKeyPassphrase("fr1edr1ch3n93l5")
        .keys(keyBefore)
        .getBytes();
```

Generate Revocation Certificates

You might want to generate a revocation certificate for your OpenPGP key. This certificate can be published to a key server to let your contacts known that your key is no longer trustworthy. The `revokeKey()` API can be used to generate a "hard-revocation", which retroactively invalidates all signatures previously issued by the key.

If the input secret key is an OpenPGP v6 key, the result will be a minimal revocation certificate, consisting of only the bare primary public key and a revocation signature. For v4 keys, the result will consist of the whole public certificate plus a revocation signature.

```
byte[] keys = ...
byte[] revoked = sop.revokeKey()
        // primary key password(s) if the key(s) are protected
        .withKeyPassword("5w0rdf1sh")
        // one or more secret keys
        .keys(keys)
        .getBytes();
```

Apply / Remove ASCII Armor

Perhaps you want to print your secret key onto a piece of paper for backup purposes, but you accidentally called `noArmor()` when generating the key.

To add ASCII armor to some binary OpenPGP data, the `armor()` API can be used:

```
// wrap data in ASCII armor
byte[] armoredData = sop.armor()
        .data(binaryData)
        .getBytes();
```

The `data(_)` method can either be called by providing a byte array, or an `InputStream`.

To remove ASCII armor from armored data, simply use the `dearmor()` API:

```
// remove ASCII armor
byte[] binaryData = sop.unarmor()
        .data(armoredData)
        .getBytes();
```

Once again, the `data(_)` method can be called either with a byte array or an `InputStream` as argument.

If the input data is not validly armored OpenPGP data, the `data(_)` method call will throw a `BadData` exception.

Encrypt a Message

Now lets get to the juicy part and finally encrypt a message! In this example, we will assume that Alice is the sender that wants to send a message to Bob. Beforehand, Alice acquired Bobs certificate, e.g. by fetching it from a key server.

To encrypt a message, you can make use of the `encrypt()` API:

```
// encrypt and sign a message
byte[] aliceKey = ...;  // Alice' secret key
byte[] aliceCert = ...; // Alice' certificate (e.g. via extractCert())
byte[] bobCert = ...;   // Bobs certificate

byte[] plaintext = "Hello, World!\n".getBytes(); // plaintext

byte[] ciphertext = sop.encrypt()
        // encrypt for each recipient
        .withCert(bobCert)
        .withCert(aliceCert)
        // Optionally: Sign the message
        .signWith(aliceKey)
        .withKeyPassword("sw0rdf1sh") // if signing key is protected
        // provide the plaintext
        .plaintext(plaintext)
        .getBytes();
```

Here you encrypt the message for each recipient (Alice probably wants to be able to decrypt the message too!) by calling `withCert(_)` with the recipients certificate as argument. It does not matter, if the certificate is ASCII armored or not, and the method can either be called with a byte array or an `InputStream` as argument.

The API not only supports asymmetric encryption via OpenPGP certificates, but it can also encrypt messages symmetrically using one or more passwords. Both mechanisms can even be used together in the same message! To (additionally or exclusively) encrypt the message for a password, simply call `withPassword(String password)` before the `plaintext(_)` method call.

It is recommended (but not required) to sign encrypted messages. In order to sign the message before encryption is applied, call `signWith(_)` with the signing key as argument. This method call can be repeated multiple times to sign the message with multiple signing keys.

If any keys used for signing are password protected, you need to provide the signing key password via `withKeyPassword(_)`. It does not matter in which order signing keys and key passwords are provided, the implementation will figure out matches on its own. If different key passwords are used, the `withKeyPassword(_)` method can be called multiple times.

You can modify the behaviour of the encrypt operation by switching between different profiles via the `profile(String profileName)` method. At the time of writing, the only available profile for this operation is `rfc4880` which applies encryption as defined in rfc4880[21].

To explore, which profiles are available, refer to the dedicated *section*.

By default, the encrypted message will be ASCII armored. To disable ASCII armor, call `noArmor()` before the `plaintext(_)` method call.

Lastly, you need to provide the plaintext by calling `plaintext(_)` with either a byte array or an `InputStream` as argument. The ciphertext can then be accessed from the resulting `Ready` object as usual.

[21] https://datatracker.ietf.org/doc/html/rfc4880

Decrypt a Message

Now let's switch perspective and help Bob decrypt the message from Alice.

Decrypting encrypted messages is done in a similar fashion using the `decrypt()` API:

```
// decrypt a message and verify its signature(s)
byte[] aliceCert = ...; // Alice' certificate
byte[] bobKey = ...;    // Bobs secret key
byte[] bobCert = ...;   // Bobs certificate

byte[] ciphertext = ...; // the encrypted message

ReadyWithResult<DecryptionResult> readyWithResult = sop.decrypt()
        .withKey(bobKey)
        .verifyWithCert(aliceCert)
        .withKeyPassword("password123") // if decryption key is protected
        .ciphertext(ciphertext);
```

The `ReadyWithResult<DecryptionResult>` can now be processed in two different ways, depending on whether you want the plaintext as bytes or simply write it out to an `OutputStream`.

To get the plaintext bytes directly, you shall proceed as follows:

```
ByteArrayAndResult<DecryptionResult> bytesAndResult = readyWithResult.
↪toByteArrayAndResult();
DecryptionResult result = bytesAndResult.getResult();
byte[] plaintext = bytesAndResult.getBytes();
```

If you instead want to write the plaintext out to an `OutputStream`, the following code can be used:

```
OutputStream out = ...;
DecryptionResult result = readyWithResult.writeTo(out);
```

Note, that in both cases you acquire a `DecryptionResult` object. This contains information about the message, such as which signatures could successfully be verified.

If you provided the senders certificate for the purpose of signature verification via `verifyWith(_)`, you now probably want to check, if the message was actually signed by the sender by checking `result.getVerifications()`.

> **Note**
>
> Signature verification will be discussed in more detail in section "Verifications".

If the message was encrypted symmetrically using a password, you can also decrypt is symmetrically by calling `withPassword(String password)` before the `ciphertext(_)` method call. This method call can be repeated multiple times. The implementation will try different passwords until it finds a matching one.

Sign a Message

There are three different main ways of signing a message:

- Inline Signatures
- Cleartext Signatures
- Detached Signatures

An inline-signature will be part of the message itself (e.g. like with messages that are encrypted *and* signed). Inline-signed messages are not human-readable without prior processing.

A cleartext signature makes use of the cleartext signature framework[22]. Messages signed in this way do have an ASCII armor header and footer, yet the content of the message is still human-readable without special software.

Lastly, a detached signature can be distributed as an extra file alongside the message without altering it. This is useful if the plaintext itself cannot be modified (e.g. if a binary file is signed).

The SOP API can generate all of those signature types.

Inline-Signatures

Let's start with an inline signature:

```
byte[] signingKey = ...;
byte[] message = ...;

byte[] inlineSignedMessage = sop.inlineSign()
        .mode(InlineSignAs.Text) // or 'Binary'
        .key(signingKey)
        .withKeyPassword("fnord")
        .data(message)
        .getBytes();
```

You can choose between two different signature formats which can be set using `mode(InlineSignAs mode)`. The default value is `Binary`. You can also set it to `Text` which signals to the receiver that the data is UTF8 text.

> **Note**
>
> For inline signatures, do NOT set the `mode()` to `CleartextSigned`, as that will create message which uses the cleartext signature framework (see further below).

You must provide at least one signing key using `key(_)` in order to be able to sign the message.

If any key is password protected, you need to provide its password using `withKeyPassword(_)` which can be called multiple times to provide multiple passwords.

Once you provide the plaintext using `data(_)` with either a byte array or an `InputStream` as argument, you will get a `Ready` object back, from which the signed message can be retrieved as usual.

By default, the signed message will be ASCII armored. This can be disabled by calling `noArmor()` before the `data(_)` method call.

[22] https://datatracker.ietf.org/doc/html/rfc4880#section-7

Cleartext Signatures

A cleartext-signed message can be generated in a similar way to an inline-signed message, however, there are is one subtle difference:

```
byte[] signingKey = ...;
byte[] message = ...;

byte[] cleartextSignedMessage = sop.inlineSign()
        .mode(InlineSignAs.CleartextSigned) // This MUST be set
        .key(signingKey)
        .withKeyPassword("fnord")
        .data(message)
        .getBytes();
```

> **Important**
>
> In order to produce a cleartext-signed message, the signature mode MUST be set to `CleartextSigned` by calling `mode(InlineSignAs.CleartextSigned)`.

> **Note**
>
> Calling `noArmor()` will have no effect for cleartext-signed messages, so such method call will be ignored.

Detached Signatures

As the name suggests, detached signatures are detached from the message itself and can be distributed separately.

To produce a detached signature, the `detachedSign()` API is used:

```
byte[] signingKey = ...;
byte[] message = ...;

ReadyWithResult<SigningResult> readyWithResult = sop.detachedSign()
        .key(signingKey)
        .withKeyPassword("fnord")
        .data(message);
```

Here you have the choice, how you want to write out the signature. If you want to write the signature to an `OutputStream`, you can do the following:

```
OutputStream out = ...;
SigningResult result = readyWithResult.writeTo(out);
```

If instead you want to get the signature as a byte array, do this instead:

```
ByteArrayAndResult<SigningResult> bytesAndResult = readyWithResult.
→toByteArrayAndResult();
SigningResult result = bytesAndResult.getResult();
byte[] detachedSignature = bytesAndResult.getBytes();
```

In any case, the detached signature can now be distributed alongside the original message.

By default, the resulting detached signature will be ASCII armored. This can be disabled by calling `noArmor()` prior to calling `data(_)`.

The `SigningResult` object you got back in both cases contains information about the signature.

Verify a Signature

In order to verify signed messages, there are two API endpoints available.

Inline and Cleartext Signatures

To verify inline-signed messages, or messages that make use of the cleartext signature framework, use the `inlineVerify()` API:

```
byte[] signingCert = ...;
byte[] signedMessage = ...;

ReadyWithResult<List<Verification>> readyWithResult = sop.inlineVerify()
        .cert(signingCert)
        .data(signedMessage);
```

The `cert(_)` method MUST be called at least once. It takes either a byte array or an `InputStream` containing an OpenPGP certificate. If you are not sure, which certificate was used to sign the message, you can provide multiple certificates.

It is also possible to reject signatures that were not made within a certain time window by calling `notBefore(Date timestamp)` and/or `notAfter(Date timestamp)`. Signatures made before the `notBefore(_)` or after the `notAfter(_)` constraints will be rejected.

You can now either write out the plaintext message to an `OutputStream`…

```
OutputStream out = ...;
List<Verifications> verifications = readyWithResult.writeTo(out);
```

… or you can acquire the plaintext message as a byte array directly:

```
ByteArrayAndResult<List<Verifications>> bytesAndResult = readyWithResult.
→toByteArrayAndResult();
byte[] plaintextMessage = bytesAndResult.getBytes();
List<Verifications> verifications = bytesAndResult.getResult();
```

In both cases, the plaintext message will have the signatures stripped.

Detached Signatures

To verify detached signatures (signatures that come separate from the message itself), you can use the `detachedVerify()` API:

```
byte[] signingCert = ...;
byte[] message = ...;
byte[] detachedSignature = ...;

List<Verification> verifications = sop.detachedVerify()
        .cert(signingCert)
        .signatures(detachedSignature)
        .data(signedMessage);
```

You can provide one or more OpenPGP certificates using `cert(_)`, providing either a byte array or an `InputStream`.

The detached signatures need to be provided separately using the `signatures(_)` method call. You can provide as many detached signatures as you like, and those can be binary or ASCII armored.

Like with Inline Signatures, you can constrain the time window for signature validity using `notAfter(_)` and `notBefore(_)`.

Verifications

In all above cases, the `verifications` list will contain `Verification` objects for each verifiable, valid signature. Those objects contain information about the signatures: `verification.getSigningCertFingerprint()` will return the fingerprint of the certificate that created the signature. `verification.getSigningKeyFingerprint()` will return the fingerprint of the used signing subkey within that certificate.

Detach Signatures from Messages

It is also possible, to detach inline or cleartext signatures from signed messages to transform them into detached signatures. The same way you can turn inline or cleartext signed messages into plaintext messages.

To detach signatures from messages, use the `inlineDetach()` API:

```
byte[] signedMessage = ...;

ReadyWithResult<Signatures> readyWithResult = sop.inlineDetach()
        .message(signedMessage);
ByteArrayAndResult<Signatures> bytesAndResult = readyWithResult.toByteArrayAndResult();

byte[] plaintext = bytesAndResult.getBytes();
Signatures signatures = bytesAndResult.getResult();
byte[] encodedSignatures = signatures.getBytes();
```

By default, the signatures output will be ASCII armored. This can be disabled by calling `noArmor()` prior to `message(_)`.

The detached signatures can now be verified like in the section above.

Explore Profiles

Certain operations allow modification of their behaviour by selecting between different profiles. An example for this is the `generateKey()` operation, where different profiles result in different algorithms used during key generation.

To explore, which profiles are supported by a certain operation, you can use the `listProfiles()` operation. For example, this is how you can get a list of profiles supported by the `generateKey()` operation:

```
List<Profile> profiles = sop.listProfiles().subcommand("generate-key");
```

Note

As you can see, the argument passed into the `subcommand()` method must match the operation name as defined in the Stateless OpenPGP Protocol specification[23].

At the time of writing (the latest revision of the SOP spec is 06), only `generate-key` and `encrypt` accept profiles.

1.2.2 PGPainless API with pgpainless-core

The `pgpainless-core` module contains the bulk of the actual OpenPGP implementation.

This is a quickstart guide. For more in-depth exploration of the API, checkout *`indepth.md`*.

Note

This chapter is work in progress.

Setup

PGPainless' releases are published to and can be fetched from Maven Central. To get started, you first need to include `pgpainless-core` in your projects build script:

```
// If you use Gradle
...
dependencies {
    ...
    implementation "org.pgpainless:pgpainless-core:XYZ"
    ...
}

// If you use Maven
...
<dependencies>
    ...
    <dependency>
        <groupId>org.pgpainless</groupId>
        <artifactId>pgpainless-core</artifactId>
        <version>XYZ</version>
    </dependency>
```

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[23] https://datatracker.ietf.org/doc/draft-dkg-openpgp-stateless-cli/

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```
    ...
</dependencies>
```

This will automatically pull in PGPainless' dependencies, such as Bouncy Castle.

> **Important**
>
> Replace `XYZ` with the current version, in this case !

The entry point to the API is the `PGPainless` class. For many common use-cases, examples can be found in the examples package[24]. There is a very good chance that you can find code examples there that fit your needs.

Read and Write Keys

Reading keys from ASCII armored strings or from binary files is easy:

```
// Secret Keys
String key = "-----BEGIN PGP PRIVATE KEY BLOCK-----\n"...;
PGPSecretKeyRing secretKey = PGPainless.readKeyRing()
        .secretKeyRing(key);

// Certificates (Public Keys)
String cert = "-----BEGIN PGP PUBLIC KEY BLOCK-----\n...";
PGPPublicKeyRing certificate = PGPainless.readKeyRing()
        .publicKeyRing(cert);
```

Similarly, keys or certificates can quickly be exported:

```
// ASCII armored key
PGPSecretKeyRing secretKey = ...;
String armored = PGPainless.asciiArmor(secretKey);

// binary (unarmored) key
byte[] binary = secretKey.getEncoded();
```

Generate a Key

PGPainless comes with a method to quickly generate modern OpenPGP keys. There are some predefined key archetypes, but it is possible to fully customize the key generation to fit your needs.

```
// EdDSA primary key with EdDSA signing- and XDH encryption subkeys
PGPSecretKeyRing secretKeys = PGPainless.generateKeyRing()
        .modernKeyRing("Romeo <romeo@montague.lit>", "thisIsAPassword");

// RSA key without additional subkeys
PGPSecretKeyRing secretKeys = PGPainless.generateKeyRing()
        .simpleRsaKeyRing("Juliet <juliet@montague.lit>", RsaLength._4096);
```

As you can see, it is possible to generate all kinds of different keys.

[24] https://codeberg.org/pgpainless/pgpainless/src/branch/main/pgpainless-core/src/test/java/org/pgpainless/example

Extract a Certificate

If you have a secret key, you might want to extract a public key certificate from it:

```
PGPSecretKeyRing secretKey = ...;
PGPPublicKeyRing certificate = PGPainless.extractCertificate(secretKey);
```

Apply / Remove ASCII Armor

ASCII armor is a layer of radix64 encoding that can be used to wrap binary OpenPGP data in order to make it save to transport via text-based channels (e.g. email bodies).

The way in which ASCII armor can be applied depends on the type of data that you want to protect. The easies way to ASCII armor an OpenPGP key or certificate is by using PGPainless' `asciiArmor()` method:

```
PGPPublicKey certificate = ...;
String asciiArmored = PGPainless.asciiArmor(certificate);
```

If you want to ASCII armor ciphertext, you can enable ASCII armoring during encrypting/signing by requesting PGPainless to armor the result:

```
ProducerOptions producerOptions = ...; // prepare as usual (see next section)

producerOptions.setAsciiArmor(true); // enable armoring

EncryptionStream encryptionStream = PGPainless.encryptAndOrSign()
        .onOutputStream(out)
        .withOptions(producerOptions);

...
```

If you have an already encrypted / signed binary message and want to add ASCII armoring retrospectively, you need to make use of BouncyCastle's `ArmoredOutputStream` as follows:

```
InputStream binaryOpenPgpIn = ...; // e.g. new ByteArrayInputStream(binaryMessage);

OutputStream output = ...; // e.g. new ByteArrayOutputStream();
ArmoredOutputStream armorOut = ArmoredOutputStreamFactory.get(output);

Streams.pipeAll(binaryOpenPgpIn, armorOut);
armorOut.close(); // important!
```

The output stream will now contain the ASCII armored representation of the binary data.

If the data you want to wrap in ASCII armor is non-OpenPGP data (e.g. the String "Hello World!"), you need to use the following code:

```
InputStream inputStream = ...;
OutputStream output = ...;

EncryptionStream armorStream = PGPainless.encryptAndOrSign()
        .onOutputStream(output)
        .withOptions(ProducerOptions.noEncryptionNoSigning()
                .setAsciiArmor(true));
```

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```
Streams.pipeAll(inputStream, armorStream);
armorStream.close();
```

To remove ASCII armor, you can make use of BouncyCastle's `ArmoredInputStream` as follows:

```
InputStream input = ...; // e.g. new ByteArrayInputStream(armoredString.
↪getBytes(StandardCharsets.UTF8));
OutputStream output = ...;

ArmoredInputStream armorIn = new ArmoredInputStream(input);
Streams.pipeAll(armorIn, output);
armorIn.close();
```

The output stream will now contain the binary OpenPGP data.

Encrypt and/or Sign a Message

Encrypting and signing messages is done using the same API in PGPainless. The type of action depends on the configuration of the `ProducerOptions` class, which in term accepts `SigningOptions` and `EncryptionOptions` objects:

```
// Encrypt only
ProducerOptions options = ProducerOptions.encrypt(encryptionOptions);

// Sign only
ProducerOptions options = ProducerOptions.sign(signingOptions);

// Sign and encrypt
ProducerOptions options = ProducerOptions.signAndEncrypt(signingOptions,␣
↪encryptionOptions);
```

The `ProducerOptions` object can then be passed into the `encryptAndOrSign()` API:

```
InputStream plaintext = ...; // The data that shall be encrypted and/or signed
OutputStream ciphertext = ...; // Destination for the ciphertext

EncryptionStream encryptionStream = PGPainless.encryptAndOrSign()
        .onOutputStream(ciphertext)
        .withOptions(options); // pass in the options object

Streams.pipeAll(plaintext, encryptionStream); // pipe the data through
encryptionStream.close(); // important! Close the stream to finish encryption/signing

EncryptionResult result = encryptionStream.getResult(); // metadata
```

The `ciphertext` output stream now contains the encrypted and/or signed data.

Now lets take a look at the configuration of the `SigningOptions` object and how to instruct PGPainless to add a simple signature to the message:

```
PGPSecretKeyRing signingKey = ...; // Key used for signing
SecretKeyRingProtector protector = ...; // Protector to unlock the signing key
```

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```
SigningOptions signOptions = SigningOptions.get()
        .addSignature(protector, signingKey);
```

This will add an inline signature to the message.

It is possible to add multiple signatures from different keys by repeating the `addSignature()` method call.

If instead of an inline signature, you want to create a detached signature instead (e.g. because you do not want to alter the data you are signing), you can add the signature as follows:

```
signOptions.addDetachedSignature(protector, signingKey);
```

Passing in the `SigningOptions` object like this will result in the signature not being added to the message itself. Instead, the signature can later be acquired from the `EncryptionResult` object via `EncryptionResult.getDetachedSignatures()`. That way, it can be distributed independent of the message.

The `EncryptionOptions` object can be configured in a similar way:

```
PGPPublicKey certificate = ...;

EncryptionOptions encOptions = EncryptionOptions.get()
        .addRecipient(certificate);
```

Once again, it is possible to add multiple recipients by repeating the `addRecipient()` method call.

In order to prevent metadata leaks, you might want to add recipients anonymously. Anonymous recipients have their key-id hidden by replacing it with a wildcard. That way, it is not easily possible for an attacker to deduce the recipients of a message without further analysis of additional metadata. Anonymous recipients can be added like follows:

```
encOptions.addHiddenRecipient(certificate);
```

You can also encrypt a message to a password like this:

```
encOptions.addPassphrase(Passphrase.fromPassword("sw0rdf1sh"));
```

Both methods can be used in combination to create a message which can be decrypted with either a recipients secret key or the passphrase.

Decrypt and/or Verify a Message

Decryption and verification of a message is both done using the same API. Whether a message was actually signed / encrypted can be determined after the message has been processed by checking the `MessageMetadata` object which can be obtained from the `DecryptionStream`.

To configure the decryption / verification process, the `ConsumerOptions` object is used:

```
PGPPublicKeyRing verificationCert = ...; // optional, signers certificate for signature␣
↪verification
PGPSecretKeyRing decryptionKey = ...; // optional, decryption key

ConsumerOptions options = ConsumerOptions.get()
        .addVerificationCert(verificationCert) // add a verification cert for signature␣
↪verification
        .addDecryptionKey(decryptionKey); // add a secret key for message decryption
```

Both verification certificates and decryption keys are optional. If you know the message is signed, but not encrypted you can omit providing a decryption key. Same goes for if you know that the message is encrypted, but not signed. In this case you can omit the verification certificate.

On the other hand, providing these parameters does not hurt. PGPainless will ignore unused keys / certificates, so if you provide a decryption key and the message is not encrypted, nothing bad will happen.

It is possible to provide multiple verification certs and decryption keys. PGPainless will pick suitable ones on the fly. If the message is signed with key `0xAAAA` and you provide certificates `0xAAAA` and `0xBBBB`, it will verify with cert `0xAAAA` and ignore `0xBBBB`.

To do the actual decryption / verification of the message, do the following:

```
InputStream ciphertext = ...; // encrypted and/or signed message
OutputStream plaintext = ...; // destination for the plaintext

ConsumerOptions options = ...; // see above
DecryptionStream consumerStream = PGPainless.decryptAndOrVerify()
        .onInputStream(ciphertext)
        .withOptions(options);

Streams.pipeAll(consumerStream, plaintext);
consumerStream.close(); // important!

// The result will contain metadata of the message
MessageMetadata result = consumerStream.getMetadata();
```

After the message has been processed, you can consult the `MessageMetadata` object to determine the nature of the message:

```
boolean wasEncrypted = result.isEncrypted();
SubkeyIdentifier decryptionKey = result.getDecryptionKey();
List<SignatureVerification> validSignatures = result.getVerifiedSignatures();
boolean wasSignedByCert = result.isVerifiedSignedBy(certificate);

// For files:
String fileName = result.getFileName();
Date modificationData = result.getModificationDate();
```

Verify a Signature

In some cases, detached signatures are distributed alongside the message. This is the case for example with Debians `Release` and `Release.gpg` files. Here, `Release` is the plaintext message, which is unaltered by the signing process while `Release.gpg` contains the detached OpenPGP signature.

To verify a detached signature, you need to call the PGPainless API like this:

```
InputStream plaintext = ...; // e.g. new FileInputStream(releaseFile);
InputStream detachedSignature = ...; // e.g. new FileInputStream(releaseGpgFile);
PGPPublicKeyRing certificate = ...; // e.g. debians public signing key

ConsumerOptions options = ConsumerOptions.get()
        .addVerificationCert(certificate) // provide certificate for verification
        .addVerificationOfDetachedSignatures(detachedSignature) // provide detached␣
↪signature
```

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```
DecryptionStream verificationStream = PGPainless.decryptAndOrVerify()
        .onInputStream(plaintext)
        .withOptions(options);

Streams.drain(verificationStream); // push all the data through the stream
verificationStream.close(); // finish verification

MessageMetadata result = verificationStream.getMetadata(); // get metadata of signed␣
↪message
assertTrue(result.isVerifiedSignedBy(certificate)); // check if message was in fact␣
↪signed
```

Legacy Compatibility

Out of the box, PGPainless is configured to use secure defaults and perform checks for recommended security features. This means that for example messages generated using older OpenPGP implementations which do not follow those best practices might fail to decrypt/verify.

It is however possible to circumvent certain security checks to allow processing of such messages.

> **Note**
>
> It is not recommended to disable security checks, as that might enable certain attacks on the OpenPGP protocol.

Missing / broken MDC (modification detection code)

RFC4880 has two different types of encrypted data packets. The *Symmetrically Encrypted Data* packet (SED) and the *Symmetrically Encrypted Integrity-Protected Data* packet. The latter has an added MDC packet which prevents modifications to the ciphertext.

While implementations are highly encouraged to only use the latter package type, some older implementations still generate encrypted data packets which are not integrity protected.

To allow PGPainless to decrypt such messages, you need to set a flag in the `ConsumerOptions` object:

```
ConsumerOptions options = ConsumerOptions.get()
        .setIgnoreMDCErrors(true) // <-
        .setDecryptionKey(secretKey)
        ...

DecryptionStream decryptionStream = PGPainless.decryptAndOrVerify()
        .onInputStream(ciphertextIn)
        .withOptions(options);
...
```

> **Note**
>
> It is highly advised to only set this flag if you know what you are doing. It might also be a good idea to try decrypting a message without the flag set first and only re-try decryption with the flag set in case of a

MessageNotIntegrityProtectedException (don't forget to rewind the ciphertextInputStream).

Weak keys and broken algorithms

Some users might cling on to older keys using weak algorithms / small key sizes. PGPainless refuses to encrypt to weak certificates and sign with weak keys. By default, PGPainless follows the recommendations for acceptable key sizes of the German BSI in 2021[25]. It can however be configured to accept older key material / algorithms too.

Minimal key lengths can be configured by changing PGPainless' policy:

```
Map<PublicKeyAlgorithm, Integer> algorithms = new HashMap<>();
// put all acceptable algorithms and their minimal key length
algorithms.put(PublicKeyAlgorithm.RSA_GENERAL, 1024);
algorithms.put(PublicKeyAlgorithm.ECDSA, 100);
...
Policy.PublicKeyAlgorithmPolicy pkPolicy =
        new Policy.PublicKeyAlgorithmPolicy(algorithms);
// set the custom algorithm policy
PGPainless.getPolicy().setPublicKeyAlgorithmPolicy();
```

Since OpenPGP uses a hybrid encryption scheme of asymmetric and symmetric encryption algorithms, it also comes with a policy for symmetric encryption algorithms. This list can be modified to allow for weaker algorithms like follows:

```
// default fallback algorithm for message encryption
SymmetricKeyAlgorithm fallbackAlgorithm = SymmetricKeyAlgorithm.AES_256;
// acceptable algorithms
List<SymmetricKeyAlgorithm> algorithms = new ArrayList<>();
algorithms.add(SymmetricKeyAlgorithm.AES_256);
algorithms.add(SymmetricKeyAlgorithm.AES_192);
algorithms.add(SymmetricKeyAlgorithm.AES_128);
algorithms.add(SymmetricKeyAlgorithm.TWOFISH);
algorithms.add(SymmetricKeyAlgorithm.BLOWFISH);
...
Policy.SymmetricKeyAlgorithmPolicy skPolicy =
        new SymmtricKeyAlgorithmPolicy(fallbackAlgorithm, algorithms);
// set the custom algorithm policy
// algorithm policy applicable when decrypting messages created by legacy senders:
PGPainless.getPolicy()
        .setSymmetricKeyDecryptionAlgorithmPolicy(skPolicy);
// algorithm policy applicable when generating messages for legacy recipients:
PGPainless.getPolicy()
        .setSymmetricKeyEncryptionAlgorithmPolicy(skPolicy);
```

Hash algorithms are used in OpenPGP to create signatures. Since signature verification is an integral part of the OpenPGP protocol, PGPainless comes with multiple policies for acceptable hash algorithms, depending on the use-case. Revocation signatures are critical, so you might want to handle revocation signatures differently from normal signatures.

By default, PGPainless uses a smart hash algorithm policy for both use-cases, which takes into consideration not only the hash algorithm itself, but also the creation date of the signature. That way, signatures using SHA-1 are acceptable if they were created before February 2013, but are rejected if their creation date is after that point in time.

[25] https://www.bsi.bund.de/SharedDocs/Downloads/EN/BSI/Publications/TechGuidelines/TG02102/BSI-TR-02102-1.pdf

A custom hash algorithm policy can be set like this:

```
HashAlgorithm fallbackAlgorithm = HashAlgorithm.SHA512;
Map<HashAlgorithm, Date> algorithms = new HashMap<>();
// Accept MD5 on signatures made before 1997-02-01
algorithms.put(HashAlgorithm.MD5,
        DateUtil.parseUTCDate("1997-02-01 00:00:00 UTC"));
// Accept SHA-1, regardless of signature creation time
algorithms.put(HashAlgorithm.SHA1, null);
...
Policy.HashAlgorithmPolicy hPolicy =
        new Policy.HashAlgorithmPolicy(fallbackAlgorithm, algorithms);
// set policy for revocation signatures
PGPainless.getPolicy()
        .setRevocationSignatureHashAlgorithmPolicy(hPolicy);
// set policy for normal signatures (certifications and document signatures)
PGPainless.getPolicy()
        .setSignatureHashAlgorithmPolicy(hPolicy);
```

Lastly, PGPainless comes with a policy on acceptable compression algorithms, which currently accepts any compression algorithm. A custom compression algorithm policy can be set in a similar way:

```
CompressionAlgorithm fallback = CompressionAlgorithm.ZIP;
List<CompressionAlgorithm> algorithms = new ArrayList<>();
algorithms.add(CompressionAlgorith.ZIP);
algorithms.add(CompressionAlgorithm.BZIP2);
...
Policy.CompressionAlgorithmPolicy cPolicy =
        new Policy.CompressionAlgorithmPolicy(fallback, algorithms);
PGPainless.getPolicy()
        .setCompressionAlgorithmPolicy(cPolicy);
```

To prevent a class of attacks described in the paper[26] “Victory by KO: Attacking OpenPGP Using Key Overwriting”, PGPainless offers the option to validate private key material each time before using it, to make sure that an attacker didn’t tamper with the corresponding public key parameters.

These checks are disabled by default, but they can be enabled as follows:

```
PGPainless.getPolicy()
        .setEnableKeyParameterValidation(true);
```

Note

Validation checks against KOpenPGP attacks are disabled by default, since they are very costly and only make sense in certain scenarios. Please read and understand the paper to decide, if enabling the checks makes sense for your use-case.

[26] https://www.kopenpgp.com/#paper

Known Notations

In OpenPGP, signatures can contain notation subpackets[27]. A notation can give meaning to a signature, or add additional contextual information. Signature subpackets can be marked as critical, meaning an implementation that does not know about a certain subpacket MUST reject the signature. The same is true for critical notations.

For that reason, PGPainless comes with a `NotationRegistry` class which can be used to register known notations, such that a signature containing a critical notation of a certain value is not rejected. To register a known notation, you can do the following:

```
NotationRegistry registry = PGPainless.getPolicy()
        .getNotationRegistry();

registry.addKnownNotation("sample@example.com");
```

1.3 User Guide PGPainless-CLI

The module `pgpainless-cli` contains a command line application which conforms to the Stateless OpenPGP Command Line Interface[28].

You can use it to generate keys, encrypt, sign and decrypt messages, as well as verify signatures.

1.3.1 Implementation

Essentially, `pgpainless-cli` is just a very small composing module, which injects `pgpainless-sop` as a concrete implementation of `sop-java` into `sop-java-picocli`.

1.3.2 Install

The `pgpainless-cli` command line application is available in Debian unstable / Ubuntu 22.10 and can be installed via APT:

```
$ sudo apt install pgpainless-cli
```

This method comes with man-pages:

```
$ man pgpainless-cli
```

1.3.3 Build

To build a standalone *fat*-jar:

```
$ cd pgpainless-cli/
$ gradle shadowJar
```

The fat-jar can afterwards be found in `build/libs/`.

To build a distributable[29]:

[27] https://www.rfc-editor.org/rfc/rfc4880#section-5.2.3.16
[28] https://datatracker.ietf.org/doc/draft-dkg-openpgp-stateless-cli/
[29] https://docs.gradle.org/current/userguide/distribution_plugin.html

```
$ cd pgpainless-cli/
$ gradle installDist
```

Afterwards, an uncompressed distributable is installed in `build/install/`. To execute the application, you can call `build/install/bin/pgpainless-cli{.bat}`

Building / updating man pages is a two-step process. The contents of the man pages is largely defined by the `sop-java-picocli` source code.

In order to generate a fresh set of man pages from the `sop-java-picocli` source, you need to clone that repository next to the `pgpainless` repository:

```
$ ls
pgpainless
$ git clone https://github.com/pgpainless/sop-java.git
$ ls
pgpainless  sop-java
```

Next, you need to execute the `asciiDoctor` gradle task inside the sop-java repository:

```
$ cd sop-java
$ gradle asciiDoctor
```

This will generate generic sop manpages in `sop-java-picocli/build/docs/manpage/`.

Next, you need to execute a script for converting the `sop` manpages to fit the `pgpainless-cli` command with the help of a script in the `pgpainless` repository:

```
$ cd ../pgpainless/pgpainless-cli
$ ./rewriteManPages.sh
```

The resulting updated man pages are placed in `packaging/man/`.

1.3.4 Usage

Hereafter, the program will be referred to as `pgpainless-cli`.

```
$ pgpainless-cli help
Stateless OpenPGP Protocol
Usage: pgpainless-cli [--stacktrace] [COMMAND]

Options:
      --stacktrace   Print stacktrace

Commands:
  version              Display version information about the tool
  list-profiles        Emit a list of profiles supported by the identified
                         subcommand
  generate-key         Generate a secret key
  change-key-password  Update the password of a key
  revoke-key           Generate revocation certificates
  extract-cert         Extract a public key certificate from a secret key
  sign                 Create a detached message signature
  verify               Verify a detached signature
```

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```
  encrypt                Encrypt a message from standard input
  decrypt                Decrypt a message
  inline-detach          Split signatures from a clearsigned message
  inline-sign            Create an inline-signed message
  inline-verify          Verify an inline-signed message
  armor                  Add ASCII Armor to standard input
  dearmor                Remove ASCII Armor from standard input
  help                   Display usage information for the specified subcommand

Exit Codes:
   0   Successful program execution
   1   Generic program error
   3   Verification requested but no verifiable signature found
  13   Unsupported asymmetric algorithm
  17   Certificate is not encryption capable
  19   Usage error: Missing argument
  23   Incomplete verification instructions
  29   Unable to decrypt
  31   Password is not human-readable
  37   Unsupported Option
  41   Invalid data or data of wrong type encountered
  53   Non-text input received where text was expected
  59   Output file already exists
  61   Input file does not exist
  67   Cannot unlock password protected secret key
  69   Unsupported subcommand
  71   Unsupported special prefix (e.g. "@ENV/@FD") of indirect parameter
  73   Ambiguous input (a filename matching the designator already exists)
  79   Key is not signing capable
  83   Options were supplied that are incompatible with each other
  89   The requested profile is unsupported, or the indicated subcommand does
         not accept profiles
```

To get help on a subcommand, e.g. `encrypt`, just call the help subcommand followed by the subcommand you are interested in (e.g. `pgpainless-cli help encrypt`).

1.3.5 Examples

```
$ # Generate a key
$ pgpainless-cli generate-key "Alice <alice@pgpainless.org>" > key.asc
$ # Extract a certificate from a key
$ cat key.asc | pgpainless-cli extract-cert > cert.asc
$ # Create an encrypted signed message
$ echo "Hello, World!" | pgpainless-cli encrypt cert.asc --sign-with key.asc > msg.asc
$ # Decrypt an encrypted message and verify the signature
$ cat msg.asc | pgpainless-cli decrypt key.asc --verify-with cert.asc --verifications-
↪out verifications.txt
Hello, World!
$ cat verifications.txt
2022-11-15T21:25:48Z 4FF67C69150209ED8139DE22578CB2FABD5D7897␣
↪9000235358B8CEA6A368EC86DE56DC2D942ACAA4
```

1.3.6 Indirect Data Types

Some commands take options whose arguments are indirect data types. Those are arguments which are not used directly, but instead they point to a place where the argument value can be sourced from, such as a file, an environment variable or a file descriptor.

It is important to keep in mind, that options like `--with-password` or `--with-key-password` are examples for such indirect data types. If you want to unlock a key whose password is `sw0rdf1sh`, you *cannot* provide the password like `--with-key-password sw0rdf1sh`, but instead you have to either write out the password into a file and provide the file's path (e.g. `--with-key-password /path/to/file`), store the password in an environment variable and pass that (e.g. `--with-key-password @ENV:myvar`), or provide a numbered file descriptor from which the password can be read (e.g. `--with-key-password @FD:4`).

Note, that environment variables and file descriptors can only be used to pass input data to the program. For output parameters (e.g. `--verifications-out`) only file paths are allowed.

1.4 Stateless OpenPGP Protocol (SOP)

The Stateless OpenPGP Protocol[30] (short *SOP*) is a specification of a standardized command line interface for a limited set of OpenPGP operations.

By standardizing the interface, users are able to choose between different, compatible implementations.

> **Note**
>
> This chapter is work in progress.

1.5 In-Depth Guide to pgpainless-core

This is an in-depth introduction to OpenPGP using PGPainless. If you are looking for a quickstart introduction instead, check out [](quickstart.md).

1.5.1 Contents

PGPainless In-Depth: Generate Keys

There are two API endpoints for generating OpenPGP keys using `pgpainless-core`:

`PGPainless.generateKeyRing()` presents a selection of pre-configured OpenPGP key archetypes:

```
// Modern, EC-based OpenPGP key with dedicated primary certification key
// This method is recommended by the authors
PGPSecretKeyRing secretKey = PGPainless.generateKeyRing()
        .modernKeyRing(
                "Alice <alice@pgpainless.org>",
                Passphrase.fromPassword("sw0rdf1sh"));

// Simple, EC-based OpenPGP key with combined certification and signing key
```

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[30] https://datatracker.ietf.org/doc/draft-dkg-openpgp-stateless-cli/

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```
// plus encryption subkey
PGPSecretKeyRing secretKey = PGPainless.generateKeyRing()
        .simpleEcKeyRing(
                "Alice <alice@pgpainless.org>",
                Passphrase.fromPassword("0r4ng3"));

// Simple, RSA OpenPGP key made of a single RSA key used for all operations
PGPSecretKeyRing secretKey = PGPainless.generateKeyRing()
        .simpleRsaKeyRing(
                "Alice <alice@pgpainless.org>",
                RsaLength._4096, Passphrase.fromPassword("m0nk3y")):
```

If you have special requirements on algorithms you can use PGPainless.buildKeyRing() instead, which offers more control over parameters:

```
// Customized key

// Specification for primary key
KeySpecBuilder primaryKeySpec = KeySpec.getBuilder(
        KeyType.RSA(RsaLength._8192),                          // 8192 bits RSA key
        KeyFlag.CERTIFY_OTHER)                                 // used for␣
↪certification
        // optionally override algorithm preferences
        .overridePreferredCompressionAlgorithms(CompressionAlgorithm.ZLIB)
        .overridePreferredHashAlgorithms(HashAlgorithm.SHA512, HashAlgorithm.SHA384)
        .overridePreferredSymmetricKeyAlgorithms(SymmetricKeyAlgorithm.AES256);

// Specification for a signing subkey
KeySpecBuilder signingSubKeySpec = KeySpec.getBuilder(
        KeyType.ECDSA(EllipticCurve._P256),                    // P-256 ECDSA key
        KeyFlag.SIGN_DATA);                                    // Used for signing

// Specification for an encryption subkey
KeySpecBuilder encryptionSubKeySpec = KeySpec.getBuilder(
        KeyType.ECDH(EllipticCurve._P256),
        KeyFlag.ENCRYPT_COMMS, KeyFlag.ENCRYPT_STORAGE);

// Build the key itself
PGPSecretKeyRing secretKey = PGPainless.buildKeyRing()
        .setPrimaryKey(primaryKeySpec)
        .addSubkey(signingSubKeySpec)
        .addSubkey(encryptionSubKeySpec)
        .addUserId("Juliet <juliet@montague.lit>")             // Primary User-ID
        .addUserId("xmpp:juliet@capulet.lit")                  // Additional User-ID
        .setPassphrase(Passphrase.fromPassword("romeo_oh_Romeo<3")) // passphrase␣
↪protection
        .build();
```

To specify, which algorithm to use for a single (sub) key, KeySpec.getBuilder(_) can be used, passing a KeyType, as well as some KeyFlags as argument.

KeyType defines an algorithm and its parameters, e.g. RSA with a certain key size, or ECDH over a certain elliptic curve. Currently, PGPainless supports the following KeyTypes:

- `KeyType.RSA(_)`: Signing, Certification, Encryption
- `KeyType.ECDH(_)`: Encryption
- `KeyType.ECDSA(_)`: Signing, Certification
- `KeyType.EDDSA(_)`: Signing, Certification
- `KeyType.XDH(_)`: Encryption

The `KeyFlags` are used to specify, how the key will be used later on. A signing key can only be used for signing, if it carries the `KeyFlag.SIGN_DATA`. A key can carry multiple key flags.

It is possible to override the default algorithm preferences used by PGPainless with custom preferences. An algorithm preference list contains algorithms from most to least preferred.

Every OpenPGP key MUST have a primary key. The primary key MUST be capable of certification, so you MUST use an algorithm that can be used to generate signatures. The primary key can be set by calling `setPrimaryKey(primaryKeySpec)`.

Furthermore, an OpenPGP key can contain zero or more subkeys. Those can be set by repeatedly calling `addSubkey(subkeySpec)`.

OpenPGP keys are usually bound to User-IDs like names and/or email addresses. There can be multiple user-ids bound to a key, in which case the very first User-ID will be marked as primary. To add a User-ID to the key, call `addUserId(userId)`.

By default, keys do not have an expiration date. This can be changed by setting an expiration date using `setExpirationDate(date)`.

To enable password protection for the OpenPGP key, you can call `setPassphrase(passphrase)`. If this method is not called, or if the passed in `Passphrase` is empty, the key will be unprotected.

Finally, calling `build()` will generate a fresh OpenPGP key according to the specifications given.

Edit Keys

User-IDs

User-IDs are identities that users go by. A User-ID might be a name, an email address or both. User-IDs can also contain both and even have a comment.

In general, the format of a User-ID is not fixed, so it can contain arbitrary strings. However, it is agreed upon to use the Below is a selection of possible User-IDs:

```
Firstname Lastname (Comment) <email@address.tld>
Firstname Lastname
Firstname Lastname (Comment)
<email@address.tld>
```

PGPainless comes with a builder class `UserId`, which can be used to safely construct User-IDs:

```
UserId nameAndEMail = UserId.nameAndEmail("Jane Doe", "jane@pgpainless.org");
assertEquals("Jane Doe <jane@pgpainless.org>", nameAndEmail.toString()):

UserId onlyEmail = UserId.onlyEmail("john@pgpainless.org");
assertEquals("<john@pgpainless.org>", onlyEmail.toString());

UserId full = UserId.newBuilder()
```

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```
        .withName("Peter Pattern")
        .withEmail("peter@pgpainless.org")
        .withComment("Work Address")
        .build();
assertEquals("Peter Pattern (Work Address) <peter@pgpainless.org>", full.toString());
```

If you have a User-ID in form of a string (e.g. because a user provided it via a text field), you can parse it into its components like this:

```
String string = "John Doe <john@doe.corp>";
UserId userId = UserId.parse(string);

// Now you can access the different components
assertEquals("John Doe", userId.getName());
assertEquals("john@doe.corp", userId.getEmail());
assertNull(userId.getComment());
```

The method `UserId.parse(String string)` will throw an `IllegalArgumentException` if the User-ID is malformed.

Passwords

In Java based applications, passing passwords as `String` objects has the disadvantage[31] that you have to rely on garbage collection to clean up once they are no longer used. For that reason, `char[]` is the preferred method for dealing with passwords. Once a password is no longer used, the character array can simply be overwritten to remove the sensitive data from memory.

Passphrase

PGPainless uses a wrapper class `Passphrase`, which takes care for the wiping of unused passwords:

```
Passphrase passphrase = new Passphrase(new char[] {'h', 'e', 'l', 'l', 'o'});
assertTrue(passphrase.isValid());

assertArrayEquals(new char[] {'h', 'e', 'l', 'l', 'o'}, passphrase.getChars()):

// Once we are done, we can clean the data
passphrase.clear();

assertFalse(passphrase.isValid());
assertNull(passphrase.getChars());
```

Furthermore, `Passphrase` can also wrap empty passphrases, which increases null-safety of the API:

```
Passphrase empty = Passphrase.emptyPassphrase();
assertTrue(empty.isValid());
assertTrue(empty.isEmpty());
assertNull(empty.getChars());
```

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[31] https://stackoverflow.com/a/8881376/11150851

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```
empty.clear();

assertFalse(empty.isValid());
```

SecretKeyRingProtector

There are certain operations that require you to provide the passphrase for a key. Examples are decryption of messages, or creating signatures / certifications.

The primary way of telling PGPainless, which password to use for a certain key is the `SecretKeyRingProtector` interface which maps `Passphrases` to (sub-)keys. There are multiple implementations of this interface, which may or may not suite your needs:

```
// If your key is not password protected, this implementation is for you:
SecretKeyRingProtector unprotected = SecretKeyRingProtector
        .unprotectedKeys();

// If you use a single passphrase for all (sub-) keys, take this:
SecretKeyRingProtector singlePassphrase = SecretKeyRingProtector
        .unlockAnyKeyWith(passphrase);

// If you want to be flexible, use this:
CachingSecretKeyRingProtector flexible = SecretKeyRingProtector
        .defaultSecretKeyRingProtector(passphraseCallback);
```

`SecretKeyRingProtector.unprotectedKeys()` will return an empty passphrase for any key. It is best used when dealing with unencrypted secret keys.

`SecretKeyRingProtector.unlockAnyKeyWith(passphrase)` will return the same exact passphrase for any given key. You should use this if you have a single key with a static passphrase.

The last example shows how to instantiate the `CachingSecretKeyRingProtector` with a `SecretKeyPassphraseProvider` as argument. As the name suggests, the `CachingSecretKeyRingProtector` caches passphrases it knows about in a map. That way, you only have to provide the passphrase for a certain key only once, after which it will be remembered. If you try to unlock a protected secret key for which no passphrase is cached, the `getPassphraseFor()` method of the `SecretKeyPassphraseProvider` callback will be called to interactively ask for the missing passphrase. Afterwards, the acquired passphrase will be cached for future use.

Note

While especially the `CachingSecretKeyRingProtector` can handle multiple keys without problems, it is advised to use individual `SecretKeyRingProtector` objects per key. The reason for this is, that internally the 64bit key-id is used to resolve `Passphrase` objects and collisions are not unlikely in this key-space. Furthermore, multiple OpenPGP keys could contain the same subkey, but with different passphrases set. If the same `SecretKeyRingProtector` is used for two OpenPGP keys with the same subkey, but different passwords, the key-id collision will cause the password to be overwritten for one of the keys, which might result in issues. See `FLO-04-004 WP2` of the 2021 security audit[32] for more details.

Most `SecretKeyRingProtector` implementations can be instantiated with custom `KeyRingProtectionSettings`. By default, most implementations use `KeyRingProtectionSettings.secureDefaultSettings()` which corresponds to iterated and salted S2K using AES256 and SHA256 with an iteration count of 65536.

[32] https://cure53.de/pentest-report_pgpainless.pdf

1.6 Migration Guide PGPainless 2.0

PGPainless 2.0 makes use of Bouncy Castles new High-Level API. As a consequence, the use of certain "mid-level" classes, such as `PGPPublicKeyRing`, `PGPSecretKeyRing` is now discouraged in favor of their high-level counterparts, e.g. `OpenPGPCertificate`, `OpenPGPKey`.

1.6.1 Terminology Changes

Bouncy Castles high-level API uses OpenPGP terminology as described in the book OpenPGP for application developers[33]. Therefore, some terms used in the mid-level API are no longer used.

Old Term	New Term	Description
key ring	OpenPGP certificate or key	
master key	primary key	
public key ring	(OpenPGP) certificate	
secret key ring	(OpenPGP) key	
subkey	component key	A component key is either a primary key, or a subkey
primary key identifier	certificate identifier	
subkey identifier	component key identifier	

1.6.2 API

PGPainless 2.0 switches away from the Singleton pattern.

The API entrypoints for PGPainless 1.X were static methods of the `PGPainless` class. Configuration was done by modifying singletons, e.g. `Policy`.

With PGPainless 2.X, the recommended way to use the API is to create individual instances of the `PGPainless` class, which provide non-static methods for different OpenPGP operations. That way, you can have multiple API instances with different, per-instance configurations.

1.6.3 Key Material

The use of `PGPPublicKeyRing` objects is now discouraged in favor of `OpenPGPCertificate`. Appropriately, `OpenPGPKey` replaces `PGPSecretKeyRing`. `OpenPGPKey` extends the `OpenPGPCertificate` class, but also contains secret key material.

An `OpenPGPCertificate` consists of `OpenPGPCertificateComponents` such as `OpenPGPComponentKeys` and `OpenPGPIdentityComponents`, which are bound to the certificate with `OpenPGPComponentSignatures`. `OpenPGPIdentityComponents` are either `OpenPGPUserIds` or `OpenPGPUserAttributes` (the latter being more or less deprecated). Components of an OpenPGP certificate, which contain key material (public keys, secret keys, subkeys…) are represented by the `OpenPGPComponentKey` class, from which `OpenPGPPrimaryKey`, `OpenPGPSubkey` and `OpenPGPSecretKey` inherit.

[33] https://openpgp.dev/book/

As stated above, `OpenPGPCertificateComponent`s are bound to the certificate using `OpenPGPSignature`s, which Bouncy Castle arranges into `OpenPGPSignatureChains` internally. This chain structure is evaluated to determine the status of a certificate component at a given time, as well as its applicable properties (algorithm preferences, features, key flags…)

In places, where you cannot switch to using `OpenPGPCertificate`, you can access the underlying `PGPPublicKeyRing` by calling `certificate.getPGPPublicKeyRing()`. Analog, you can access the underlying `PGPSecretKeyRing` of an `OpenPGPKey` via `key.getPGPSecretKeyRing()`.

Key Versions

PGPainless 1.X primarily supported OpenPGP keys of version 4. The 2.X release introduces support for OpenPGP v6 as well, which makes it necessary to specify the desired key version e.g. when generating keys.

This can be done by passing an `OpenPGPKeyVersion` enum.

1.6.4 `KeyIdentifier`

OpenPGP has evolved over time and with it the way to identify individual keys. Old protocol versions rely on 64-bit key-ids, which are nowadays deprecated, as 64-bits are not exactly collision-resistant. For some time already, the use of fingerprints is therefore encouraged as a replacement. However, key-ids were not everywhere at once in the protocol, so many artifacts still contain elements with key-ids in them. An example for this are public-key encrypted session-key packets, which in version 1 still only contain the recipients key-id. In signatures, both key-ids and fingerprints are present.

To solve this inconsistency, Bouncy Castle introduced the `KeyIdentifier` type as an abstraction of both key-ids and fingerprints. Now most methods that take some sort of identifier, be it fingerprint or key-id, now also accept a `KeyIdentifier` object.

Consequently, `KeyIdentifier` is now also the preferred way to reference keys in PGPainless and many places where previously a key-id or fingerprint was expected, now also accept `KeyIdentifier` objects. In places, where you need to access a 64-bit key-id, you can call `keyIdentifier.getKeyId()`.

1.6.5 `SecretKeyRingProtector`

When an OpenPGP v6 key is encrypted, the public key parts are incorporated as authenticated data into the encryption process. Therefore, when instantiating a `PBESecretKeyEncryptor`, the public key needs to be passed in. As a consequence, the API of `SecretKeyRingProtector` changed and now a `PGPPublicKey` needs to be passed in, instead of merely a key-id or `KeyIdentifier`.

1.6.6 Differences between BCs high-level API and PGPainless

With Bouncy Castle now introducing its own high-level API, you might ask, what differences there are between high-level PGPainless classes and their new Bouncy Castle counterparts.

KeyRingInfo vs. OpenPGPCertificate/OpenPGPKey

PGPainless' KeyRingInfo class fulfils a similar task as the new OpenPGPCertificate/OpenPGPKey classes, namely evaluating OpenPGP key material, checking self signatures, exposing certain properties like subkeys, algorithm preferences etc. in a way accessible for the user, all with respect to a given reference time.

However, KeyRingInfo historically gets instantiated *per reference time*, whileOpenPGPCertificate/OpenPGPKey is instantiated only *once* and expects you to pass in the reference time each time you are using a property getter, lazily evaluating applicable signatures as needed. Under the hood, the Bouncy Castle classes now cache expensive signature verification results for later use. Consequently, KeyRingInfo now wraps OpenPGPCertificate/OpenPGPKey, forwarding method calls while passing along the chosen reference time and mapping basic data types to PGPainless' high-level types / enums.

1.6.7 Type Replacements

Old	New	Comment
PGPPublicKeyRing	OpenPGPCertificate	Self-Signatures are automagically evaluated
PGPSecretKeyRing	OpenPGPKey	Same as OpenPGPCertificate, but also contains secret key material
PGPPublicKey (primary key)	OpenPGPPrimaryKey	Primary keys provide getters to access bound user identities
PGPPublicKey (subkey)	OpenPGPComponentKey	-
PGPSecretKey (primary key)	OpenPGPSecretKey	-
PGPSecretKey (subkey)	OpenPGPSecretKey	-
PGPPrivateKey	OpenPGPPrivateKey	-
Long (Key-ID)	KeyIdentifier	-
byte[] (Key Fingerprint)	KeyIdentifier	-
MissingPublicKeyCallb	OpenPGPCertificateProv	-
(detached) PGPSignature	OpenPGPDocumentSignatu	-

1.6.8 Algorithm Support

The use of ElGamal as public key algorithm is now deprecated. Consequently, it is no longer possible to generate ElGamal keys.

RFC9580 introduced new key types Ed25519, Ed448, X25519, X448.