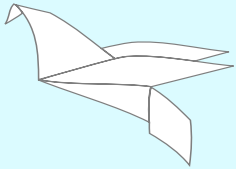
Sequoia git: Making Signed Commits Matter

Neal H. Walfield <neal@sequoia-pgp.org>
8F17777118A33DDA9BA48E62AACB3243630052D9

Security Dev Room, FOSDEM 2026

January 31, 2026



Version Control Systems

- Version Control Systems track:
  - Changes to code
  - Authorship
  - Other meta-data
  - Commit message

```
$ git diff
diff --git a/openpgp/NEWS b/openpgp/NEWS
index 2395a7a59..9cf2dc45b 100644
--- a/openpgp/NEWS
+++ b/openpgp/NEWS
@@ -7,6 +7,17 @@
...
$ git log -1
commit 46b1ccdf72edb4eddcd7e73e33f71cf6fd9901dc (HEAD -> main, origin/main)
Author: Neal H. Walfield <neal@sequoia-pgp.org>
Date:   Thu Sep 11 10:22:53 2025 +0200

    openpgp: Add support for importing v4 Ed448, X25519, and X448 keys.

        - Add `Key4::import_public_ed448`, `Key4::import_public_x25519` and
          `Key4::import_public_x448` to import v4 variants of Ed448, X25519
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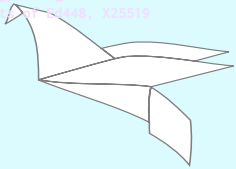

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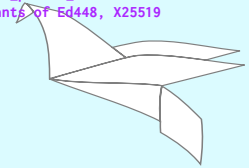


Impersonation

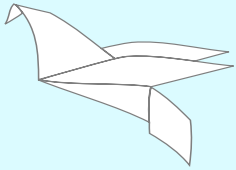
- Author can be faked
  - Meta-data is set by the author
  - Including the author's name

```
$ git config user.email torvalds@linux-foundation.org
$ git config user.name 'Linus Torvalds'

$ emacs openpgp/build.rs
$ git add openpgp/build.rs

$ git commit -m 'Improve build. Definitely does not add a backdoor.'
[main ee8f3108d] Improve build. Definitely does not add a backdoor.
 1 file changed, 1 insertion(+)
$ git log -1
commit ee8f3108d4c36fa332a26477b8de5c3f2e3f17e6 (HEAD -> main)
Author: Linus Torvalds <torvalds@linux-foundation.org>
Date:   Wed Jan 28 13:44:42 2026 +0100

    Improve build. Definitely does not add a backdoor.
```



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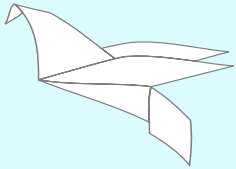
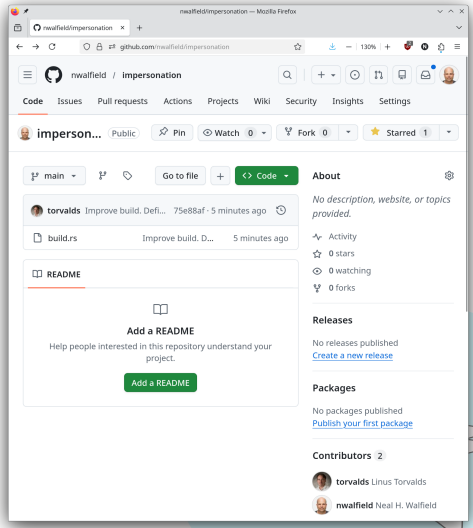


GitHub

- GitHub knows who pushed a commit
  - The person has to be logged in to push
- But the committer and the author are different
  - We don't want to overwrite it
  - We want attribution



https://github.com/nwalfield/impersonation

Why care about Impersonation?

- Scenario #1
  - Project hosted on a forge
  - Forge adds a commit inserting a backdoor
  - How do we catch it?

https://www.flickr.com/photos/31797838@N00/26003405317 by Alexandre Dulaunoy, CC BY-SA 2.0.

Why care about Impersonation?

- Scenario #2
  - Project hosted on forge
  - Account compromised
  - Attacker adds a commit inserting a backdoor
  - How do we prevent it?

https://www.flickr.com/photos/31797838@N00/26003405317 by Alexandre Dulaunoy, CC BY-SA 2.0.

Why care about Impersonation?

- Scenario #3
  - Attacker submits low-quality commits
  - Reputation damaged
  - How do we catch it?

https://www.flickr.com/photos/40702206@N00/367078304 by Pierre Tourigny, CC BY 2.0.

Preventing Impersonations

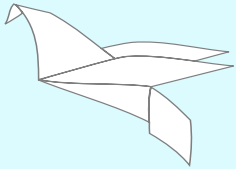
- Digitally sign commits
  - Cryptographic proof!

```
$ git log --show-signature
commit 75e88afb252fe350ea23d8d61502ec7f8bd5f747 (HEAD -> main, origin/main)
Author: Linus Torvalds <torvalds@linux-foundation.org>
Date:   Wed Jan 28 14:07:38 2026 +0100

    Improve build.  Definitely not a backdoor.

commit c296a9b13a66eb6acc7ca99d0c112faeac8ec1df
gpg: Signature made Wed Jan 28 14:06:14 2026 +01:00
gpg:                using EDDSA key 7FAF6ED7238143557BDF7ED26863C9AD5B4D22D3
gpg: Good signature from "Neal H. Walfield (Code Signing Key) <neal@pep.foundation>" [ultimate]
gpg:                    "Neal H. Walfield (Code Signing Key) <neal@sequoia-pgp.org>"
Author: Neal H. Walfield <neal@walfield.org>
Date:   Wed Jan 28 14:06:14 2026 +0100

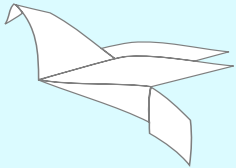
    Lots of impressive code.
```



But...

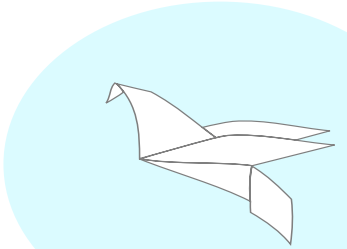
- Nothing stops anyone from making a certificate with a given user ID

```
$ sq key generate --userid 'Linus Torvalds <torvalds@linux-foundation.org>' --own-key
Enter a password to protect the new certificate (press enter to not use a password):
                                                                    Repeat the password:
 -  B43099ECCDD9A6E62C7E75510B4ABC607AC2A515
    Linus Torvalds <torvalds@linux-foundation.org>
   - certification created
...
```



Need Authentication

- Is `B43099ECCDD9A6E62C7E75510B4ABC607AC2A515` really Linus' certificate?
- (No, I just generated it.)



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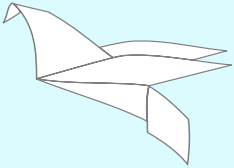

Authenticating Certificates

- Talk to the developer
- Key signing party
- Central authority
  - Verifying key server: `https://keys.openpgp.org`
  - Linux kernel developer keyring
  - `distribution-gpg-keys`
  - `https://github.com/user.gpg`
- Linus' certificate is:
  ABAF11C65A2970B130ABE3C479BE3E4300411886

Marta Marczykowska-Górecka from Qubes OS at FOSS Backstage Design, 2025.

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Authenticating a Project

- Check that commits are signed

```
$ git log --show-signature
commit 859b3ce7248806e331bd1caa8d07cdc7ecb7f3d6 (HEAD -> main)
gpg: Signature made Wed Jan 28 17:27:14 2026 +01:00
gpg:                using EDDSA key D09FF325B8EFCD5B4C59BAB92910E29B0D031323
gpg: Good signature from "Linus Torvalds <torvalds@linux-foundation.org>" [unknown]
gpg: WARNING: This key is not certified with a trusted signature!
gpg:          There is no indication that the signature belongs to the owner.
Primary key fingerprint: ACBB D3A8 19D1 2CCD C50E  C25F F5FE 8250 A9BF F91F
     Subkey fingerprint: D09F F325 B8EF CD5B 4C59  BAB9 2910 E29B 0D03 1323
Author: Linus Torvalds <torvalds@linux-foundation.org>
Date:   Wed Jan 28 14:07:38 2026 +0100

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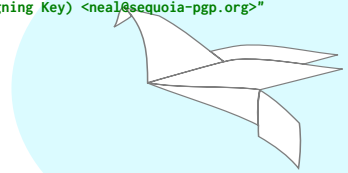

Authenticating a Project

- Check that commits are signed *by the expected certificates*

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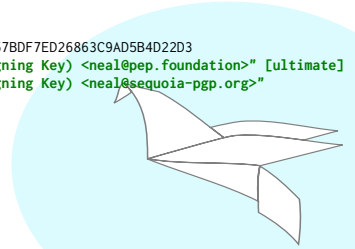
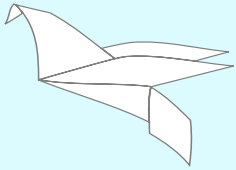


How to Authenticate a Project

- Curate a list of contributors and their certificates
- Track when contributors join and leave project
  - Authenticate old commits of retired contributors
  - Reject new commits of retired contributors
- Complicated much?
  - Maintainer: Need tooling
  - Third-party: Infeasible, but can rely on maintainer

- Alice joins project
- Alice adds a commit
- Alice leaves project
- Alice adds a commit
- Now



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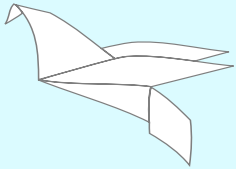

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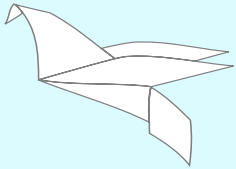
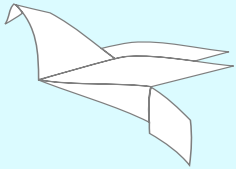


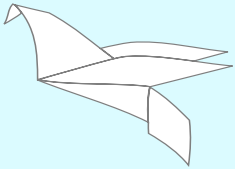
Why Authenticate a Project?

- Detect unauthorized commits
  - Malicious forge
  - Compromised forge or account
  - Machine in the middle
- Detect when forge or registry gives a project to a new maintainer



Shape of Solution

- Clear semantics for signing commits
- Project maintains a signing policy
  - Policy evolves with time
- Third-party uses maintainers' policy to authenticate project
  - Delegates responsibility for signing policy to maintainers
  - Audits project and policy
- Limitations
  - Can't detect social engineering attack



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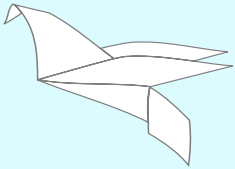
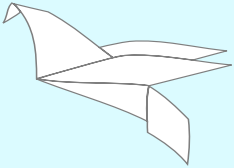


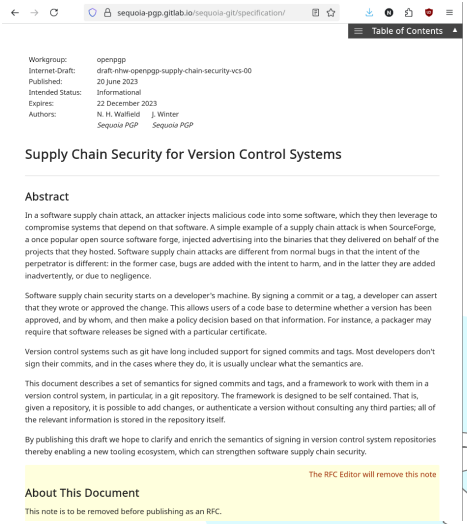
Goals

- Do not rely on an authority
  - Verification, not attestation
- Work off line



Sequoia git

- Specification
- Configuration
- Tooling



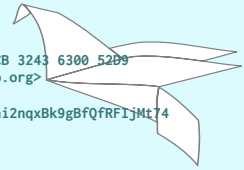
https://sequoia-pgp.gitlab.io/sequoia-git/specification/

Signing policy

- Stored in project's `git` repository
  - Evolves with project
  - Off-line verification
- Users ■
  - Capabilities ■
    - Add a commit
    - Add a tag
    - Create a release
    - Add / remove a user
    - Audit commits
  - OpenPGP certificates ■
- Good list ■
  - Good commits from hard revoked certificates

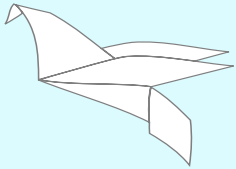
openpgp-policy.toml

```
version = 0
commit_goodlist = []

[authorization.neal]
sign_commit = true
keyring = """
-----BEGIN PGP PUBLIC KEY BLOCK-----
Comment: F717 3B3C 7C68 5CD9 ECC4  191B 74E4 45BA 0E15 C957
Comment: Neal H. Walfield (Code Signing Key) <neal@sequoia-pgp.o

xjMEWhaZ2xYJKwYBBAHaRw8BAQdAinglS6SRXyMb51hMk+mpM4y0Uh0vcGcTyXa+
...

[authorization.neal-offline]
sign_commit = true
sign_tag = true
sign_archive = true
add_user = true
retire_user = true
audit = true
keyring = """
-----BEGIN PGP PUBLIC KEY BLOCK-----
Comment: 8F17 7771 18A3 3DDA 9BA4  8E62 AACB 3243 6300 52D9
Comment: Neal H. Walfield <neal@sequoia-pgp.org>

xsEhBFUjmukBDqCpmVI7Ve+2xTFSTG+mXMFHml63/Yai2nqxBk9gBfQfRFIjMt74
...
```



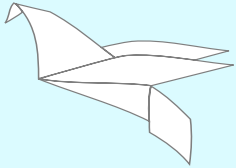
Authorizing a Committer

```
$ sq-git policy authorize alice --committer C1A5D7F4CB832012208AA598C4AA55549C5AB20F
  - User alice was added.
  - User alice was granted the right sign-commit.
  - User alice: new certificate C1A5D7F4CB832012208AA598C4AA55549C5AB20F.
```



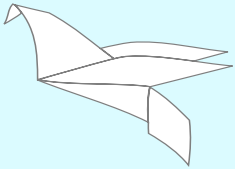
Updating Certificates

```
$ sq-git policy sync
Updating F7173B3C7C685CD9ECC4191B74E445BA0E15C957 (neal) from the local certificate store... not found.
Updating F7173B3C7C685CD9ECC4191B74E445BA0E15C957 (neal) from hkps://keys.openpgp.org... unchanged.
Updating F7173B3C7C685CD9ECC4191B74E445BA0E15C957 (neal) from hkps://mail-api.proton.me... Cert not found.
Updating F7173B3C7C685CD9ECC4191B74E445BA0E15C957 (neal) from hkps://keys.mailvelope.com... Cert not found.
Updating F7173B3C7C685CD9ECC4191B74E445BA0E15C957 (neal) from hkps://keyserver.ubuntu.com... updated.
Updating F7173B3C7C685CD9ECC4191B74E445BA0E15C957 (neal) from hkps://sks.pod01.fleetstreetops.com... updated.
...
Note: certificates are stripped so not all certificate updates may be relevant.
```



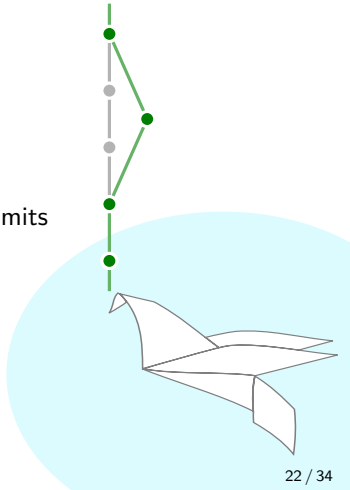
Examining the Policy

```
$ sq-git policy describe
# OpenPGP policy file for git, version 0

## Commit Goodlist


## Authorizations

0. alice
   - may sign commits
   - has OpenPGP cert: C1A5D7F4CB832012208AA598C4AA55549C5AB20F
1. neal
   - may sign commits
   - has OpenPGP cert: F7173B3C7C685CD9ECC4191B74E445BA0E15C957
2. neal-offline
   - may sign commits
   - may sign tags
   - may sign archives
   - may add users
   - may retire users
   - may goodlist commits
   - has OpenPGP cert: 8F17777118A33DDA9BA48E62AACB3243630052D9
```



Authenticating Commits

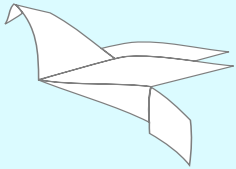
- A commit is authenticated if:
  - The policy of at least one parent says the commit is acceptable
  - (Policy determines types of changes that are allowed.)
- A range of commits is authenticated if:
  - There is a path from one commit to another along which all commits are authenticated



Authenticating Commits: Example

```
$ git log --graph
* commit 34f03107faac28ea8b6018579af829b54afe6517 (HEAD -> master)
| Author: Alice <alice@example.org>
| Date:   Fri Jan 30 15:53:31 2026 +0100
|
|     Add feature.
|
* commit a7a40e007990e84ce1794a5b4e62bb38b81e443d
| Author: Neal H. Walfield <neal@sequoia-pgp.org>
| Date:   Fri Jan 30 15:46:48 2026 +0100
|
|     Make alice a commiter
|
* commit 61cd610f0c53cbd73e1733c10edaa081ab356c96
| Author: Neal H. Walfield <neal@sequoia-pgp.org>
| Date:   Fri Jan 30 15:46:15 2026 +0100
|
|     Make neal (coding signing cert) a commiter
|
* commit aab50d699240a3d022fc11464ac458b5fbb7bb22
  Author: Neal H. Walfield <neal@sequoia-pgp.org>
  Date:   Fri Jan 30 15:47:35 2026 +0100

      Make neal a project maintainer
```

```
$ sq-git log --trust-root aab50d699240a3d022fc11464ac458b5fbb7bb22
a7a40e007990e84ce1794a5b4e62bb38b81e443d..34f03107faac28ea8b6018579af829b54afe6517:
  Signer: alice [C1A5D7F4CB832012208AA598C4AA55549C5AB20F]
  Add feature.
61cd610f0c53cbd73e1733c10edaa081ab356c96..a7a40e007990e84ce1794a5b4e62bb38b81e443d:
  Signer: neal-offline [8F17777118A33DDA9BA48E62AACB3243630052D9]
  Make alice a commiter
aab50d699240a3d022fc11464ac458b5fbb7bb22..61cd610f0c53cbd73e1733c10edaa081ab356c96:
  Signer: neal-offline [8F17777118A33DDA9BA48E62AACB3243630052D9]
  Make neal (coding signing cert) a commiter
Verified that there is an authenticated path from the trust root
aab50d699240a3d022fc11464ac458b5fbb7bb22 to 34f03107faac28ea8b6018579af829b54afe6517.
$ echo $?
0
```

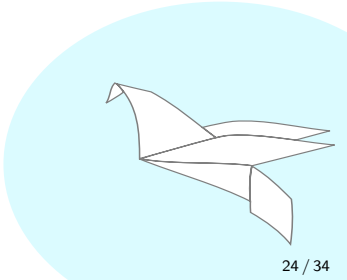


Not Authenticating a Commit

```
$ git log --show-signature -n 2
commit d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb (HEAD -> master)
gpg: Signature made Fri Jan 30 16:27:28 2026 +01:00
gpg:                using EDDSA key 1F660C60C700B41CA8AE351FD44ECFCFB9093212
gpg: Good signature from "Bob" [full]
gpg:                     "<bob@example.org>"
Author: Bob <bob@example.org>
Date:   Fri Jan 30 16:27:28 2026 +0100

    Improve build system.

commit 34f03107faac28ea8b6018579af829b54afe6517
gpg: Signature made Fri Jan 30 15:53:31 2026 +01:00
gpg:                using EDDSA key 1742E6737DAE88C2227FD1B05A78679CBCA65B79
gpg: Good signature from "Alice" [full]
gpg:                     "<alice@example.org>"
Author: Alice <alice@example.org>
Date:   Fri Jan 30 15:53:31 2026 +0100

    Add feature.
```

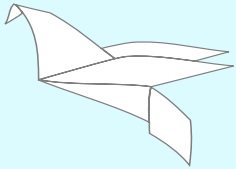
- Bob adds a commit
- Bob is not authorized

```
$ sq-git log --trust-root 34f03107faac28ea8b6018579af829b54afe6517
34f03107faac28ea8b6018579af829b54afe6517..
  d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb:
  Error: Key `1F660C60C700B41CA8AE351FD44ECFCFB9093212` missing
  Improve build system.
Error: Could not verify commits 34f03107faac28ea8b6018579af829b54afe6517..
  d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb

Caused by:
    0: While verifying commit d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb
    1: Key `1F660C60C700B41CA8AE351FD44ECFCFB9093212` missing
$ echo $?
1
```



Merging Bob's Commit

- Strategies
  - Committer re-signs Bob's commit
    - Preserves linear history
  - Committer merges Bob's commit
    - Preserves Bob's signature
    - Allowed by single path rule

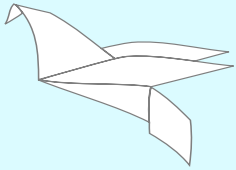


Merging Bob's Commit

```
$ git merge 34f03107faac28ea8b6018579af829b54afe6517 d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb --no-ff
```

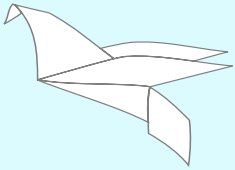
```
$ git log --graph 34f03107faac28ea8b6018579af829b54afe6517^..
*   commit 2fcccb9948ad094c56c551c4d8550d4ced6f6751 (HEAD -> master)
|\  Merge: 34f0310 d709fcc
| | Author: Alice <alice@example.org>
| | Date:   Fri Jan 30 16:52:46 2026 +0100
| |
| |     Merge Bob's work.
| |
| * commit d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb
|/  Author: Bob <bob@example.org>
|   Date:   Fri Jan 30 16:27:28 2026 +0100
|
|       Improve build system.
|
* commit 34f03107faac28ea8b6018579af829b54afe6517
  Author: Alice <alice@example.org>
  Date:   Fri Jan 30 15:53:31 2026 +0100

      Add feature.
```

```
$ sq-git log --trust-root a7a40e007990e84ce1794a5b4e62bb38b81e443d
34f03107faac28ea8b6018579af829b54afe6517..2fcccb9948ad094c56c551c4d8550d4ce
  Signer: alice [C1A5D7F4CB832012208AA598C4AA55549C5AB20F]
  Merge Bob's work.
d709fccaaeb4c45b33080c07ceb1eb68eaca2aeb..2fcccb9948ad094c56c551c4d8550d4ce
  Cached positive verification
34f03107faac28ea8b6018579af829b54afe6517..d709fccaaeb4c45b33080c07ceb1eb68e
  Error: Key `1F660C60C700B41CA8AE351FD44ECFCFB9093212` missing
  Improve build system.
a7a40e007990e84ce1794a5b4e62bb38b81e443d..34f03107faac28ea8b6018579af829b54
  Signer: alice [C1A5D7F4CB832012208AA598C4AA55549C5AB20F]
  Add feature.
Verified that there is an authenticated path from the trust root
a7a40e007990e84ce1794a5b4e62bb38b81e443d to 2fcccb9948ad094c56c551c4d8550d4
```



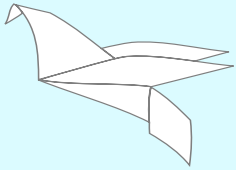
More Details

- Updating own expired certificate: yes
- Recover from a hard revoked key: yes, commit good listing
- Verifying tags and tarballs: yes, but incomplete
- See man pages and documentation



Forking a Project

- New maintainer not added to the signing policy?
  - `sq-git` will not consider the first commit authenticated
- These are the semantics we want!
- To use a fork, users must opt in by setting a new trust root



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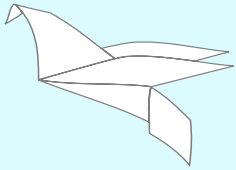
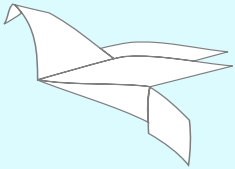


Integrating sq-git into Your Git Repository

- Insert the following line into hooks/update

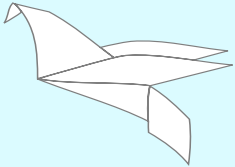
```
sq-git update-hook --trust-root=<COMMIT> "$@"
```



Integrating sq-git on GitLab

- Add to your `.gitlab-ci.yml`:

```
authenticate-commits:
  stage: test
  image: registry.gitlab.com/sequoia-pgp/sequoia-git:latest
  before_script: []
  script:
    - sq-git policy describe
    - /usr/sbin/gitlab.sh # Script baked-in to image
  after_script: []
  rules:
    - if: '$CI_COMMIT_BRANCH != $CI_DEFAULT_BRANCH'
```

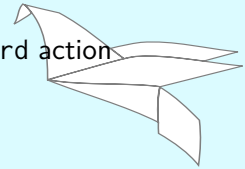


Integrating sq-git on GitHub

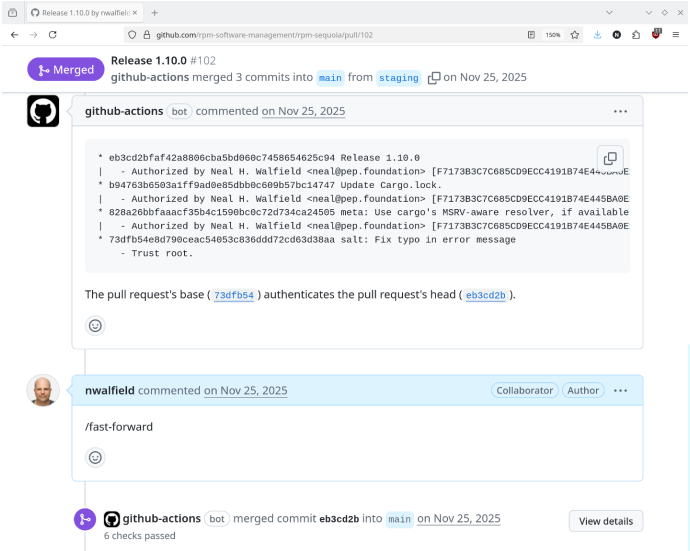
- Add `.github/workflows/authenticate-commits.yml`:

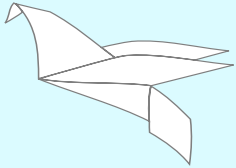
```
name: authenticate-commits
on:
  pull_request:
    types: [opened, reopened, synchronize]
jobs:
  authenticate-commits:
    runs-on: ubuntu-latest

    permissions:
      contents: read
      pull-requests: write
      issues: write

    steps:
      - name: Authenticating commits
        uses: sequoia-pgp/authenticate-commits@v1
```

- GitHub destroys signatures on fast-forward, so need to use `fast-forward` action



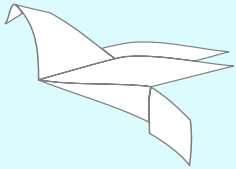
authenticate-commits on GitHub





Related Work

- *Building a Secure Software Supply Chain with GNU Guix* by Ludovic Courtès
- *Arista: Commit Signing with Git at Enterprise Scale*
- List of commit signing solutions
  - `https://gitlab.torproject.org/tpo/tpa/team/-/wikis/service/gitlab#git-repository-integrity-solutions`



Summary

- Signing commits is useful
  - Protects against impersonation
  - Detects unauthorized commits
  - No need to trust forge
- `sq-git` helps
  - Clear semantics
  - Tooling for managing signing policies
  - Tooling for checking commits against a policy

Questions?