TRAIL OF BITS

Trusted Publishing: Lessons from PyPI

William Woodruff

Hello!

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  - long-term OSS contributor (Homebrew, LLVM, Python) and maintainer (pip-audit, sigstore-python)
  - @yossarian@infosec.exchange
- **Trail of Bits**
  - ~150 person cybersecurity engineering and auditing consultancy
  - specialities: cryptography, compilers, program analysis research, “supply chain”, OSS package management, general high assurance software development

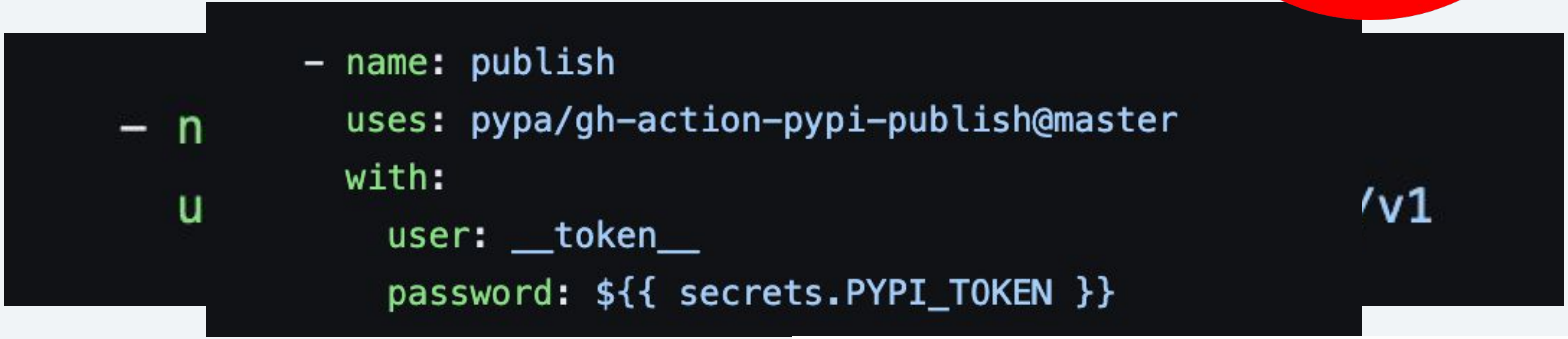
Some thank-yous

- **This work wouldn't have happened without Dustin Ingram and the GOSST team's vision for improving PyPI's security!**
- **The other maintainers of PyPI (Donald, Ee, Mike) all reviewed this work or otherwise made it possible**
- **Other members of PyPA for being early testers and ensuring a smooth rollout**
    - Special thanks to Sviatoslav Sydorenko
- **PyCA maintainers (Paul and Alex) for being guinea pigs and providing early feedback on usability**

Magic

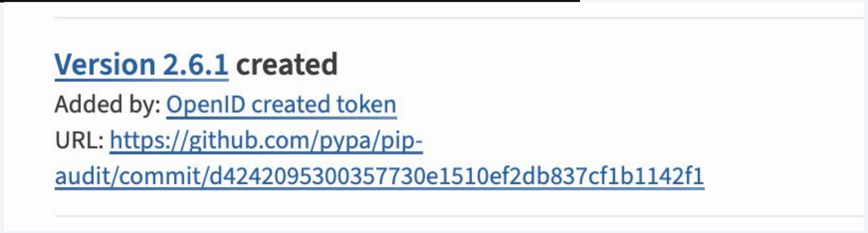
What's wrong with this picture?

What's ~~wrong~~ right with this picture?



```
- n
  u                                                    /v1
```

```
- name: publish
  uses: pypa/gh-action-pypi-publish@master
  with:
    user: __token__
    password: ${{ secrets.PYPI_TOKEN }}
```



Version 2.6.1 created
Added by: OpenID created token
URL: https://github.com/pypa/pip-audit/commit/d4242095300357730e1510ef2db837cf1b1142f1

PyPI

- **Pronounced 🥧-□-👁**
- **The primary package index for the Python ecosystem**
  - ~500K projects, ~5M releases, ~9M files, ~750K users (i.e. packagers)
  - ~20 **billion** downloads per month (August 2023)
- **Rewritten in ~2017, security features added since**
  - 2018/19: API tokens, TOTP and WebAuthn, security event logging for users and projects
  - 2019/20: Malware scanning
  - 2020/21: Vulnerability feeds, GitHub secret scanning integration
  - 2022/23: Trusted publishing (you are here!)

Uploading to PyPI: then and ~now

- **< 2019: username/password authentication for uploads**
  - 👎 *No credential separation*: same user/pass could **modify all projects** under the same user!
    - As well as log into PyPI and do normal account admin things
  - 👎 *No straightforward revocation:* compromise means full account recovery needed!
  - 👎 *No security events:* attacker who steals creds can remain (relatively) stealthy!
- **>= 2019: Macaroon-based API tokens**
  - 👍 Configurable scopes (per-user, per-project)
    - Per-user means "all projects," not "can modify the user's profile"!
  - 👍 Integrated into security events + GitHub secret scanning
  - 👎 Still need to be manually configured + revoked on compromise
  - 👎 Too easy to over-scope (developer confusion, fatigue)
  - 👎 Chicken-and-egg problems with new projects (can't scope a token for a nonexistent project)

API tokens are a major improvement; let's do even better!

Doing better than API tokens

API tokens are still somewhat manual; doing better means *automation*.

What we want:

- **No more manual token transfers; CI/CD should receive credentials *automatically***
- **Maximum scoping: credentials should be scoped down to the smallest unit of work they're intended to perform, and should *automatically* expire once that work is done**
- **Misuse resistance: users *can't* leak credentials that don't exist!**

Trusted Publishing

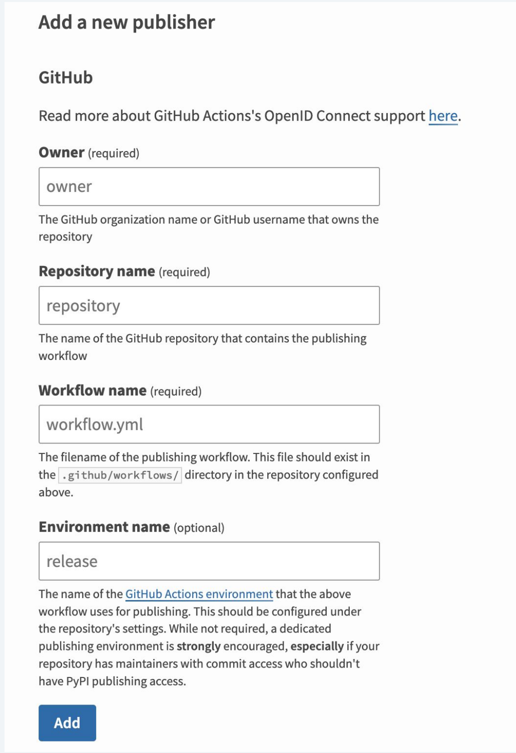
✨OpenID Connect✨

- **CI/CD providers like GitHub support *machine identities* through OIDC**
  - These credentials are strongly bound to the repository + workflow that made them
  - Can be verified by any third-party service using OIDC Discovery!
- **OIDC credentials are short-lived + scoped to an intended audience**
  - Fewer compromise opportunities + no domain contamination!
  - Service B won't accept credentials made for Service A
- **Already widely applied to other services (GH ⟵⟶ AWS, GCP, etc.)**
  - Why not PyPI too?

OpenID Connect for PyPI publishing

The rough idea:

- **Ahead of time: Users configure a *trust relationship* between a specific OIDC provider (e.g. GitHub) and their PyPI project**
  - The trust relationship itself isn't secret, so no potential leaks here!
  - For GitHub: user/repo slug, workflow name (e.g. `release.yml`), optional environment name
  - We call this relationship the "trusted publisher"
- **During publishing: OIDC provider creates an OIDC credential**
  - PyPI accepts that credential, verifies it, and *exchanges* it for a short-lived PyPI API token scoped for the project
  - Package publishing (e.g. through `twine`) continues as normal, none the wiser!



Add a new publisher

GitHub

Read more about GitHub Actions's OpenID Connect support here.

Owner (required)

owner

The GitHub organization name or GitHub username that owns the repository

Repository name (required)

repository

The name of the GitHub repository that contains the publishing workflow

Workflow name (required)

workflow.yml

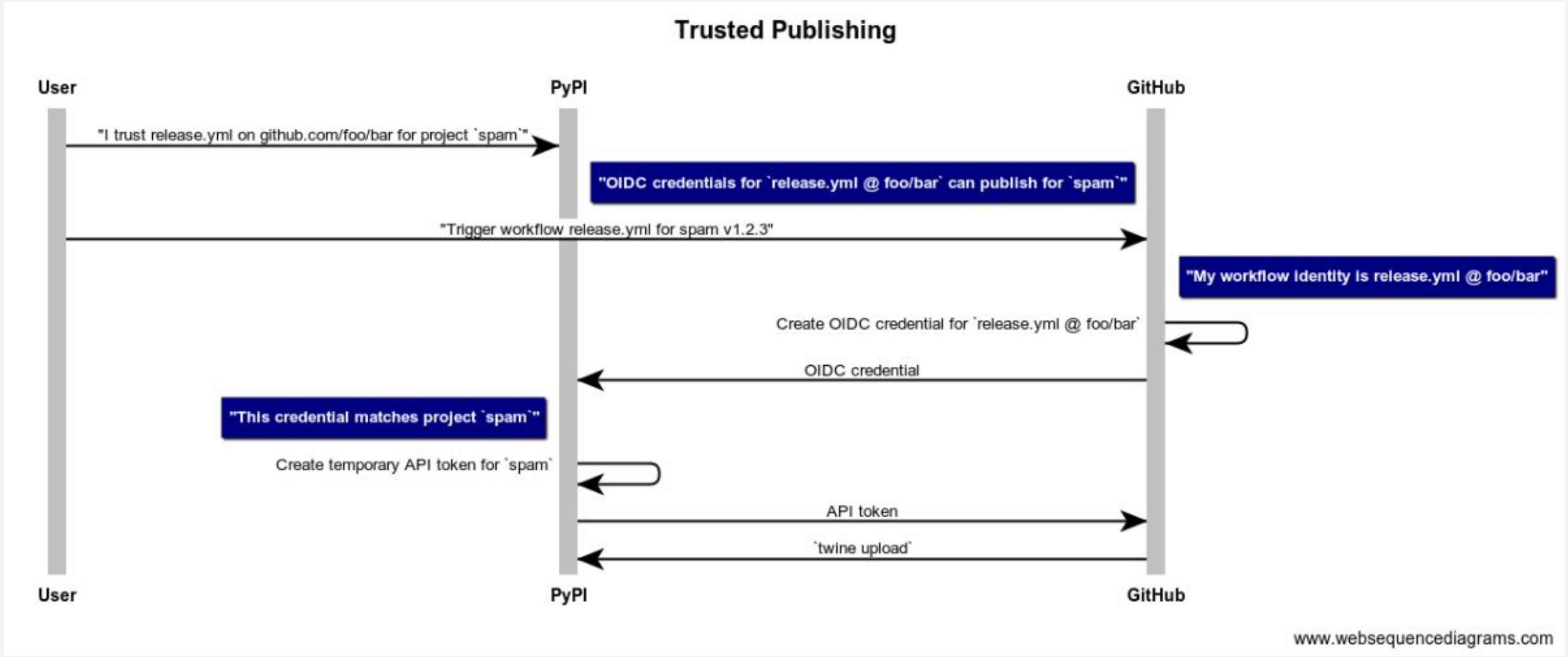
The filename of the publishing workflow. This file should exist in the `.github/workflows/` directory in the repository configured above.

Environment name (optional)

release

The name of the GitHub Actions environment that the above workflow uses for publishing. This should be configured under the repository's settings. While not required, a dedicated publishing environment is **strongly** encouraged, **especially** if your repository has maintainers with commit access who shouldn't have PyPI publishing access.

Trusted publishing: the bird’s-eye view

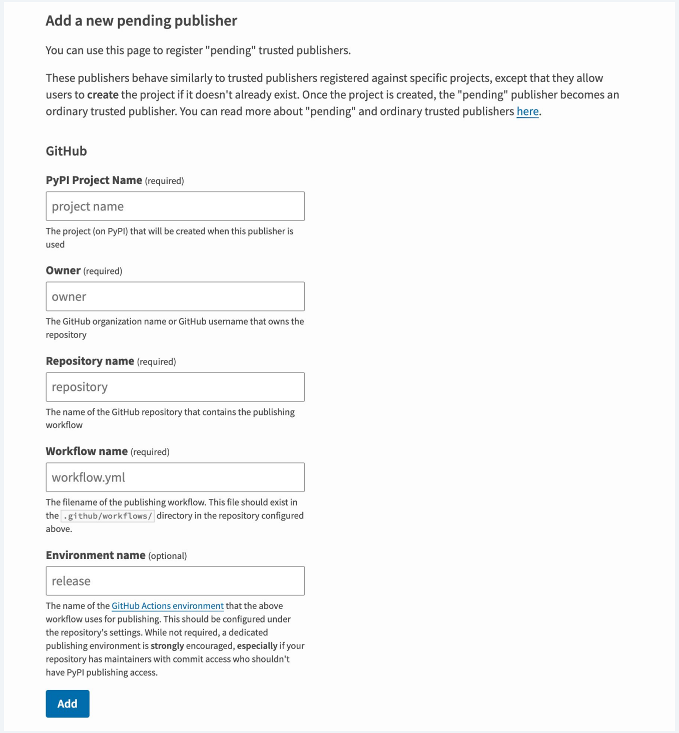

Trusted Publishing
User
PyPI
GitHub
"I trust release.yml on github.com/foo/bar for project `spam`"
"OIDC credentials for `release.yml @ foo/bar` can publish for `spam`"
"Trigger workflow release.yml for spam v1.2.3"
"My workflow identity is release.yml @ foo/bar"
Create OIDC credential for `release.yml @ foo/bar`
OIDC credential
"This credential matches project `spam`"
Create temporary API token for `spam`
API token
`twine upload`
User
PyPI
GitHub
www.websequencediagrams.com

What about nonexistent projects?

This first approach doesn't solve the "chicken-and-egg" problem with API tokens: the project still needs to exist to register a trusted publisher to it!

We solve this with "pending publishers": registered similarly to a trusted publisher, but associated with a user instead.

- **Contains the name of the project that will be created**
- **On first use, the project is created (in an empty state) and the "pending" publisher is *reified* into a full "trusted publisher"**



Add a new pending publisher

You can use this page to register "pending" trusted publishers.

These publishers behave similarly to trusted publishers registered against specific projects, except that they allow users to **create** the project if it doesn't already exist. Once the project is created, the "pending" publisher becomes an ordinary trusted publisher. You can read more about "pending" and ordinary trusted publishers here.

GitHub

PyPI Project Name (required)

project name

The project (on PyPI) that will be created when this publisher is used

Owner (required)

owner

The GitHub organization name or GitHub username that owns the repository

Repository name (required)

repository

The name of the GitHub repository that contains the publishing workflow

Workflow name (required)

workflow.yml

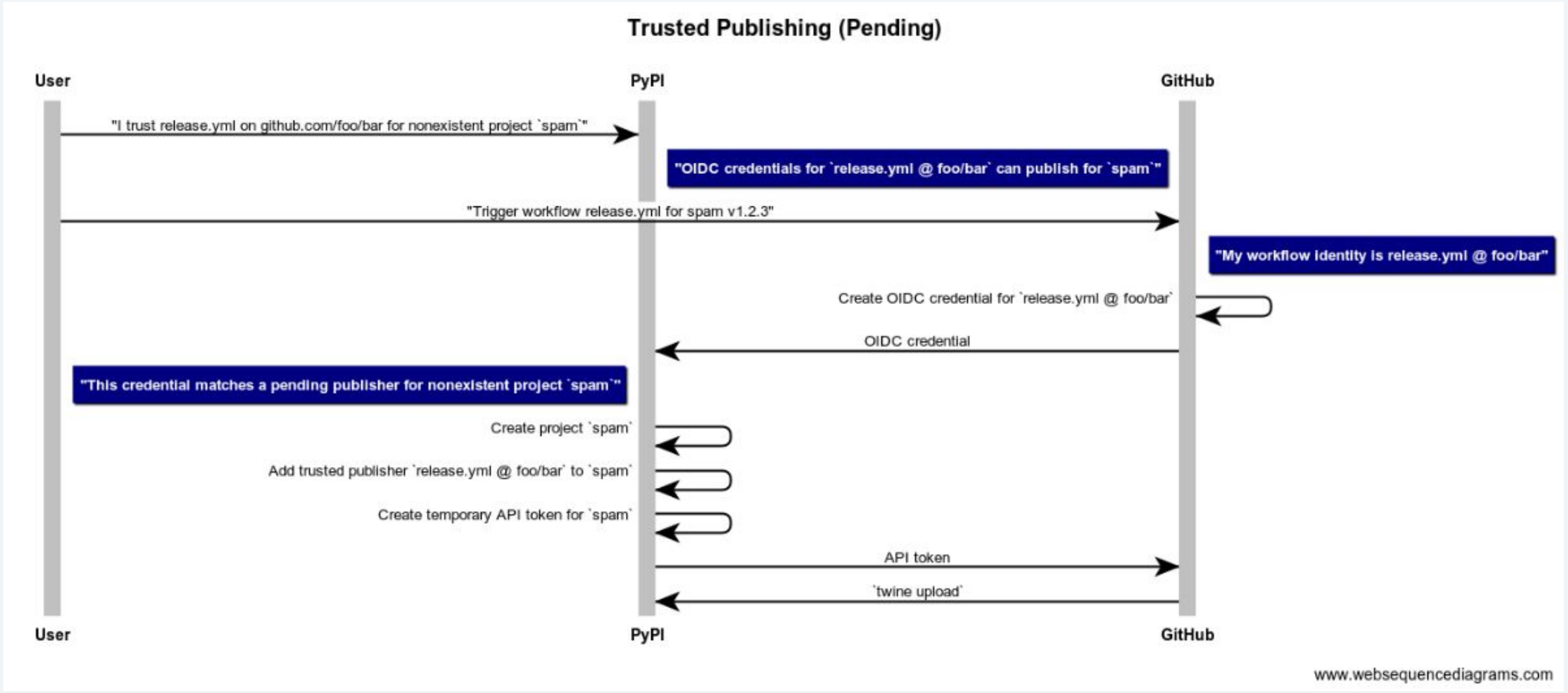
The filename of the publishing workflow. This file should exist in the `.github/workflows/` directory in the repository configured above.

Environment name (optional)

release

The name of the GitHub Actions environment that the above workflow uses for publishing. This should be configured under the repository's settings. While not required, a dedicated publishing environment is **strongly** encouraged, **especially** if your repository has maintainers with commit access who shouldn't have PyPI publishing access.

Pending publishers: the bird's-eye view


Trusted Publishing (Pending)
User
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GitHub
"I trust release.yml on github.com/foo/bar for nonexistent project `spam`"
"OIDC credentials for `release.yml @ foo/bar` can publish for `spam`"
"Trigger workflow release.yml for spam v1.2.3"
"My workflow identity is release.yml @ foo/bar"
Create OIDC credential for `release.yml @ foo/bar`
OIDC credential
"This credential matches a pending publisher for nonexistent project `spam`"
Create project `spam`
Add trusted publisher `release.yml @ foo/bar` to `spam`
Create temporary API token for `spam`
API token
`twine upload`
User
PyPI
GitHub
www.websequencediagrams.com

It works!

With this scheme, we achieve all of our security goals:

- ✅ All credentials are temporary and self-expiring
- ✅ All credentials are minimally scoped (no user scopes)
- ✅ Users only perform configuration once (initial trusted setup)
- ✅ All configuration is over public information (no private metadata)
- ✅ No more chicken-and-egg ("pending" publishers transition seamlessly to full publishers once used)

We also solve supply chain problems in the process:

- ✅ Flattening of state: the source repository itself becomes the "ground truth"
- ✅ Maintenance transitions: projects can transition maintainers without playing "who owns the credential"

nitty-gritty time

lessons for other possible implementations

Lesson #1: the data model is unintuitive

“One trusted publisher per package, how hard could it be?”

Realities:

- **Multiple logical projects live under the same logical publisher**
  - Example: GitHub monorepo with multiple PyPI projects
- **Multiple logical publishers are responsible for a single project**
  - Example: Single PyPI project with multiple arch-specific publishing workflows
    - Users ideally wouldn’t do this, but we want to encourage adoption!

Conclusion: trusted publishing is actually many-many; this may have surprising complexity implications for the ecosystem you’re adding it to!

```python
class OIDCPublisherProjectAssociation(db.Model):
    __tablename__ = "oidc_publisher_project_association"

    oidc_publisher_id = Column(
        UUID(as_uuid=True),
        ForeignKey("oidc_publishers.id"),
        nullable=False,
        primary_key=True,
    )
    project_id = Column(
        UUID(as_uuid=True), ForeignKey("projects.id"), nullable=False, primary_key=True
    )
```

Lesson #2: OIDC is *very* narrowly standardized

“They’re just JWTs under the hood, how different could they be?”

Realities:

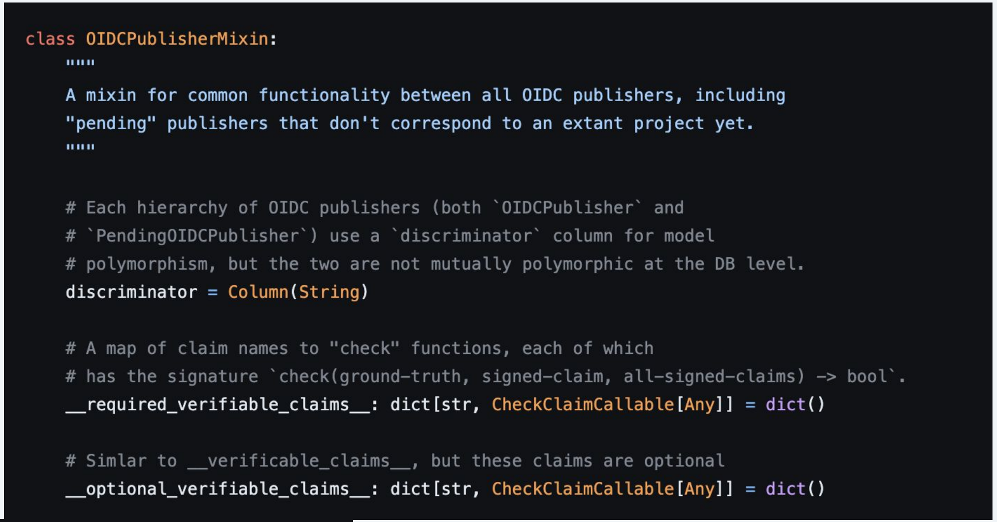
Individual providers have wide latitude in claim availability/format

- **Only basic things can be assumed to be universal: `iss`, `exp`, `aud`, etc.**
- **Each new provider needs to be carefully inspected to determine *which parts* of the OIDC credential constitute sufficient trusted metadata**
    - This requires in-depth knowledge of the provider’s internals/behavior, e.g. which users are entitled to run GitHub workflows within a particular repository!

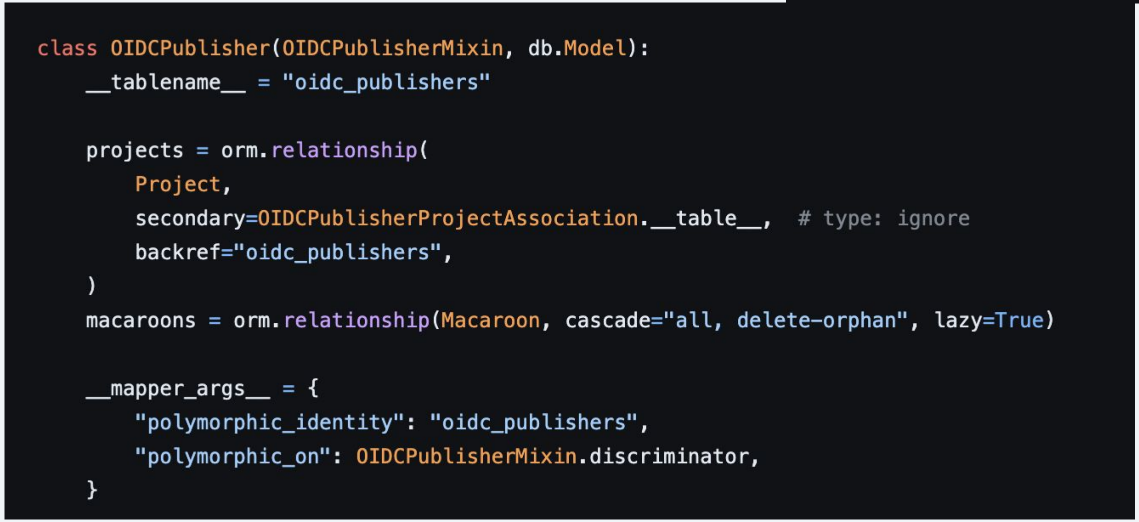
Conclusions:

- **Adding new trusted publisher providers (GitLab, etc.) is time intensive; ecosystems should prioritize the providers they see used the most (GitHub for PyPI)**
- **Supporting multiple providers = more data model complexity!**

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NO
as described in **RFC 2119** [RFC2119].



```python
class OIDCPublisherMixin:
    """
    A mixin for common functionality between all OIDC publishers, including
    "pending" publishers that don't correspond to an extant project yet.
    """

    # Each hierarchy of OIDC publishers (both `OIDCPublisher` and
    # `PendingOIDCPublisher`) use a `discriminator` column for model
    # polymorphism, but the two are not mutually polymorphic at the DB level.
    discriminator = Column(String)

    # A map of claim names to "check" functions, each of which
    # has the signature `check(ground-truth, signed-claim, all-signed-claims) -> bool`.
    __required_verifiable_claims__: dict[str, CheckClaimCallable[Any]] = dict()

    # Simlar to __verificable_claims__, but these claims are optional
    __optional_verifiable_claims__: dict[str, CheckClaimCallable[Any]] = dict()
```



```python
class OIDCPublisher(OIDCPublisherMixin, db.Model):
    __tablename__ = "oidc_publishers"

    projects = orm.relationship(
        Project,
        secondary=OIDCPublisherProjectAssociation.__table__,  # type: ignore
        backref="oidc_publishers",
    )
    macaroons = orm.relationship(Macaroon, cascade="all, delete-orphan", lazy=True)

    __mapper_args__ = {
        "polymorphic_identity": "oidc_publishers",
        "polymorphic_on": OIDCPublisherMixin.discriminator,
    }
```

Lesson #2.5: OIDC varies wildly *within* IdPs

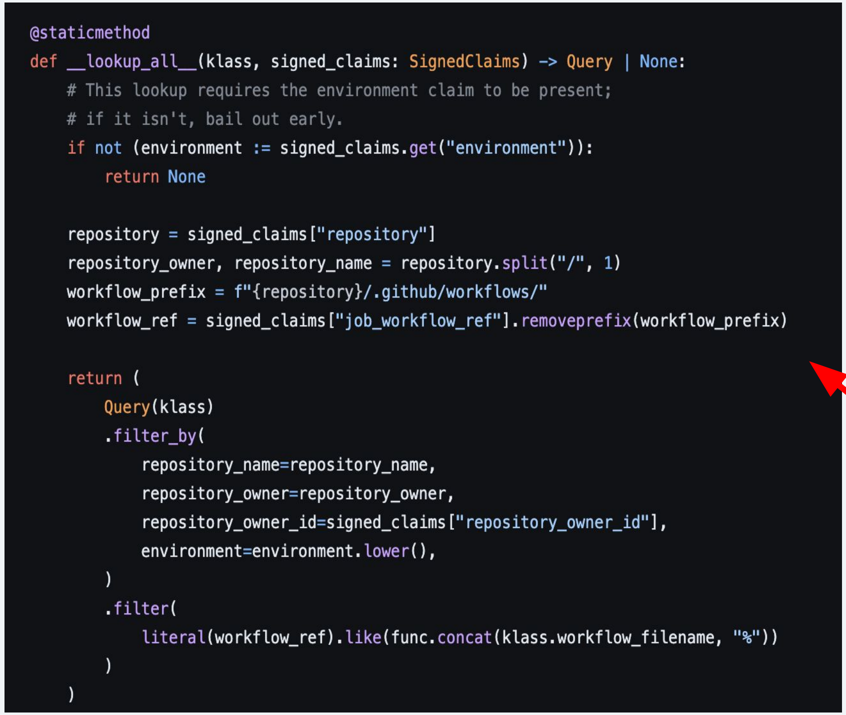
“Every trusted publisher through e.g. GitHub should look basically the same”

Realities:

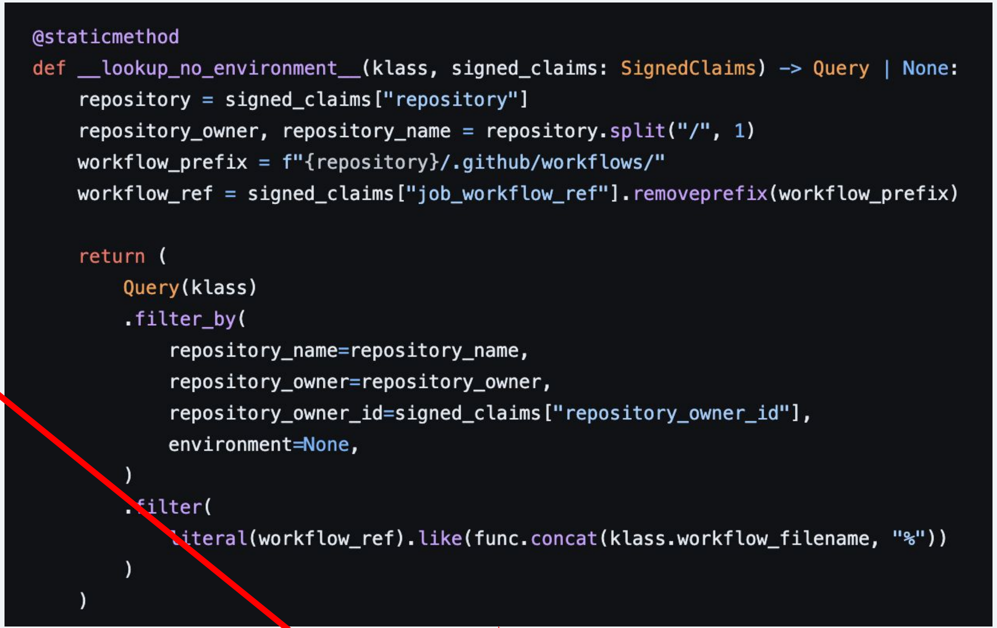
- **OIDC identities vary wildly even within a provider: GitHub has special claims for reusable workflows, claims for different CI event types, etc.**
    - Providers like to change their claims without telling anyone!
- **Differences between these claims can’t be paved over without (1) excluding some users or (2) ignoring some claims that might be important!**

Conclusion:

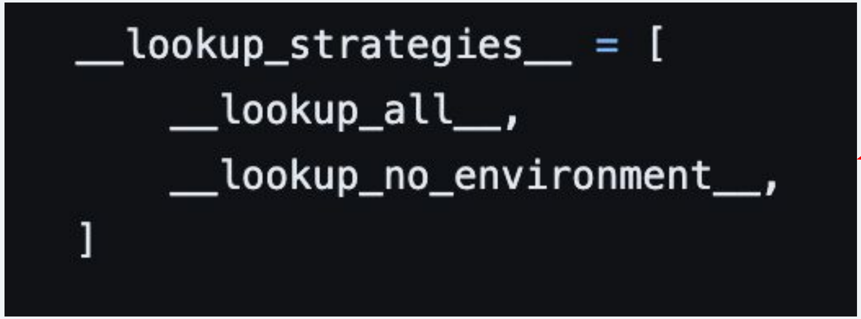
- **Supporting every possible configuration of a trusted publisher is hard + trying to do so opens up a lot of potential logic errors!**



```python
@staticmethod
def __lookup_all__(klass, signed_claims: SignedClaims) -> Query | None:
    # This lookup requires the environment claim to be present;
    # if it isn't, bail out early.
    if not (environment := signed_claims.get("environment")):
        return None

    repository = signed_claims["repository"]
    repository_owner, repository_name = repository.split("/", 1)
    workflow_prefix = f"{repository}/.github/workflows/"
    workflow_ref = signed_claims["job_workflow_ref"].removeprefix(workflow_prefix)

    return (
        Query(klass)
        .filter_by(
            repository_name=repository_name,
            repository_owner=repository_owner,
            repository_owner_id=signed_claims["repository_owner_id"],
            environment=environment.lower(),
        )
        .filter(
            literal(workflow_ref).like(func.concat(klass.workflow_filename, "%"))
        )
    )
```



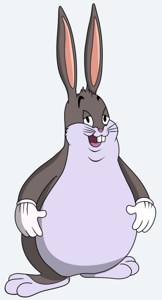
```python
@staticmethod
def __lookup_no_environment__(klass, signed_claims: SignedClaims) -> Query | None:
    repository = signed_claims["repository"]
    repository_owner, repository_name = repository.split("/", 1)
    workflow_prefix = f"{repository}/.github/workflows/"
    workflow_ref = signed_claims["job_workflow_ref"].removeprefix(workflow_prefix)

    return (
        Query(klass)
        .filter_by(
            repository_name=repository_name,
            repository_owner=repository_owner,
            repository_owner_id=signed_claims["repository_owner_id"],
            environment=None,
        )
        .filter(
            literal(workflow_ref).like(func.concat(klass.workflow_filename, "%"))
        )
    )
```



```python
__lookup_strategies__ = [
    __lookup_all__,
    __lookup_no_environment__,
]
```

terrible!

Lesson #3: OIDC tokens are not API tokens

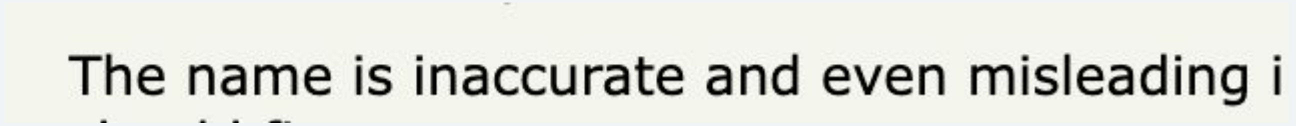


"An OIDC credential is basically an API token; I don't need to do an exchange"

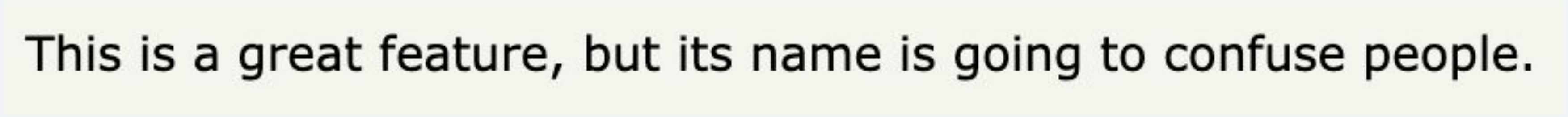
Reality: you *can* do this, but…

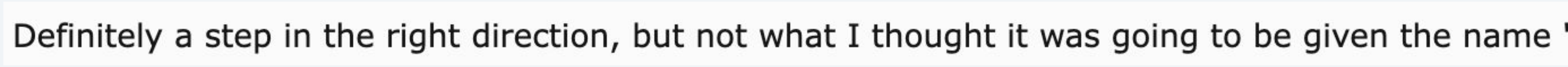
- **OIDC credentials aren't plugged into your preexisting AuthN/Z or permissions/scopes; you'll end up re-implementing a bunch of what you already have (and reimplementation means more bugs)**
- **OIDC credentials are ~~chonky~~ contain all kinds of stuff you might not want to hold onto for prolonged periods (user emails, other potential PII)**
- **IdPs can change expiration and other policies without notice; creating your own temporary token makes you resilient to these changes!**

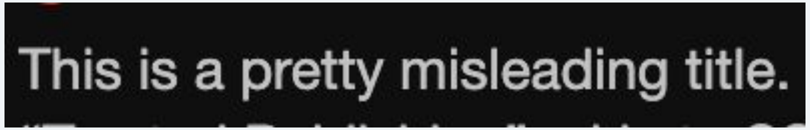
Conclusion: Performing token exchange minimizes the amount of novel code needed; reduces potential sources of PII; offers additional resilience against IdP changes.

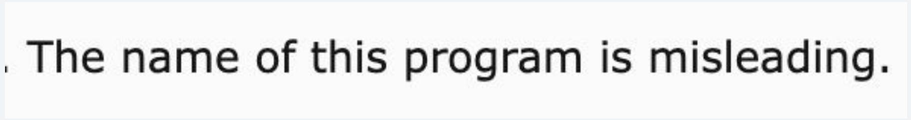

The name is inaccurate and even misleading i

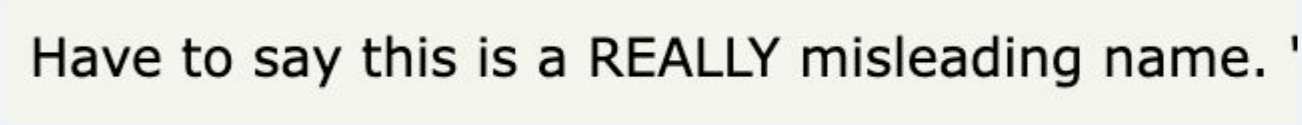
Lesson #4: Words are hard


This is a great feature, but its name is going to confuse people.


Definitely a step in the right direction, but not what I thought it was going to be given the name '


This is a pretty misleading title.


. The name of this program is misleading.

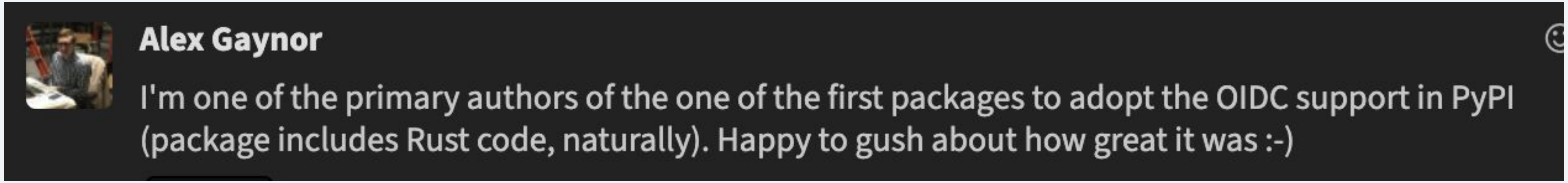

Have to say this is a REALLY misleading name. '

Lesson #5: It's all worth it!

OIDC is complicated; trusted publishing's model on top of it even more so.

But the *user experience and security gains make it worth it*:

- **User feedback (once they understand it) is overwhelmingly positive**
  - High demand for more IdPs/more trust relationships (e.g. reusable GitHub workflows)
- **Adoption by critical projects is (slowly) advancing:**
  - 219 critical projects have trusted publishers, 152 actively publishing (2023-09-18)
  - High and growing "top 20" coverage: urllib3, certifi, cryptography, charset-normalizer, idna, wheel, etc.

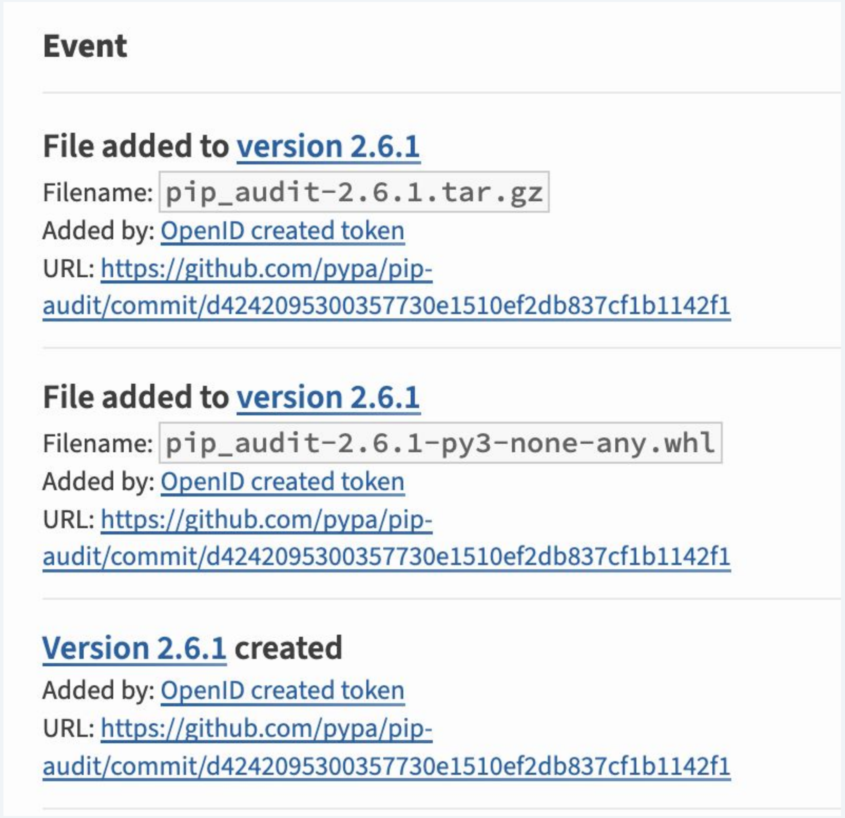

Alex Gaynor

I'm one of the primary authors of the one of the first packages to adopt the OIDC support in PyPI (package includes Rust code, naturally). Happy to gush about how great it was :-)

What comes next?

The same building blocks that give us trusted publishing (OIDC, machine identities) are *also* the building blocks for build provenance and code signing!

The goal: ecosystems that support trusted publishing should find it relatively easy to enable Sigstore for codesigning.


Event

File added to version 2.6.1
Filename: `pip_audit-2.6.1.tar.gz`
Added by: OpenID created token
URL: https://github.com/pypa/pip-audit/commit/d4242095300357730e1510ef2db837cf1b1142f1

File added to version 2.6.1
Filename: `pip_audit-2.6.1-py3-none-any.whl`
Added by: OpenID created token
URL: https://github.com/pypa/pip-audit/commit/d4242095300357730e1510ef2db837cf1b1142f1

Version 2.6.1 created
Added by: OpenID created token
URL: https://github.com/pypa/pip-audit/commit/d4242095300357730e1510ef2db837cf1b1142f1

sigstore

Takeaways

- **Trusted publishing is a double win: both for security *and* for usability**
  - The best kind of security improvements make users' lives easier, not harder!
  - Cynically: the *only* kinds of security improvements that matter are the ones that engineers want to use
- **Trusted publishing is not tied to PyPI; other package indices can use the same techniques and reap the same benefits!**
  - We (Trail of Bits) would be thrilled to reapply our experience on PyPI to other ecosystems; please come find me during the day and chat with me about it!
- **Trusted publishing is a logical step towards our shared supply chain goals: source and build provenance, code signing, generalized verifiable attestations over software/dependency graphs**

end of the talk

thank you!

- **these slides will soon be available here:**

  https://yossarian.net/publications#ossfeu-2023

- **resources:**
  - docs.pypi.org/trusted-publishers: official PyPI documentation for trusted publishing
  - “Introducing ‘Trusted Publishers’”: official PyPI announcement post
  - "Trusted publishing: a new benchmark for packaging security": ToB’s writeup on trusted publishing, threat modeling, etc.
- **Contact:**
  - william@trailofbits.com
  - @yossarian@infosec.exchange