Provenance Identity Continuity (PIC): *Secure Authority Propagation from Human and Non-Human Origins Across Trust Boundaries*

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PIC

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NitroAgility

Permguard

From Possession to Execution

- A token can prove: “I hold valid authority now.”
- It cannot prove: “this step is still part of the same authorized execution.”
- That gap is not a policy gap.

It is a model gap

This talk explains:

- why possession is local
- why execution is temporal-causal
- and why execution continuity must become part of the security model

Not a better token.
A **different primitive**.

What This Talk Is Not About

It is not about:

- Centralization vs Decentralization
- OAuth vs Capabilities

It is about:

- security models
- distributed execution
- authority propagation through execution

PIC changes the primitive:

- **Proof of Relationship (PoR)** makes execution membership representable
- **Proof of Continuity (PoC)** makes valid continuation verifiable

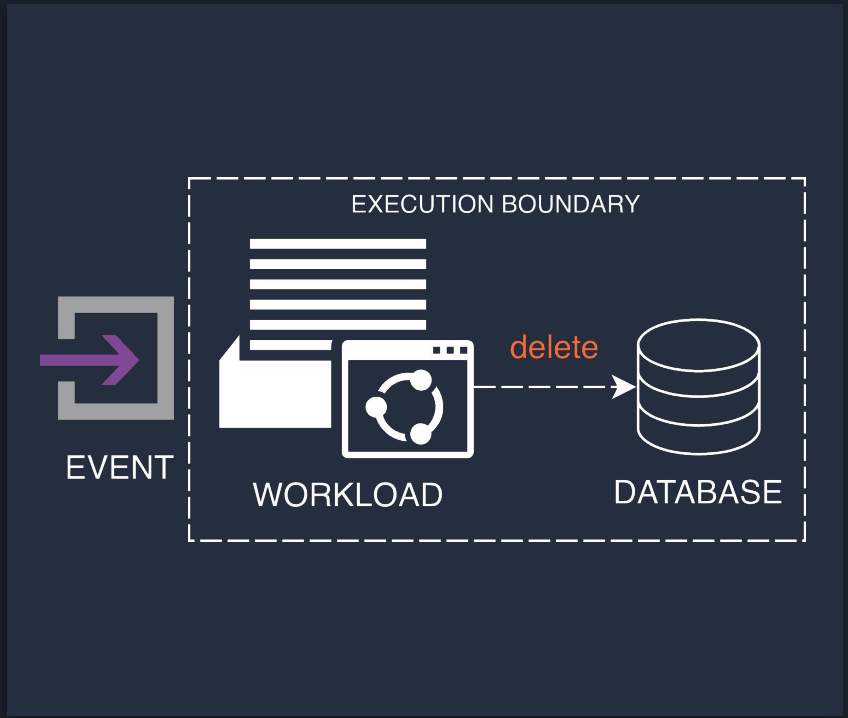
From authority-as-possession
to **authority-as-continuity**

A Workload Is Autonomous Within Its Execution Boundary

First Precondition of the Execution Model

It can act at any time — triggered by a request, an event, or even by itself.

And once it starts executing, it can do anything within its execution boundaries — across its resources, devices, and connected systems.

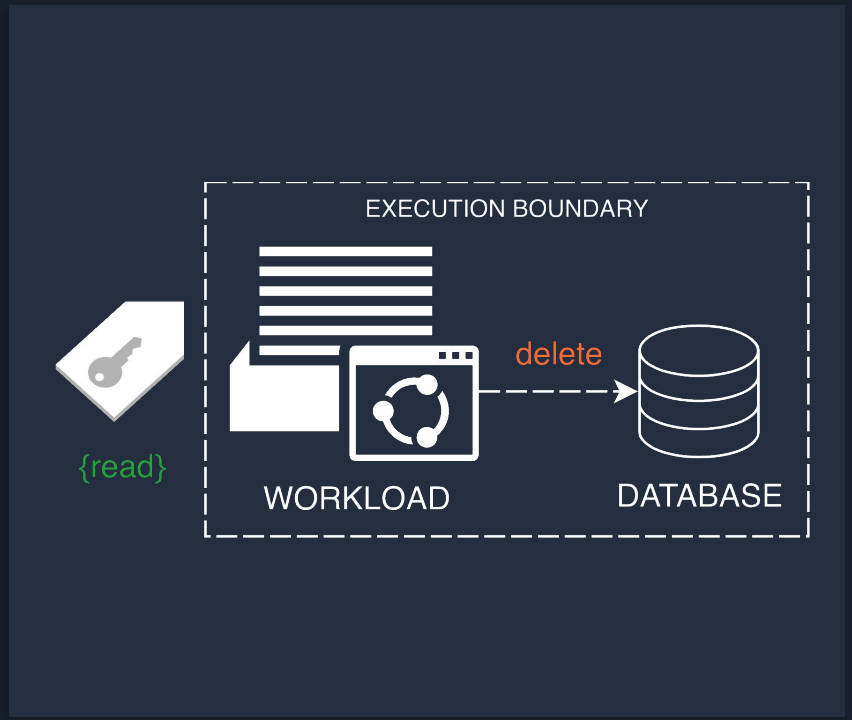


Execution Can Deviate from Intent

Second Precondition of the Execution Model

Even with a valid request and valid authority, it may do something completely different within its execution boundaries.

Whether it's a bug or malicious behavior doesn't matter.



What Does Trust Mean in an Execution Model?

Trust Assumptions in an Execution Model

The key point is:
We cannot control what happens inside a workload.

When we say we “trust” a workload, we usually mean:

- We trust who operates it
- We trust the organization behind it
- We trust their engineering practices
- We trust their security measures
- We trust the software behaves as intended

We already trust external providers

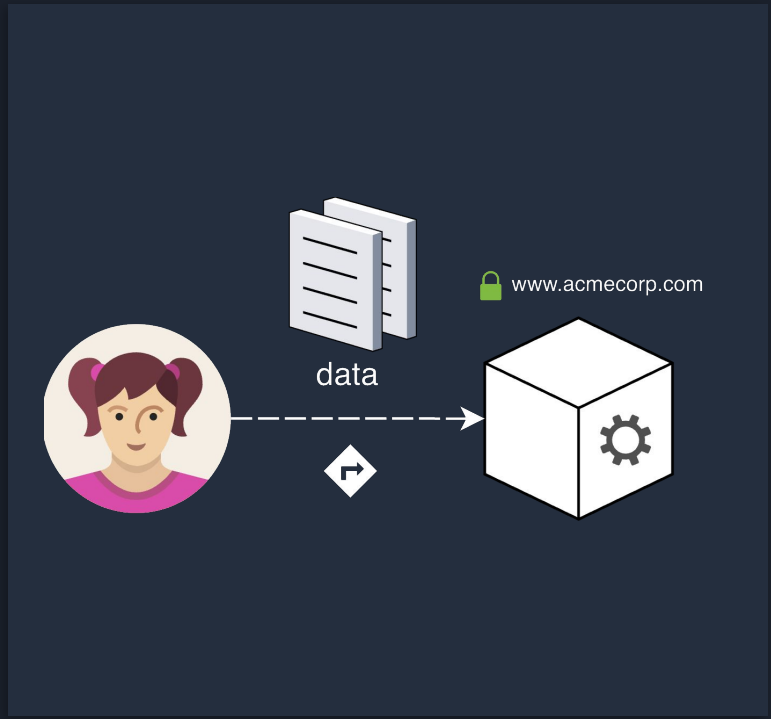
We already give our data to systems we don’t control.

We trust them to behave correctly.
We trust their security practices.

But that’s not security — that’s trust.

AI agents don’t introduce a new problem.
They make an existing assumption visible.

What’s missing is a model to reason about authority and execution.



What Does Trust Mean for AI Agents?

The Problem Is the Framing

When we say we trust AI agents

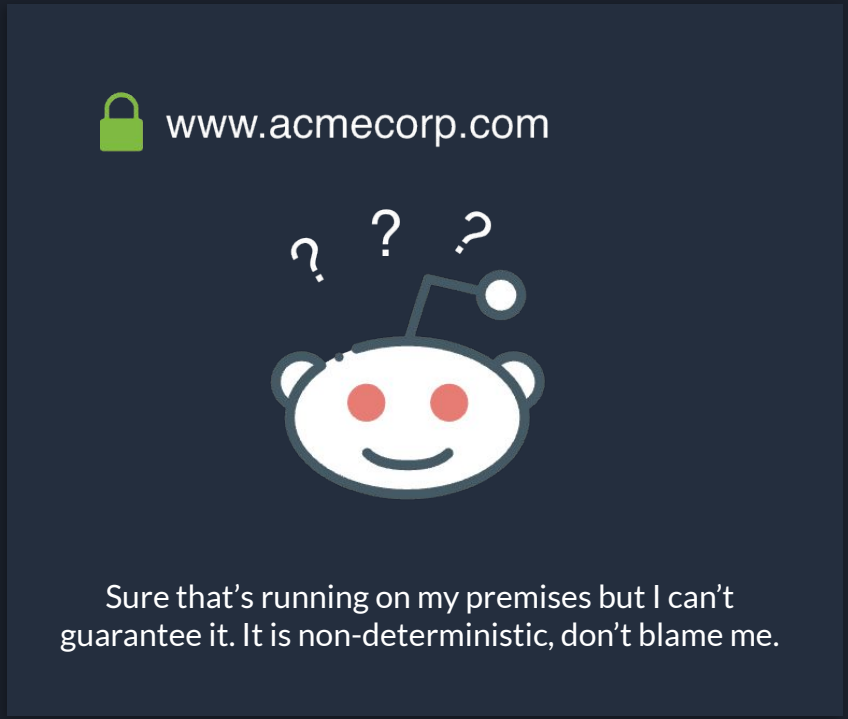
- We trust the organization behind them
- We trust their engineering and safeguards

But AI agents are non-deterministic

- They can produce unpredictable outcomes
- They cannot guarantee correctness

This is not a reliability problem

A Trust Problem not a Security Model Problem



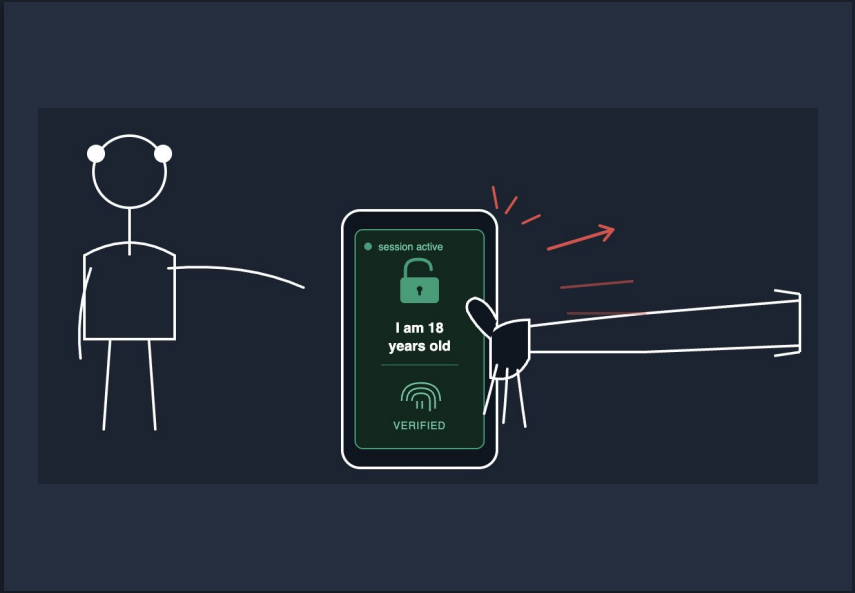
Trust Begins Before the Security Model

Physical Preconditions of Authentication and Intent

When we talk about trust, we mean one thing:
the process was initiated legitimately.

- If Alice unlocks her phone with her fingerprint and someone snatches it from her hand while the session is open, that's not a software problem. It's physics.
- If Alice asks Bob to act on her behalf using his mobile, that's not something cryptography can prevent. It's physics.

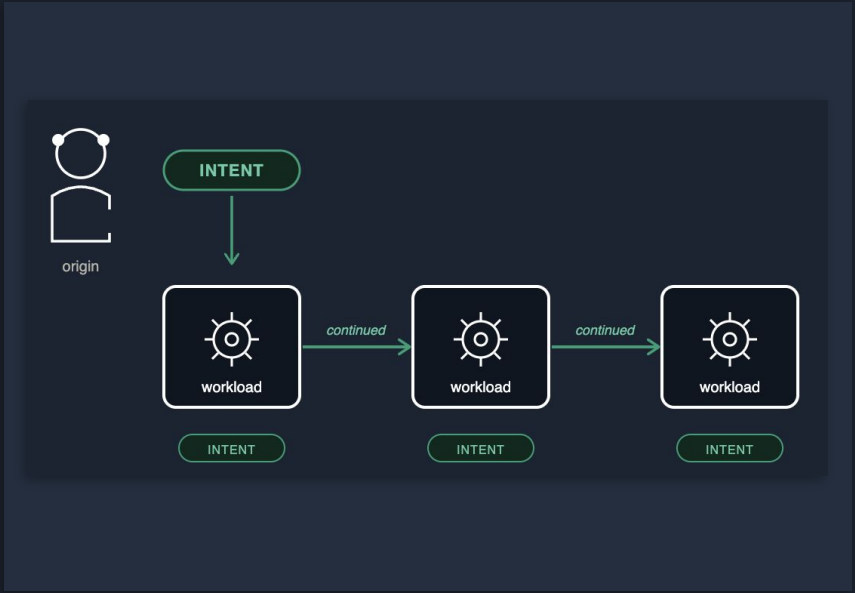
Authentication and intent are preconditions, not guarantees.
No amount of checks downstream can undo a compromised origin.



Machines don't prove attributes. They continue intent

Physical Preconditions of Authentication and Intent

It does not need to choose which identity to present or which attestations it holds — it only needs to continue.



Trust Begins Before the Security Model

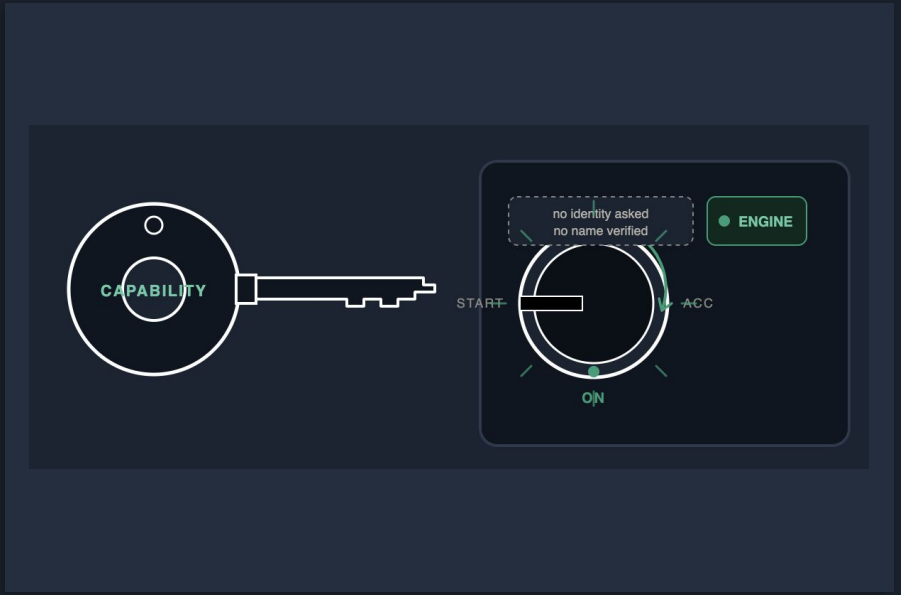
Physical Preconditions of Authentication and Intent

If privacy matters, once the origin is assumed correct, the model can take over:

➢ authority becomes anonymous capability

The physical problem at the origin cannot be mitigated by software.

Given that, everything else becomes execution and authority propagation, something we can reason about.



Trust & Security Model

- Trust Model: Who/what is trusted, for what, under which conditions.
  Trust anchors, boundaries, assumptions (e.g., trusted IdP/AS, accepted issuers, audiences, delegation).

- Security Model: How the system is protected given those assumptions.
  Mechanisms, policies, enforcement (e.g., OAuth 2.1/OIDC, Capabilities, PKCE, DPoP, mTLS, RBAC/ABAC).

What about the Security Model?

Workloads are connected to each other. Each has an execution boundary.

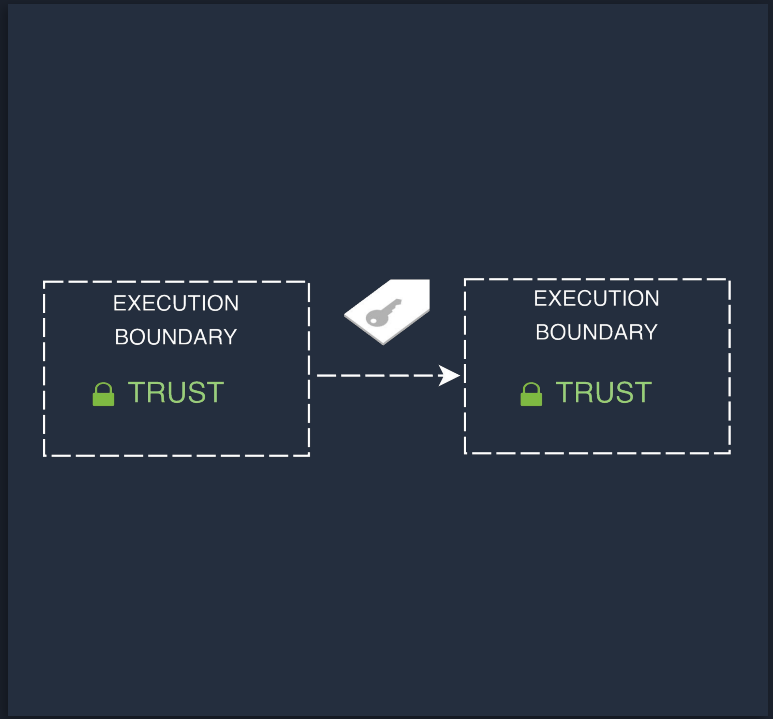
- Internal behavior cannot be controlled
- Trust is assumed (Hardware, OS, Configuration, Security practices, Risk management)

A security model connects the execution boundaries

- Between workloads
- Through their interactions

A security model = constraints on communication

Not what a workload does
but what it can ask others to do



What about Security Models?

Communication is a chain of delegated executions

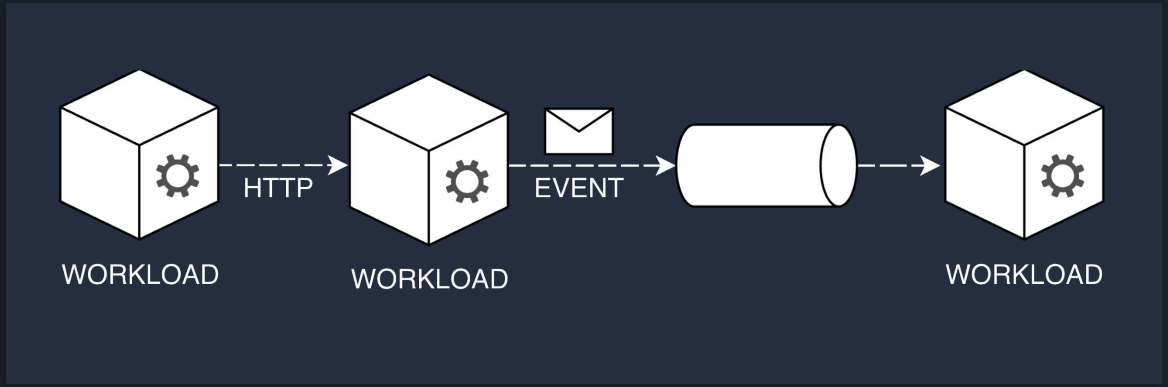
- Across workloads
- Across boundaries

It uses different transports

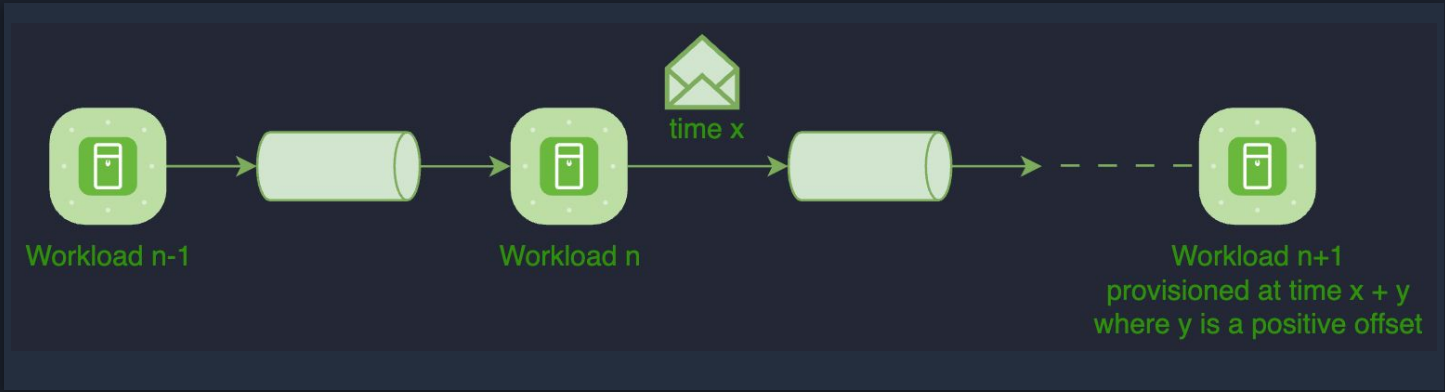
- HTTP, gRPC
- Messaging, Streams

But execution remains the same

A causal chain over time



Canonical Execution Model



Execution is temporal and causal, not positional.

- Workload n+1 provisioned at time x + y (y > 0)
- Authority flows from origin — never re-created
- Every hop must prove continuity, not possession

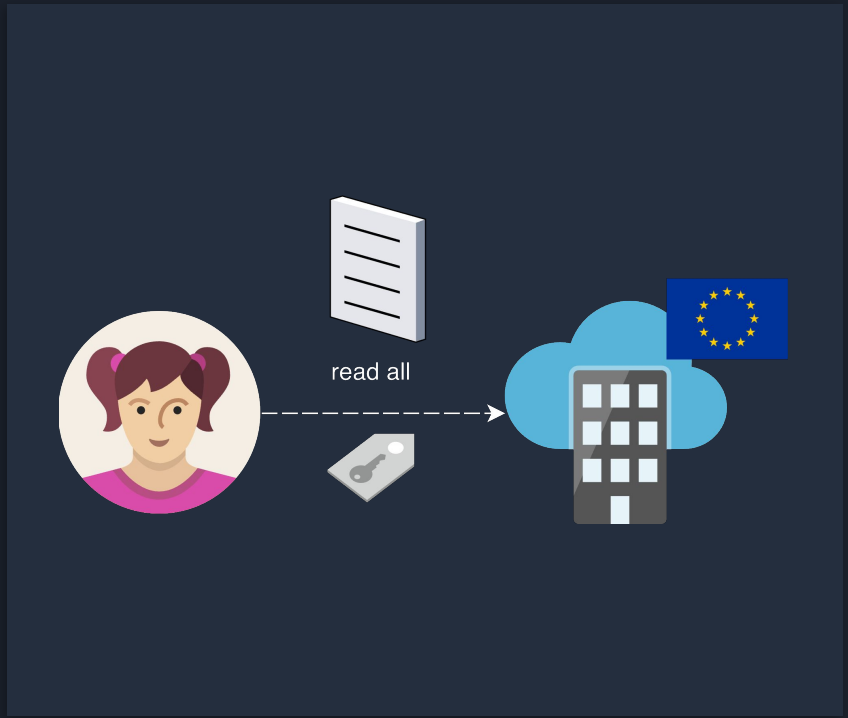
The Alice Example

Alice trusts the provider

- Alice connects to a saas
- She provides access to her files
- She relies on the service agreement

Backup will run under defined constraints
(e.g. computation in EU)

Trust is assumed

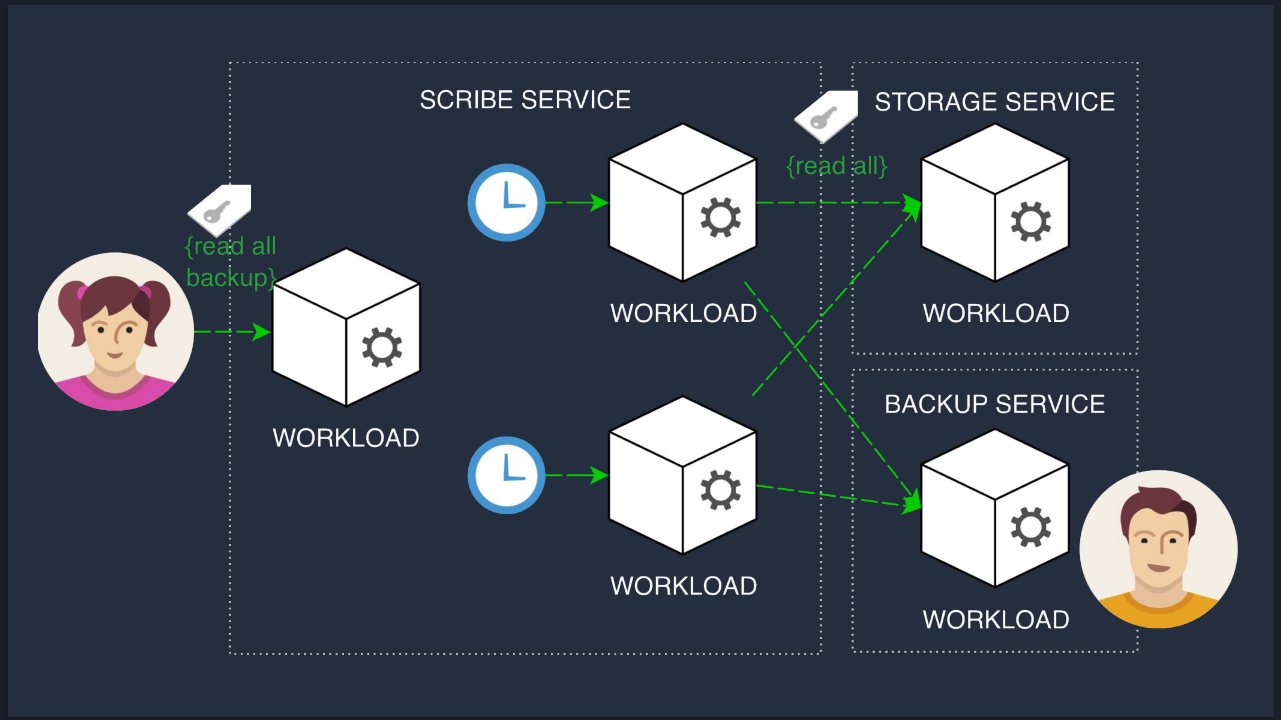


The Alice Example

Periodic execution

- The SaaS periodically runs backups
- It calls the storage service
- It retrieves and stores Alice's data

Execution matches the intended authority



The Alice Example

A new request

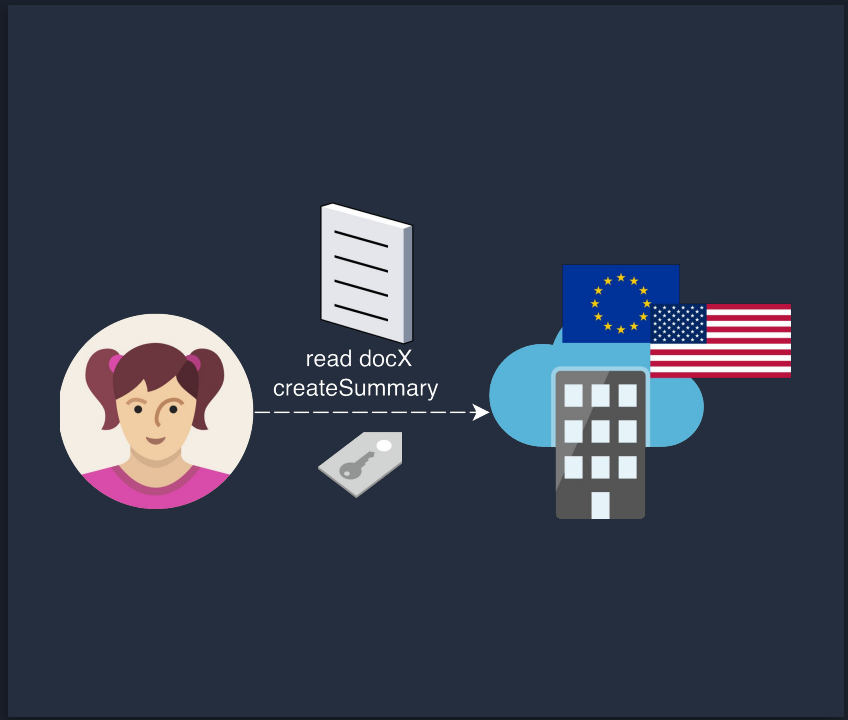
The provider introduces a new feature

Document summarization

Alice provides a new request:

- Summarize DocX
- Classified as low risk
- Send summary to a collaborator

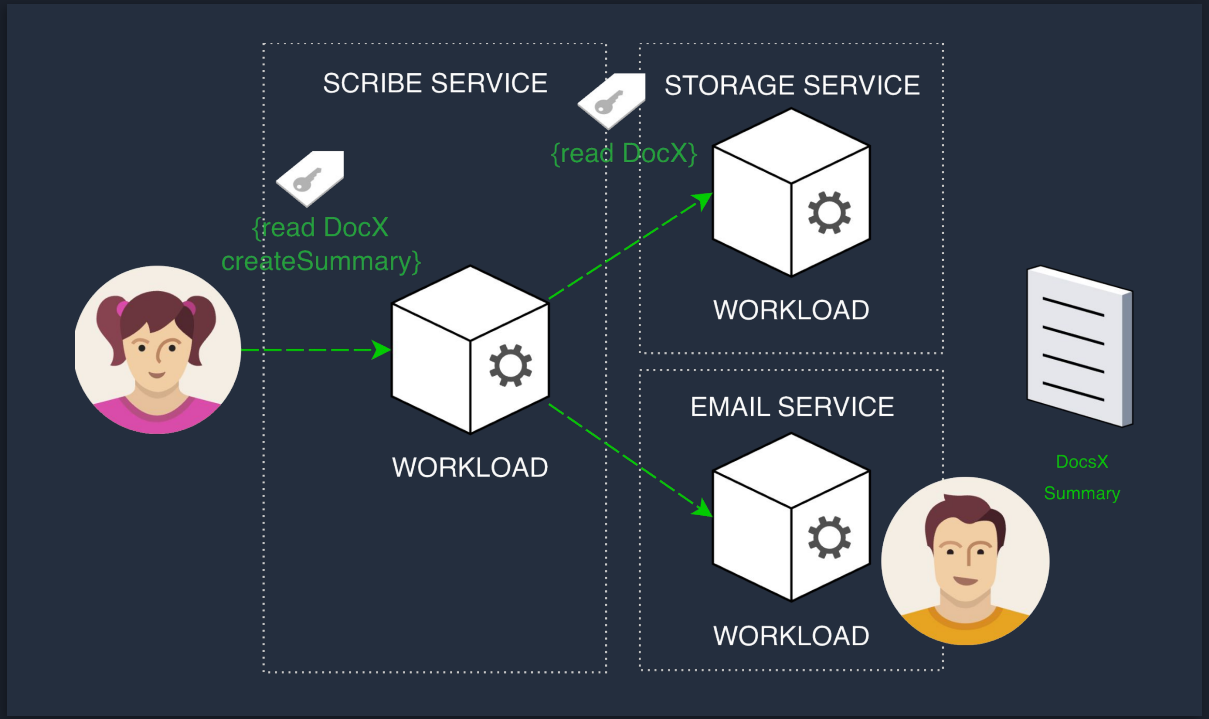
A new, scoped intent is defined



The Alice Example

Correct behavior

- The SaaS executes the summary
- Uses the scoped access
- Sends the result
- Execution matches intent



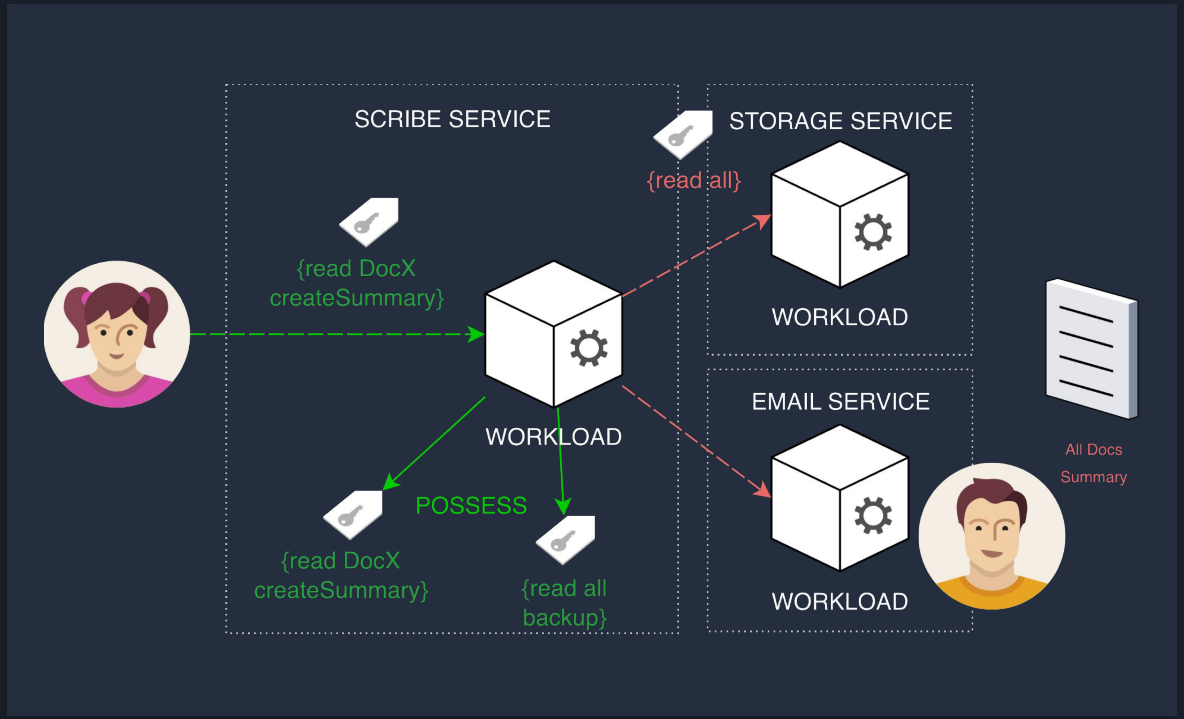
The Alice Example

Execution confusion

- The SaaS mixes execution contexts
- Uses the backup token instead of the summary token

- Retrieves all documents
- Generates a broad summary
- Sends it out

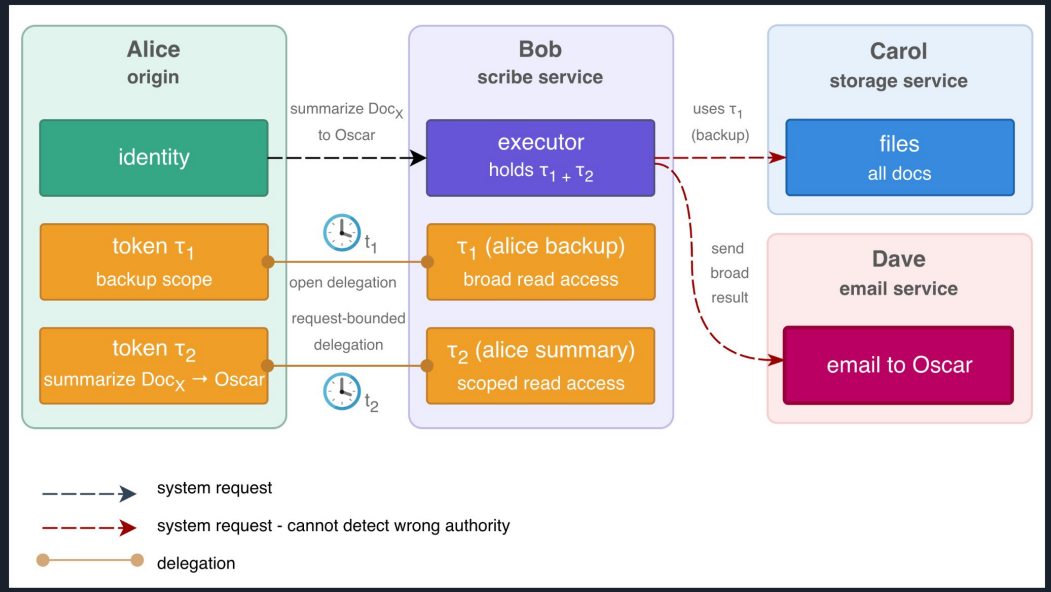
Execution does not match intent



The Alice Example

Confused Deputy (Revisited)

This is a revisited confused deputy problem where authority is misused within the same identity.



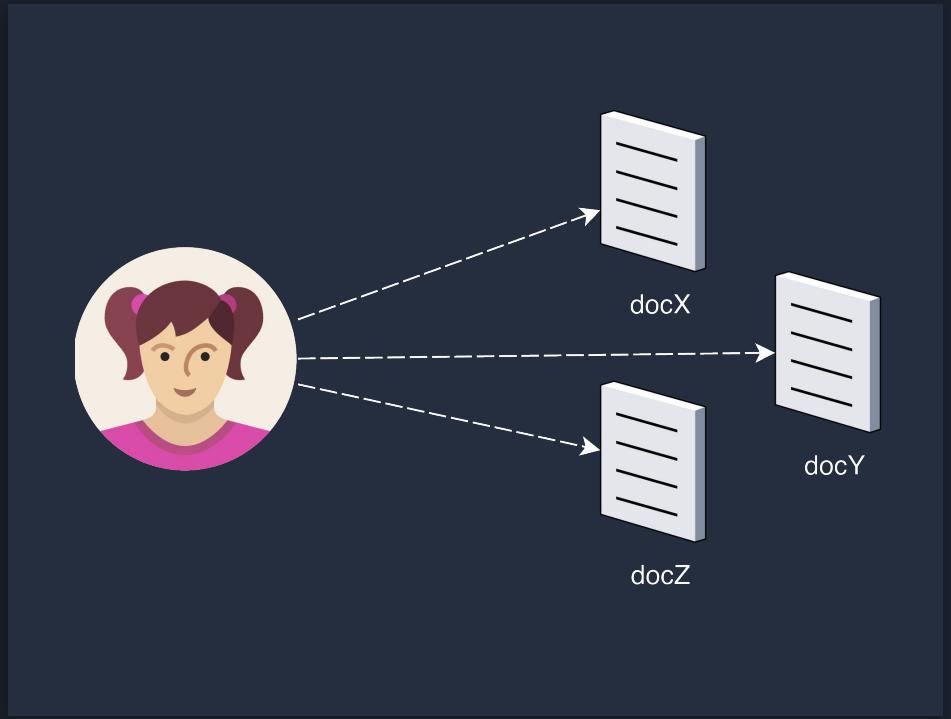
At this point, it’s clear that…

Same identity
Same permissions

No permission expansion
Still wrong

Execution intent was expanded
Authority applied to the wrong execution context

Authority did not exist for this execution
Confused deputy — within the same identity



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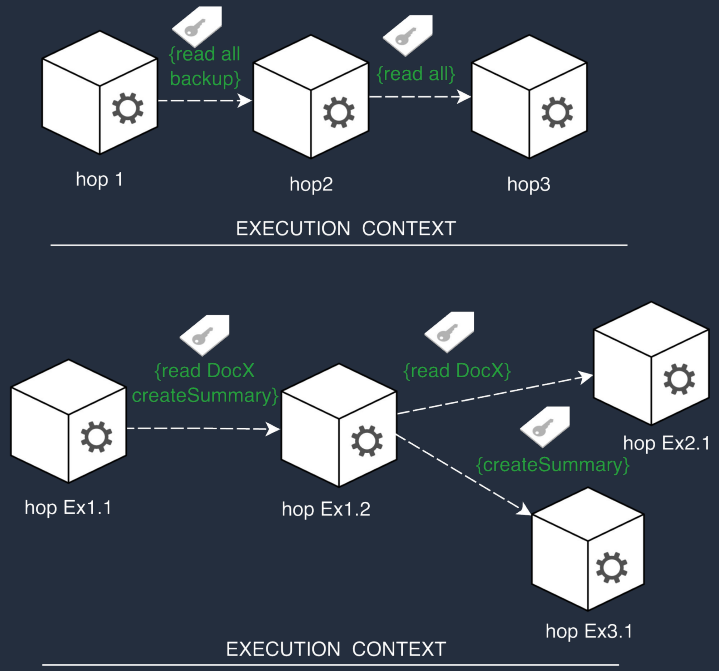


The Execution Model

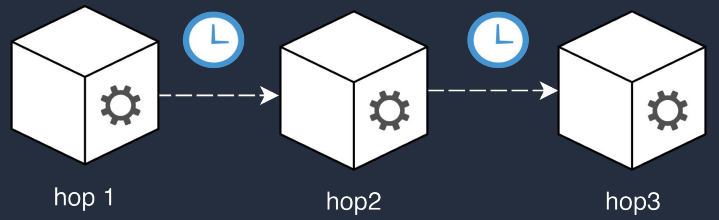
From Proof of Possession to the Proof of Continuity

We don’t need Proof of Possession
But we need to prove that execution is correct

- A chain of hops
- Ordered in time

A causal chain

$$\pi = \langle (p_0, ops_0), (p_1, ops_1), \ldots, (p_n, ops_n) \rangle$$



The Execution Model

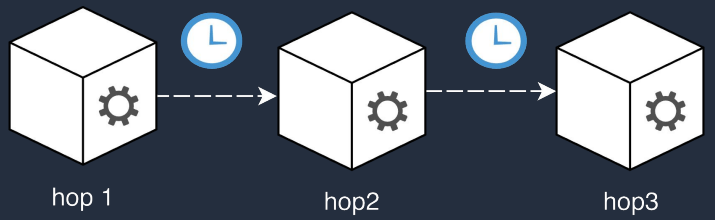
Execution Invariants

Execution is constrained by invariants

- Bound to the origin
- No expansion of authority

Every step must respect both

Across the entire execution chain



Definition 1 (PIC Model). *A system enforces Provenance Identity Continuity if, for every execution chain π, the set of privileges at the final hop is bounded by the privileges at the origin:*

$$ops_n \subseteq ops_0$$

and every privilege exercised at hop n is causally linked to the origin via a verifiable chain.

Theorem 1 (PIC Safety). *If the PIC Model holds, no principal can exercise a privilege not present at the origin.*

Proof. By construction, $ops_{i+1} \subseteq ops_i$ for all i, so $ops_n \subseteq ops_0$. Thus, any $(o, r) \in ops_n$ must also be in ops_0. Therefore, no privilege can be gained beyond the origin.

The Proof of Continuity

Not possession, but Continuity of Execution

At each step, the executor must prove:

- Its relation to the execution
- Its link to the previous step
- Uses its characteristics

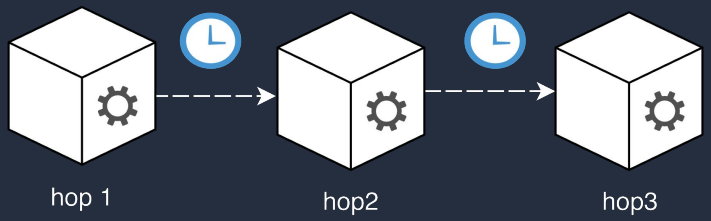
Proof of Relationship (PoR)

And verifying invariants:

- Bound to the origin
- No expansion of authority

These together enable:

Proof of Continuity (PoC)



4 Proof-of-Continuity (PoC / PIC)

Execution is a causal chain:

$$p_0 \to p_1 \to \cdots \to p_n,$$

with $p_0 = U$.

Each hop transfers:

$$ops_{i+1} \subseteq ops_i.$$

Let:

$$\pi = \langle (p_0, ops_0), (p_1, ops_1), \ldots, (p_n, ops_n) \rangle.$$

Structural Elimination

Detect

Monitor for confused deputy at runtime

Traditional approach

Mitigate

Add scopes, bindings, policies to reduce risk

Current best practice

Eliminate

Make the attack structurally inexpressible

PIC

The Confused Deputy becomes non-formulable. Not prevented — inexpressible.

Structural Elimination

4.1 Authorization Rule

(o, r) is authorized at the final hop iff:

$$(o, r) \in \bigcap_{i=0}^{n} ops_i.$$

Since the chain is monotonic decreasing:

$$\bigcap_{i=0}^{n} ops_i = ops_n.$$

Thus no hop may acquire authority not already present at the origin.

Lemma 1 (Irreversible loss of authority)**.** *If $(o, r) \notin ops_j$ for some hop j, then $(o, r) \notin ops_k$ for all $k \geq j$.*

Proof. By monotonicity, $ops_k \subseteq ops_j$ for all $k \geq j$.

5 Safety Property

Definition 3 (Origin-bounded authority)**.** *A model enforces origin-bounded authority if every executable privilege at hop n was originally granted at hop 0.*

Theorem 3 (PoC prevents confused deputy)**.** *If $ops_0 = \{(convert, r)\}$, then $(write, r)$ can never be authorized.*

Proof. $(\text{write}, r) \notin ops_0$ and $ops_{i+1} \subseteq ops_i$. Thus $(\text{write}, r) \notin ops_n$.

6 Elimination of the Confused Deputy

The Confused Deputy requires an ontological assumption: that authority is a transferable or rebindable object that a principal may hold or reinterpret on behalf of another.

PIC eliminates this ontology entirely.

Theorem 4 (Confused Deputy is non-formulable under PIC)**.** *In any system satisfying PIC monotonicity $ops_{i+1} \subseteq ops_i$ and origin-bounded authority $ops_n \subseteq ops_0$, the Confused Deputy conditions cannot be jointly satisfied.*

Proof. The Confused Deputy requires:

$$(o, r) \notin ops_0 \quad \text{and} \quad (o, r) \in ops_k \text{ for some } k > 0.$$

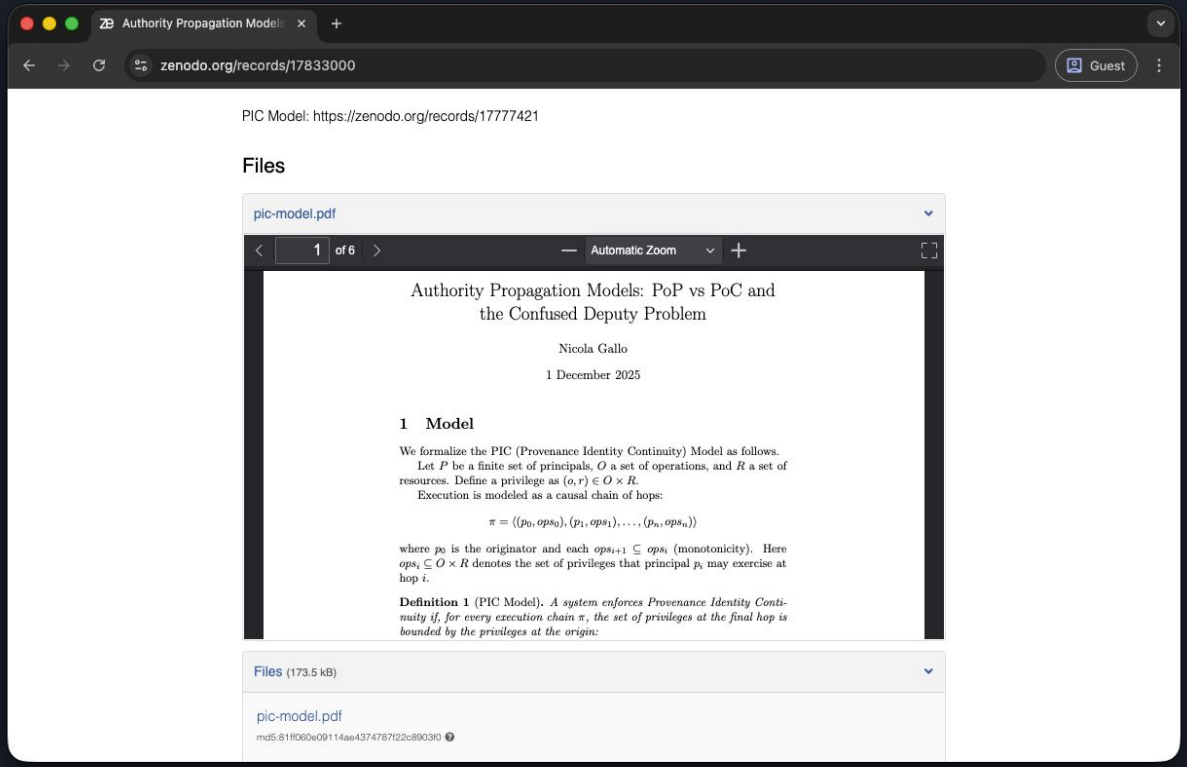
But PIC enforces:

$$ops_k \subseteq ops_0 \ \ \forall k.$$

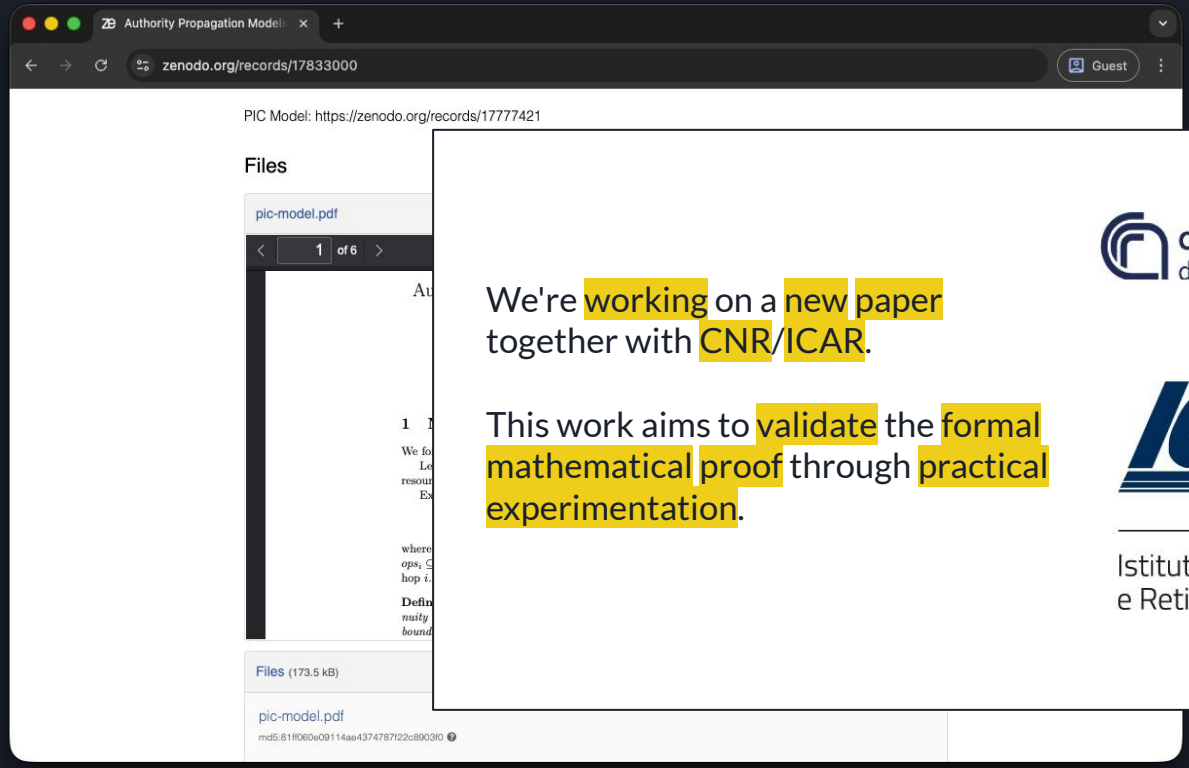
Thus if $(o, r) \notin ops_0$, it cannot appear in any ops_k. The privilege mismatch required for a Confused Deputy is impossible.

Interpretation. Authority in PIC is not something that a subject *has*; it is a continuity property of the execution chain. Since no hop may introduce or reinterpret authority absent at the origin, no deputy can be "confused." The attack does not occur; it is not even definable in the model.

The formal Proof



The Research Journey



We're working on a new paper together with CNR/ICAR.

This work aims to validate the formal mathematical proof through practical experimentation.

Consiglio Nazionale delle Ricerche

ICAR CNR

Istituto di Calcolo e Reti ad Alte Prestazioni

Provenance Identity Continuity (PIC) Model

Provenance

The causal chain is always traceable and auditable. From Origin to end, unbroken. If it breaks, it stops.

Identity

The origin is immutable. It generates authority. It cannot change throughout the chain.

Continuity

Continuity is proven at every step. Proof of Continuity replaces Proof of Possession. Authority can only shrink.

A different Ontology

A subject creates authority by expressing intent.

After that:

> **Authority must only be continued, never recreated.**

Humans (OIDC, VC) **Non-humans** (SPIFFE, DID/VC)

A New Primitive is Required

We need a new primitive.

Tokens encode possession.

We need a primitive that encodes intent and execution.

Proof of Continuity (PoC)

To continue authority, a workload must prove:

Causal Continuity

Execution is a valid continuation of its predecessor.

Origin Invariance

The origin (p_0) is immutable throughout the chain.

Monotonic Authority Restriction

Authority is monotonically non-increasing. $ops_{i+1} \subseteq ops_i$ — authority never expands.

Proof of Continuity (PoC) is built from **Proof of Relationship (PoP)**.
Proof of Possession is one mechanism, not the primitive.

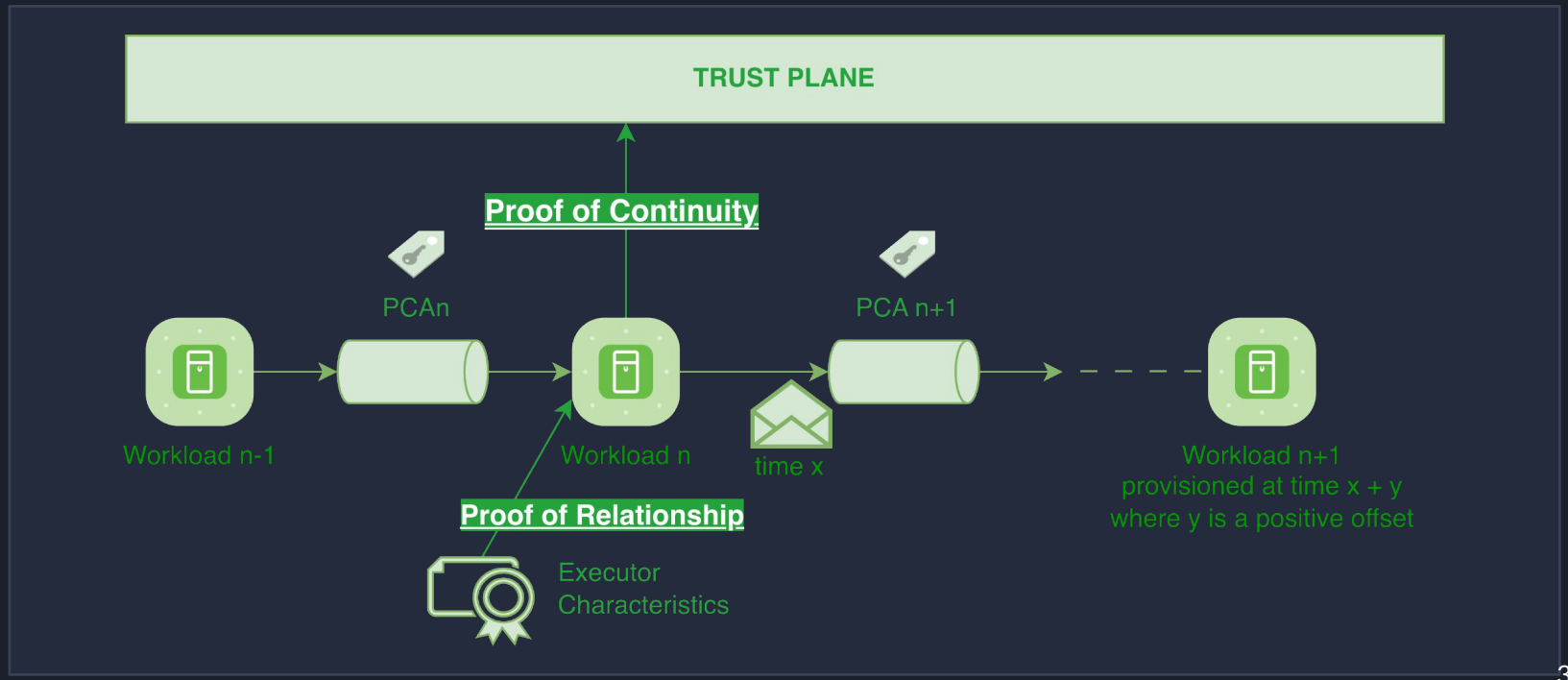
Execution is powered by continuity.

No continuity. No execution.

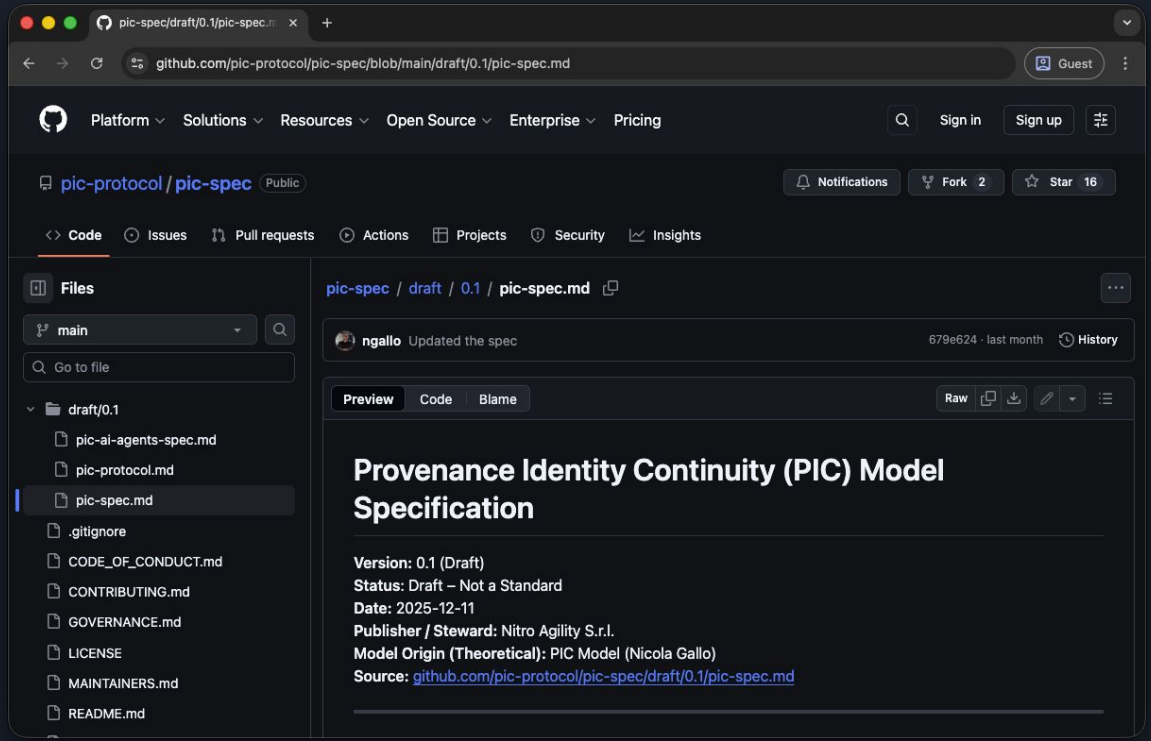
This is Authority Continuity.

What about the Canonical Execution Model?

Rethinking the Canonical Execution Model from execution to implementation



PIC Specification



At This Point, You Might Ask

Essentially we're saying Proof of Possession alone can't solve everything, and we're introducing new primitives.

… Does this replace everything?

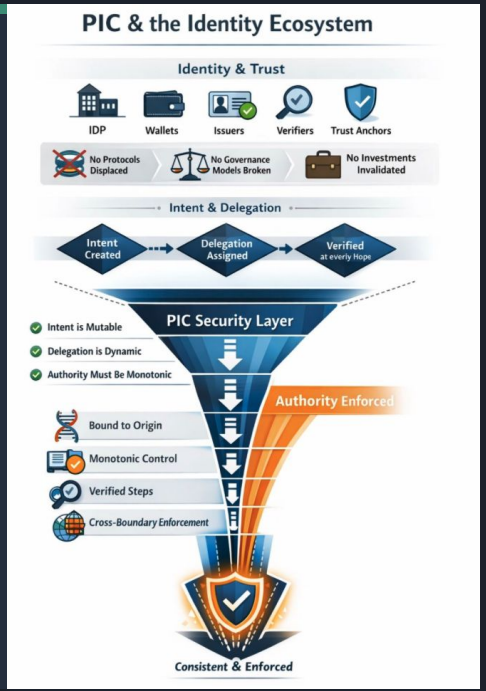
Provenance Identity Continuity (PIC) Model

Keep in mind that

🪪 PIC is not a new identity protocol ⟶ No changes to the identity infrastructure: IdPs and wallets stay exactly where they are.

⚙️ PIC does not interfere with the authentication process.

🛡️ It encodes execution into the security model itself ⟶ enables authority propagation through execution.

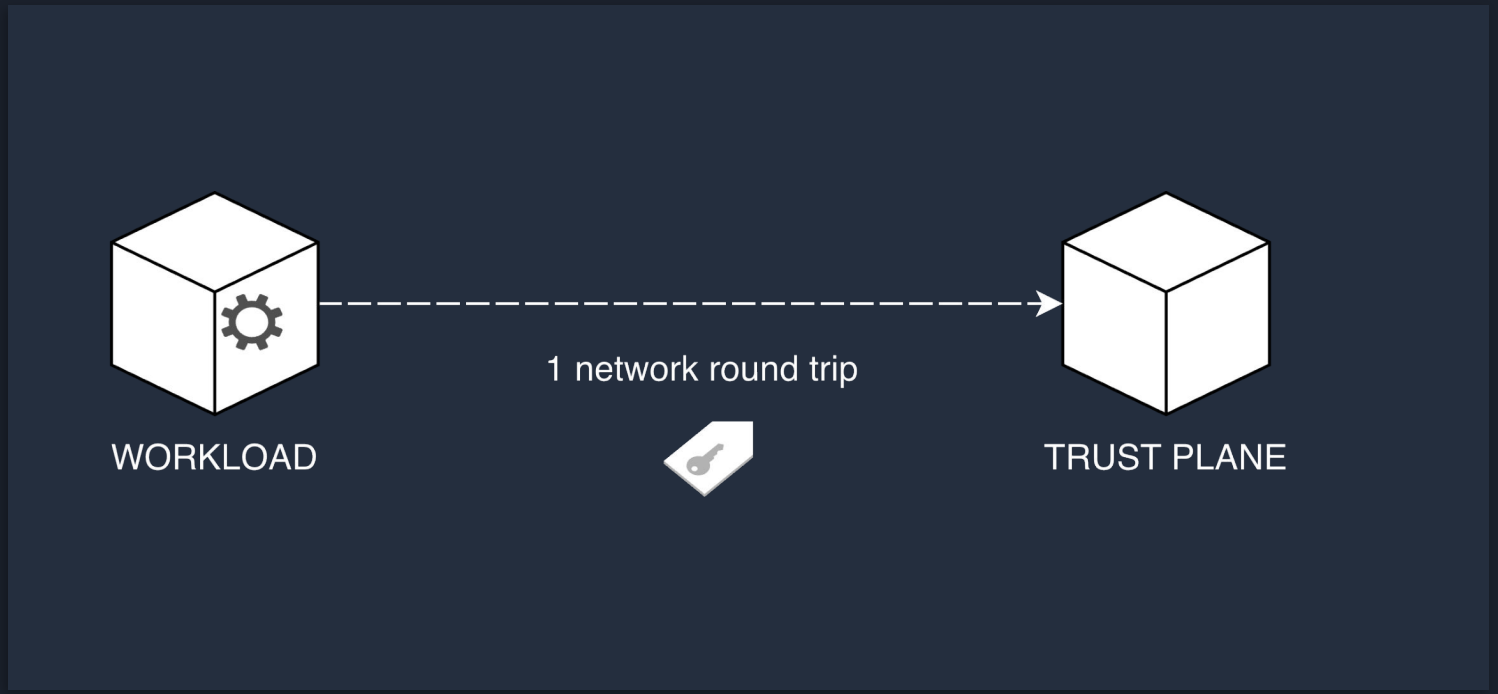


At This Point, You Might Ask

Is this acceptable in terms of latency?

PIC vs OAuth Token Exchange: Network Latency

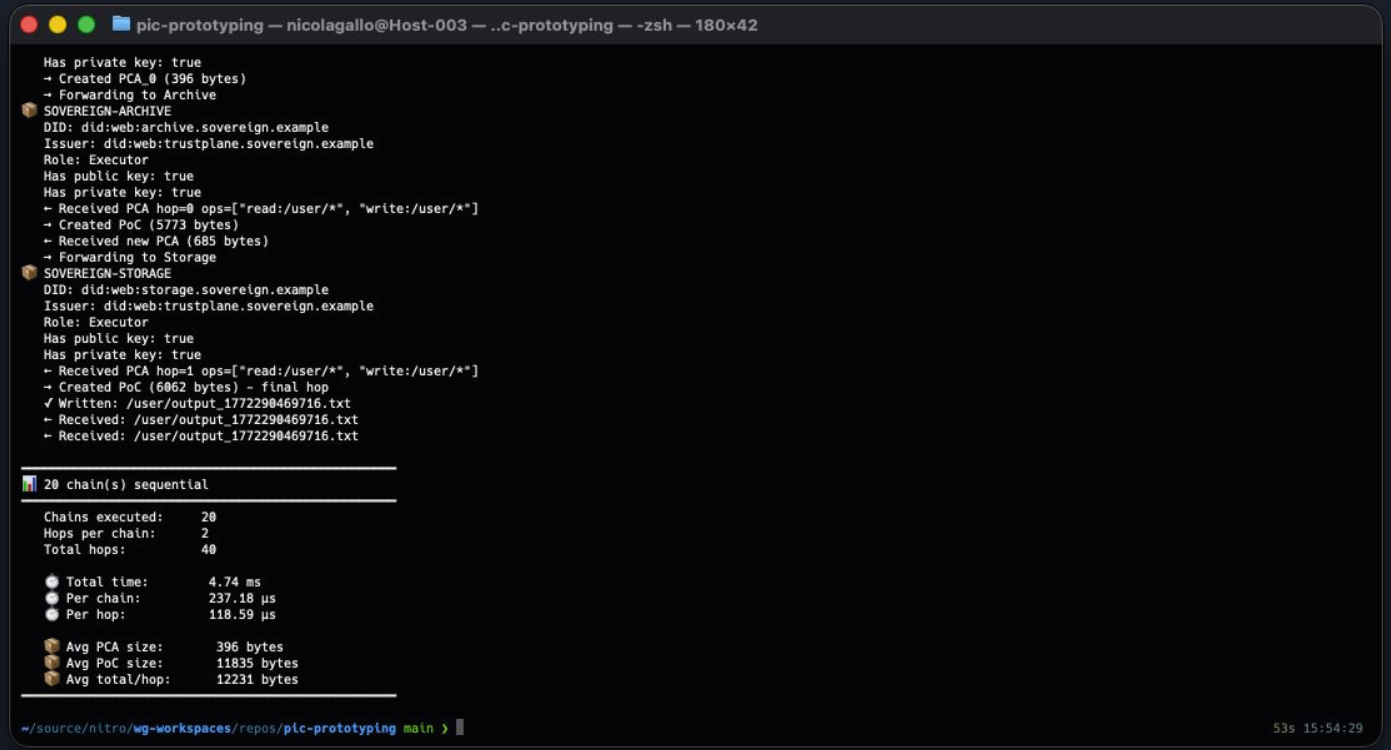
Latency is not the problem, it's a single network round trip, like the one used for the Authorization Server (IdP)



At This Point, You Might Ask

What does this mean for execution time?

Execution Times

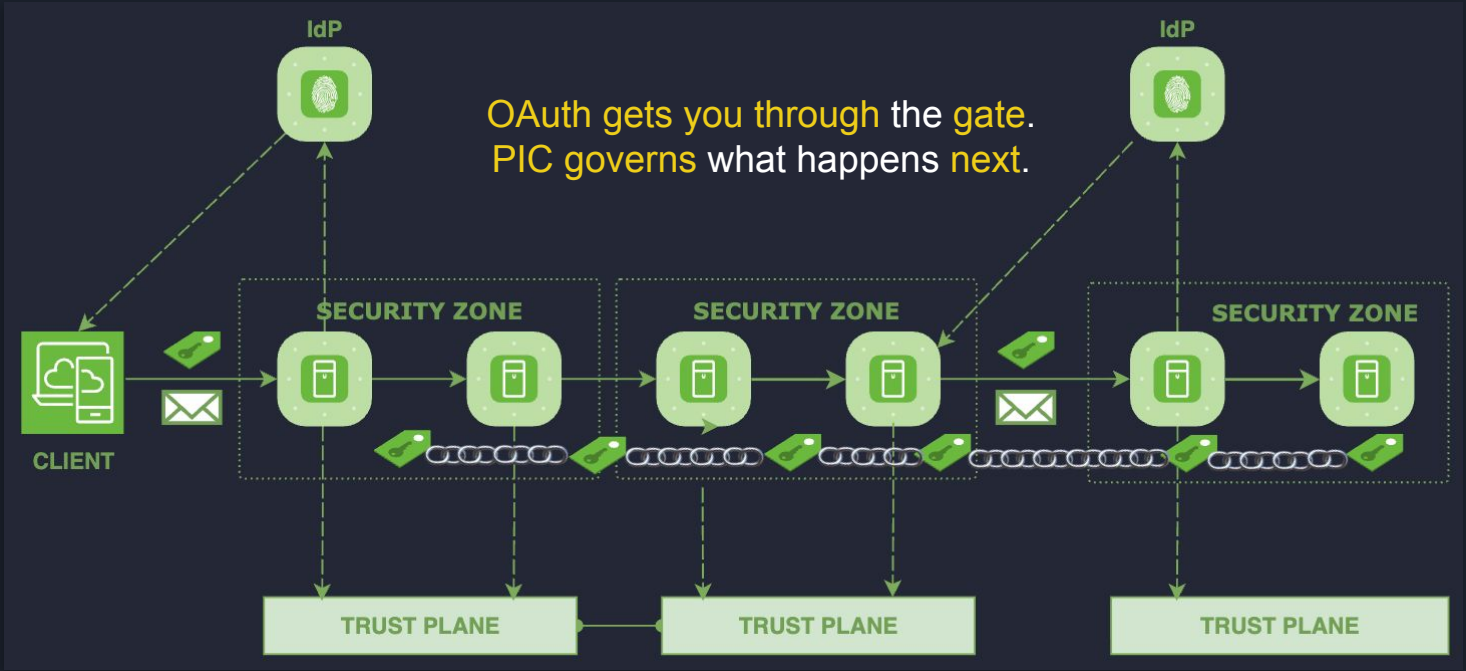


At This Point, You Might Ask

How would you industrialize this?

OAuth as a PIC Federation Backbone

OAuth can serve as the federation backbone, with the PCA encoded into the access token as a custom claim. Ensuring full compatibility with existing infrastructure and applications.

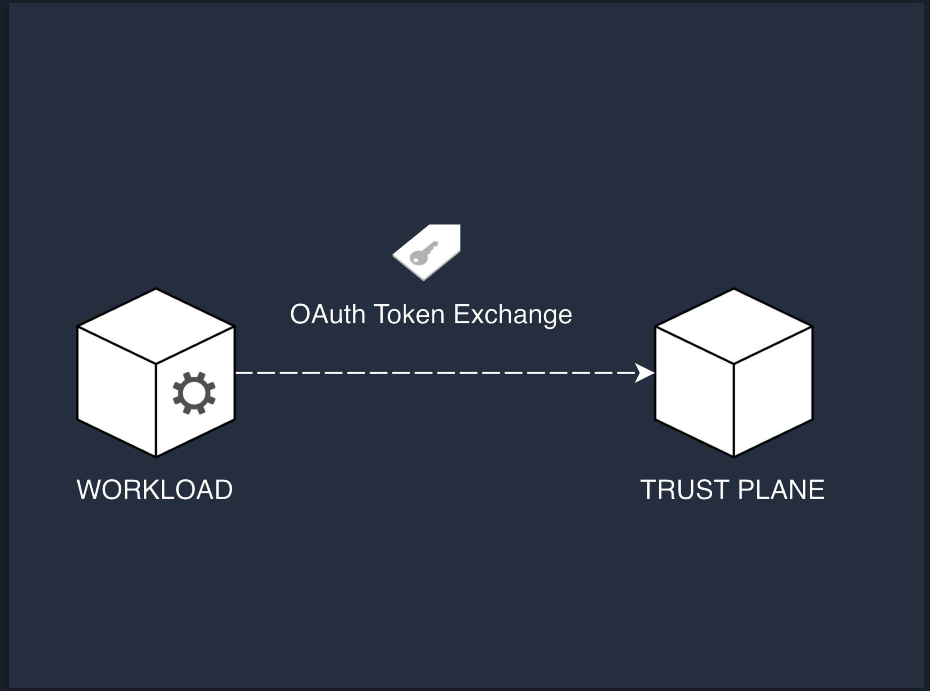


At This Point, You Might Ask

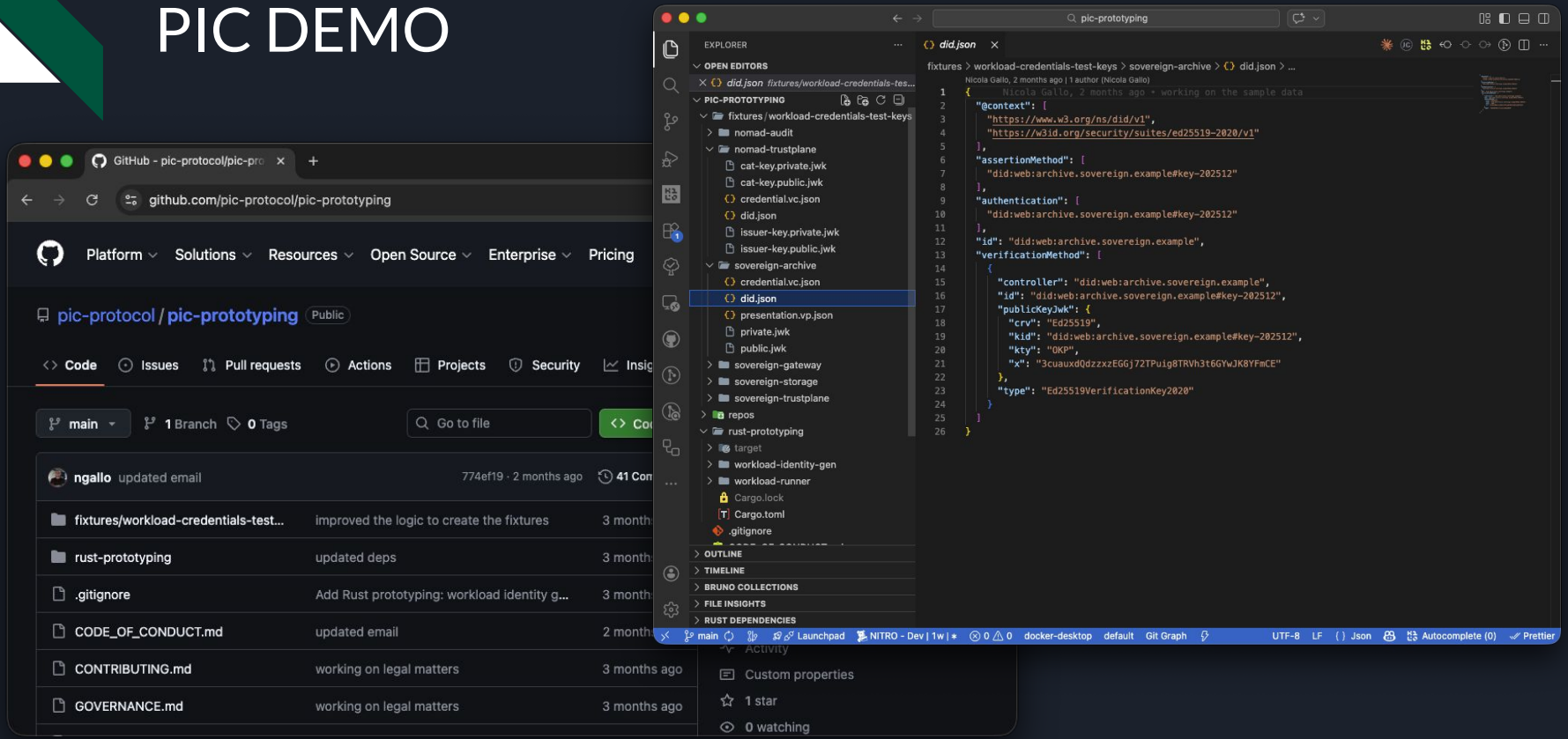
Are you saying that a Trust Plane could also adopt an interface like OAuth Token Exchange with a custom profile, enabling the industrialization path?

At This Point, You Might Ask

Yes, an OAuth Token Exchange custom profile is a viable solution for industrialization.



PIC DEMO



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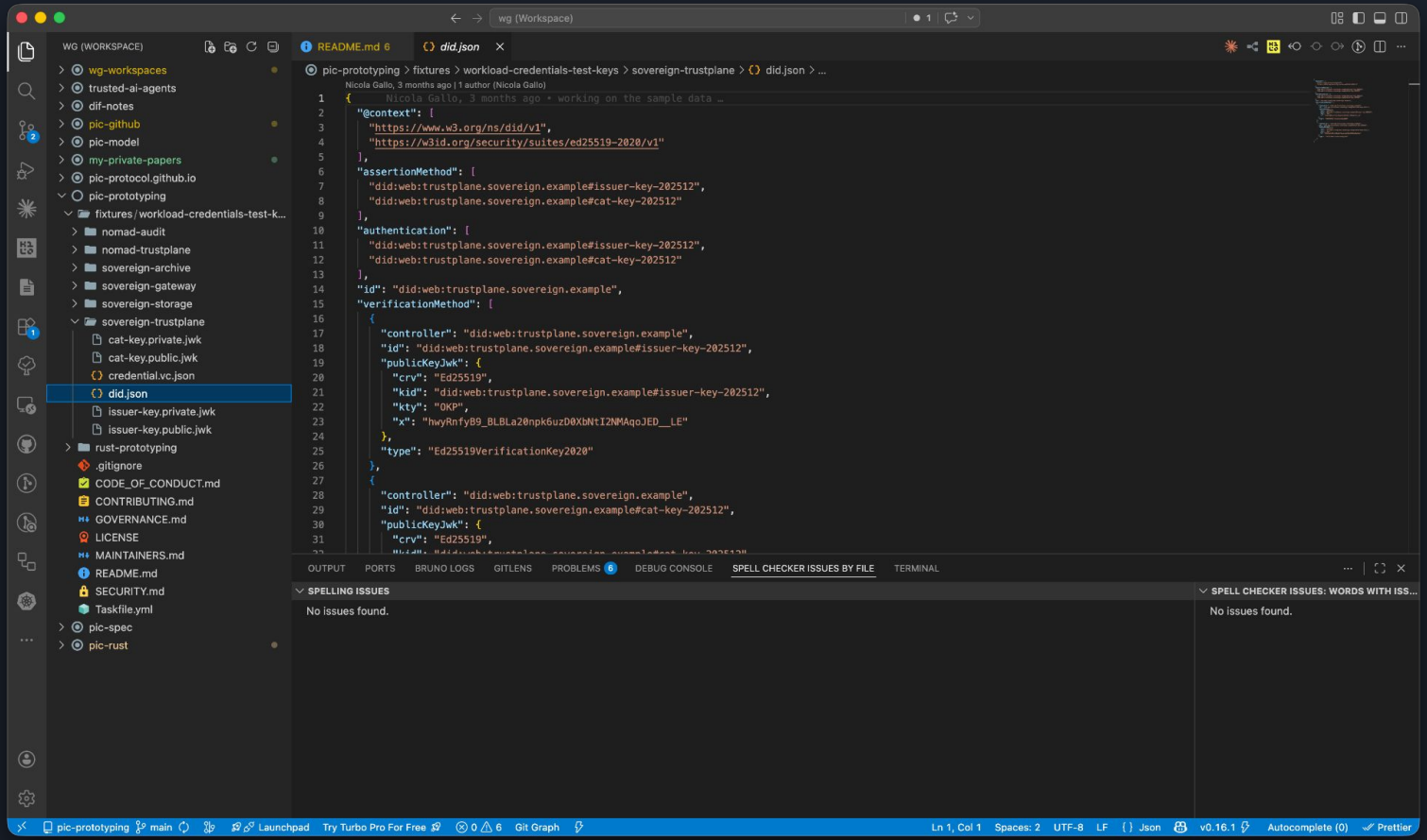

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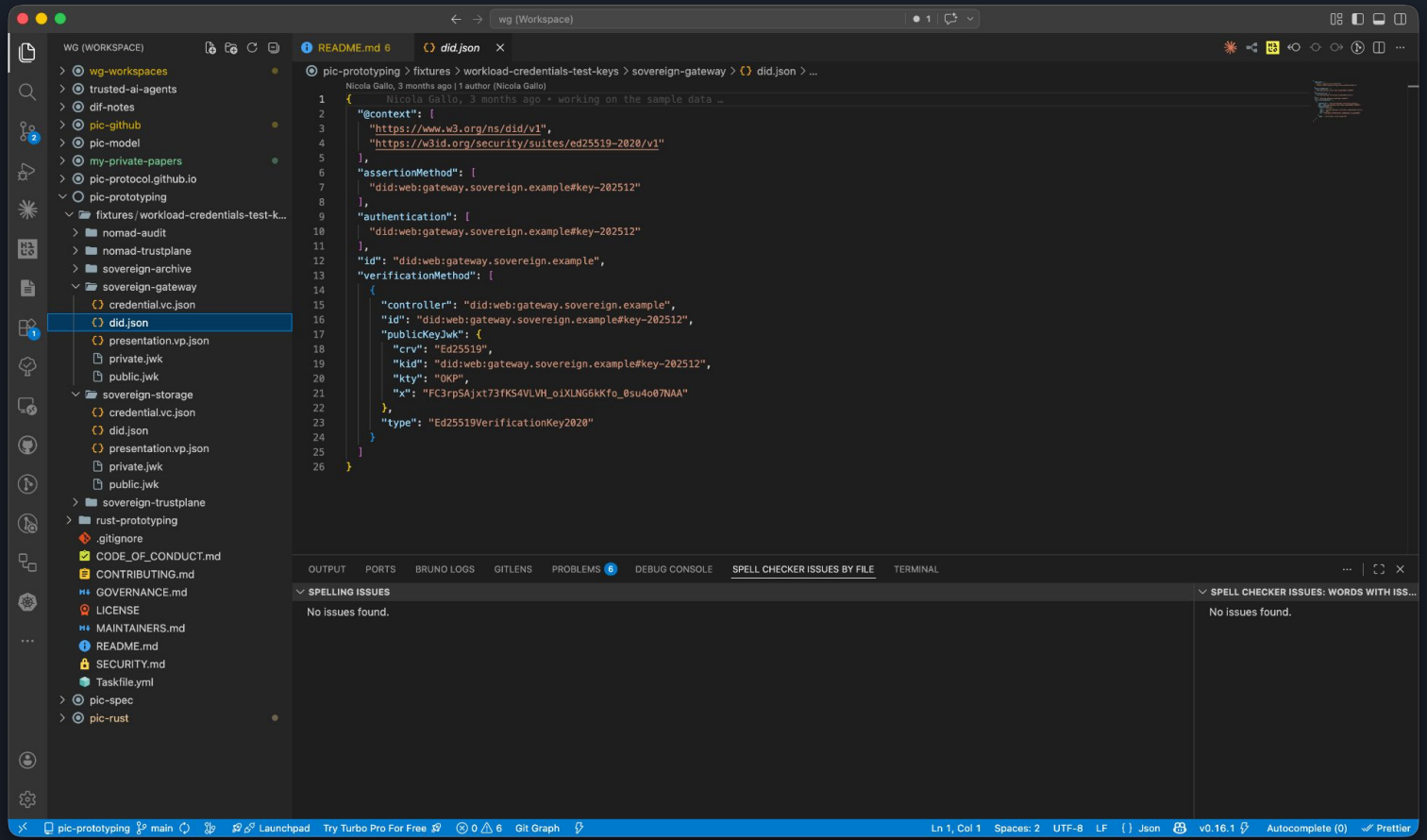
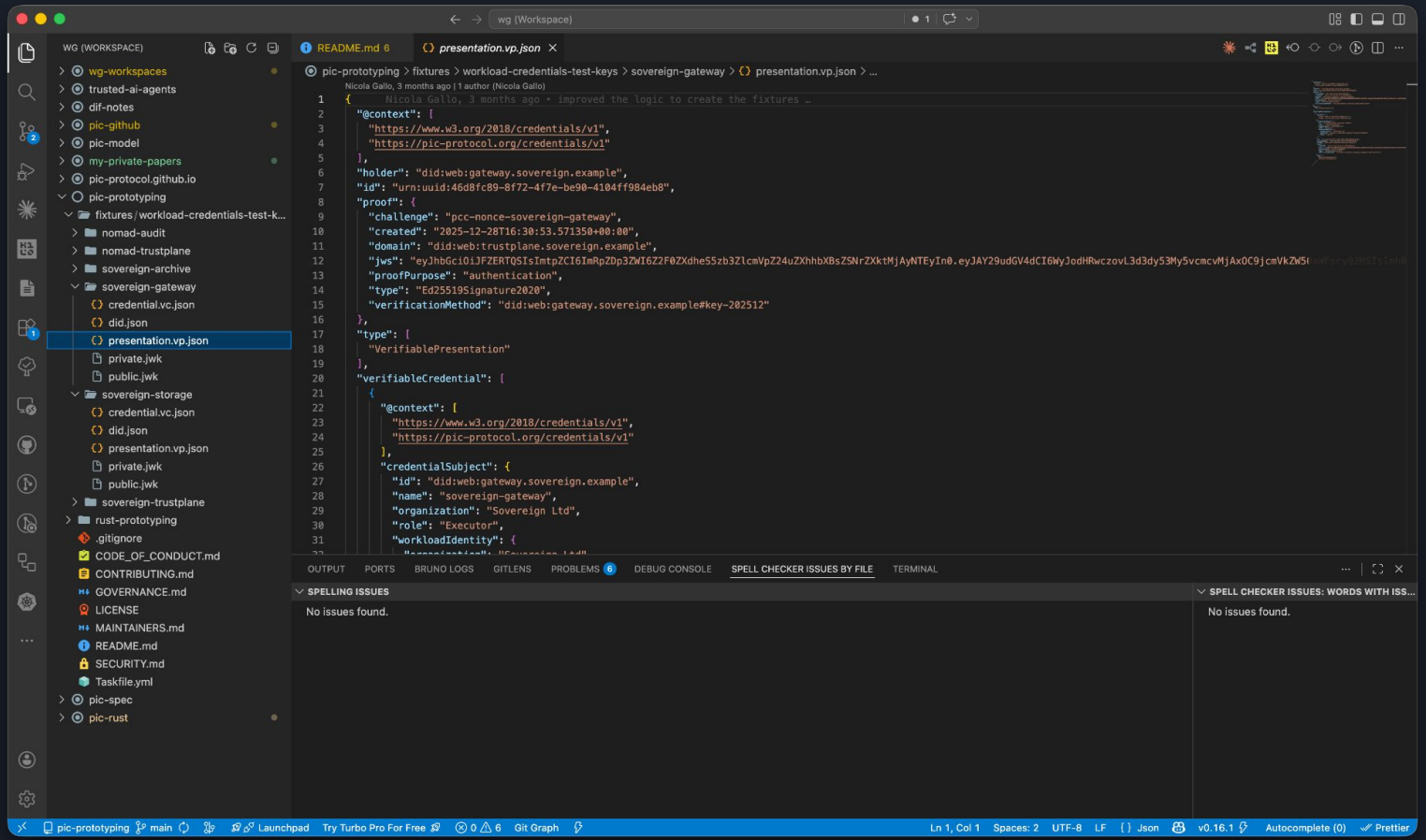
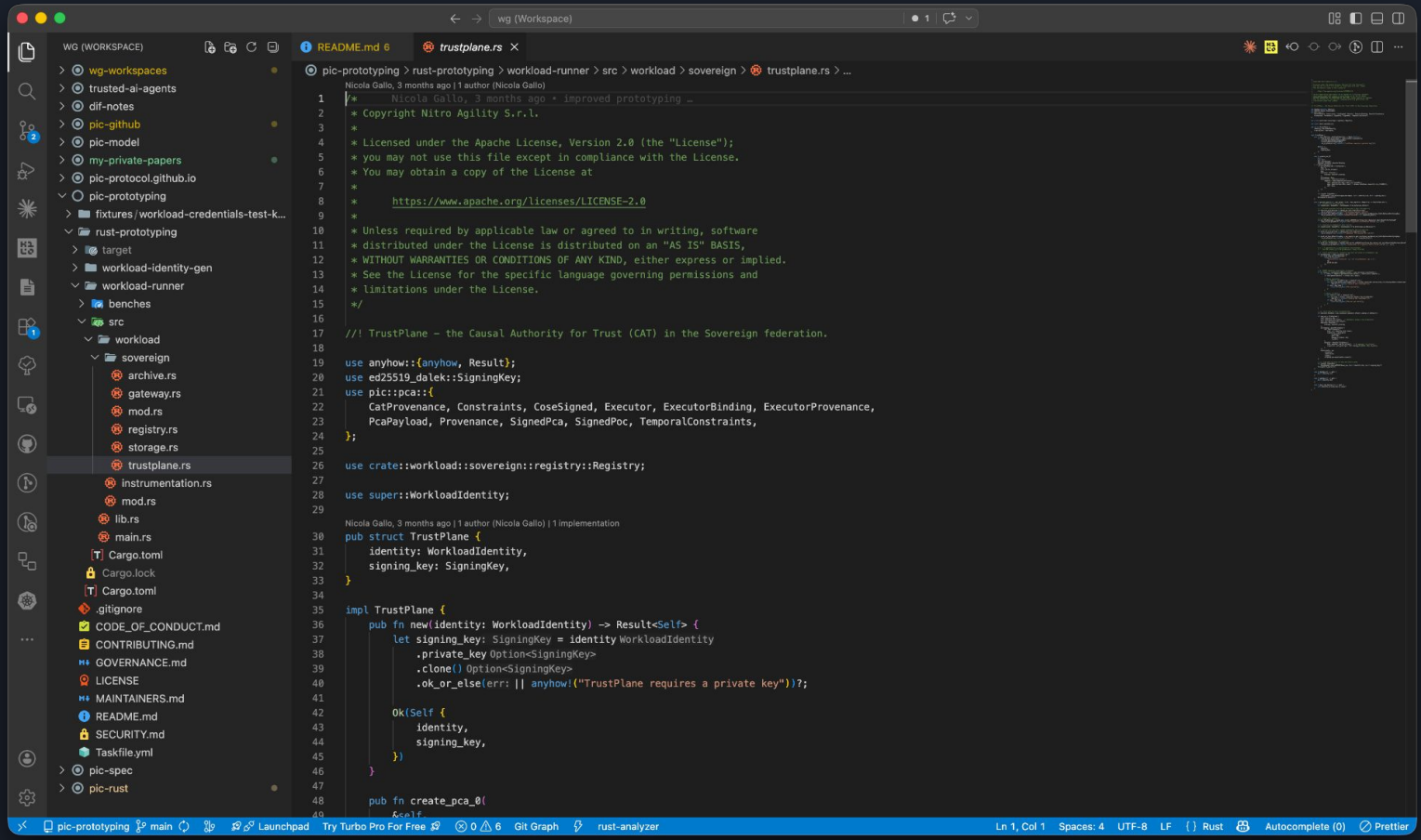


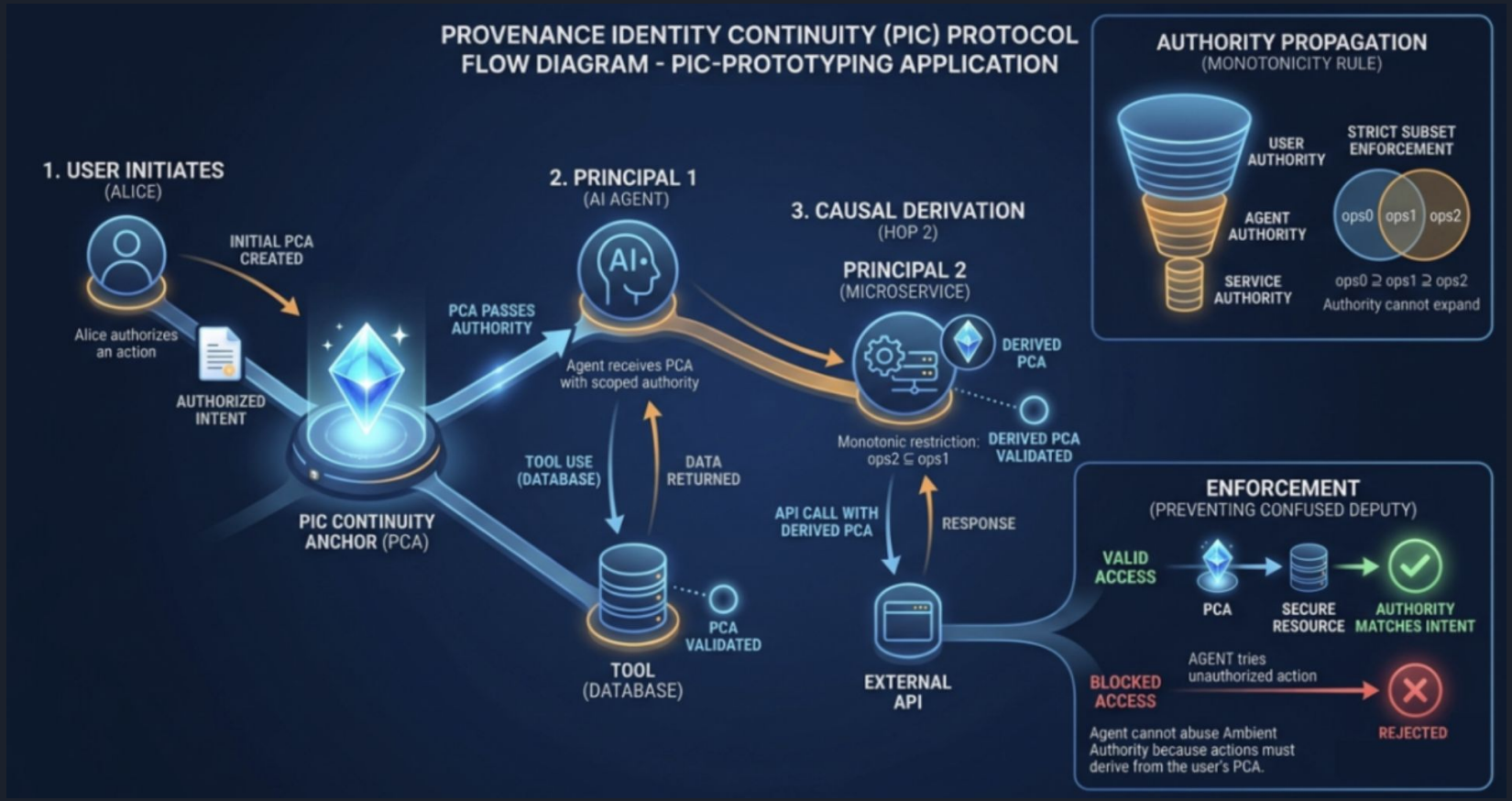
PIC DEMO



PIC DEMO



This implementation uses a decentralized approach, but PIC is deployment-agnostic. A centralized implementation based on WIMSE / Attestation is equally valid. We chose the decentralized path only to accelerate the first prototype.



Authority is not identity.

Authority is not possession.

Authority is continuity.

PIC is not just a protocol.
It is a correction of the model.
It is a new security primitive.

Get Involved

Website

www.pic-protocol.org

Specification

github.com/pic-protocol/pic-spec

Formal Model

Zenodo (DOI: 10.5281/zenodo.17833000)

PIC

www.pic-protocol.org

Not a Policy.
Not a Token.
An *Ontological Shift*
Proven Mathematically.

Thank you!

JOIN THE PIC SLACK CHANNEL

Appendixes

Crossing the OAuth Perimeter

Once past the gate, full PIC with Trust Planes. Authority is created, continued, and verified natively. No tokens, no re-materialization, no confused deputy in the security model itself.

PIC Enables

- Federated Trust Planes
- Partitioned security domains
- Zero-trust by construction
- Refactoring-invariant security

No need to rewrite everything

- Integrates with OAuth / OIDC
- Works with SPIFFE / DID
- Federate with existing IdPs
- Incremental adoption path

Transitional Path

1. Federate IdP with Trust Plane → 2. Exchange intent for PCA → 3. Embed PCA as custom claim → 4. Enter perimeter → PIC-native