Cedar: a new language for expressive, fast, safe, and analyzable authorization

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Joint work with

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What is authorization?

- Document authoring
- Social media
- Trouble Ticketing
- Payroll
- On-line gaming
- Project management
- Microservices

Determining ***who*** can do ***what*** in a multi-user application

What is hard about authorization?

The theory is known …

but hard to implement

- Role-based access control (**RBAC**)
- Attribute-based access control (**ABAC**)
- Relation-based access control (**ReBAC**)

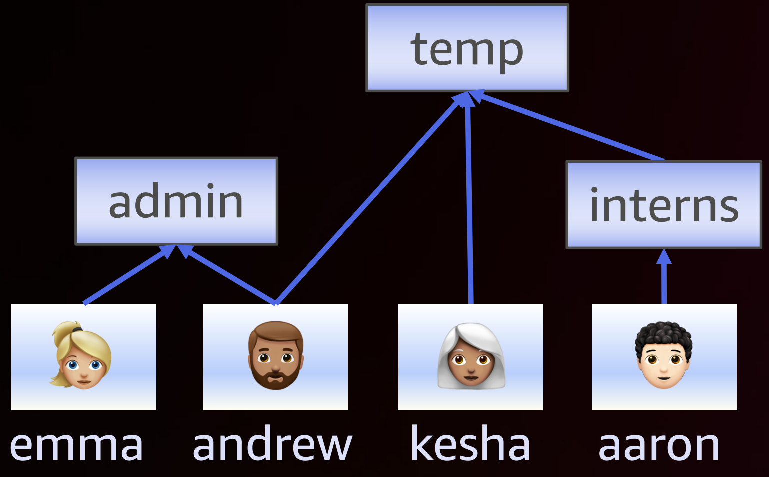
□ author
□ audit
□ maintain

What is hard about authorization? An example

TinyTodo✓

Allow **users and teams** to create, manage, and share **task lists**

- ❑ author
- ❑ audit
- ❑ maintain



List123

name: “Demo”
owner: User::"aaron"
editors: Team::”interns”
readers: Team::”temp”
tasks: […]

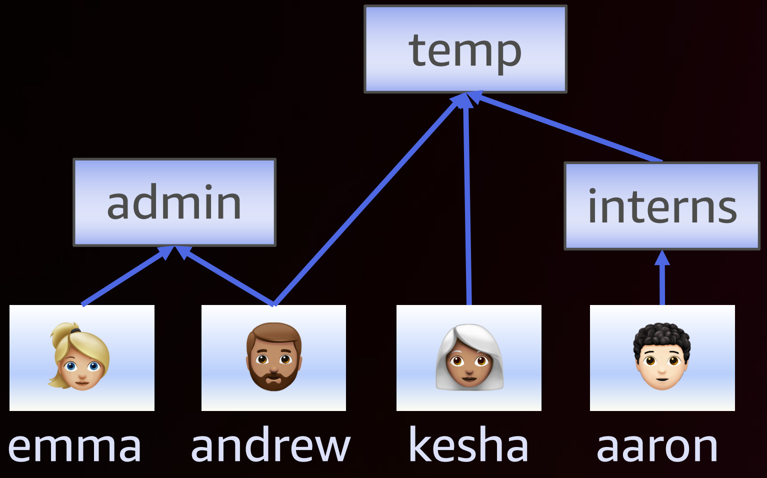
What is hard about authorization? An example

TinyTodo✓

Allow **users and teams** to create, manage, and share **task lists**

☒ author
☒ audit
☒ maintain

```
def get_list(request):
  if not request.user in db.query(admin):
   if db.query(request.listId).owner != request.user:
    if not request.user in db.query(request.listId).readers:
     if not request.user in db.query(request.listId).editors:
      return 'AccessDenied'
  list = db.query(request.listId)
  return { 'id': list.id, 'owner': list.owner, ... }
```



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tasks: […]

List123

Better authorization: policies as code

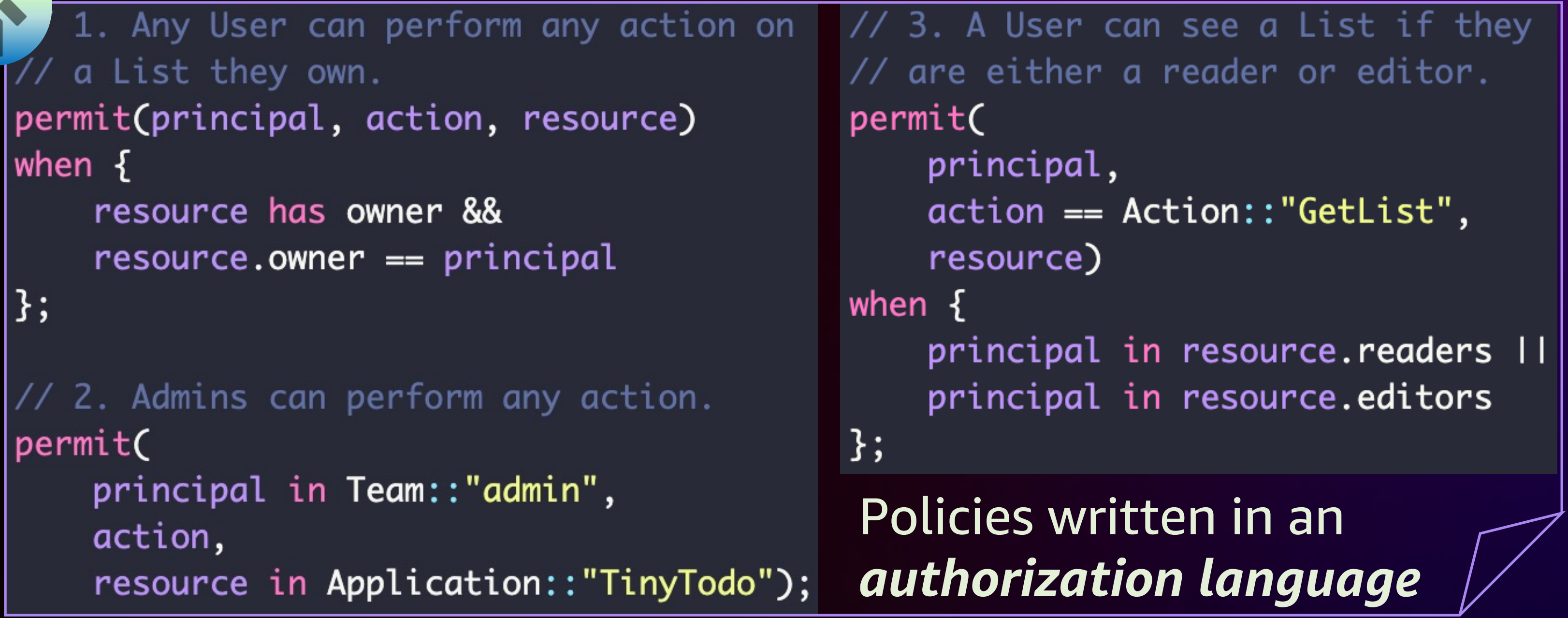
TinyTodo✓

Allow users and teams to create, manage, and share task lists

☑ author
☑ audit
☑ maintain

```
def get_list(request):
  if not is_authorized(request):
    return 'AccessDenied'
  list = db.query(request.listId)
  return { 'id': list.id, 'owner': list.owner, ... }
```

Delegate decision to an ***authorization engine***



```
   1. Any User can perform any action on
// a List they own.
permit(principal, action, resource)
when {
    resource has owner &&
    resource.owner == principal
};

// 2. Admins can perform any action.
permit(
    principal in Team::"admin",
    action,
    resource in Application::"TinyTodo");
```

```
// 3. A User can see a List if they
// are either a reader or editor.
permit(
    principal,
    action == Action::"GetList",
    resource)
when {
    principal in resource.readers ||
    principal in resource.editors
};
```

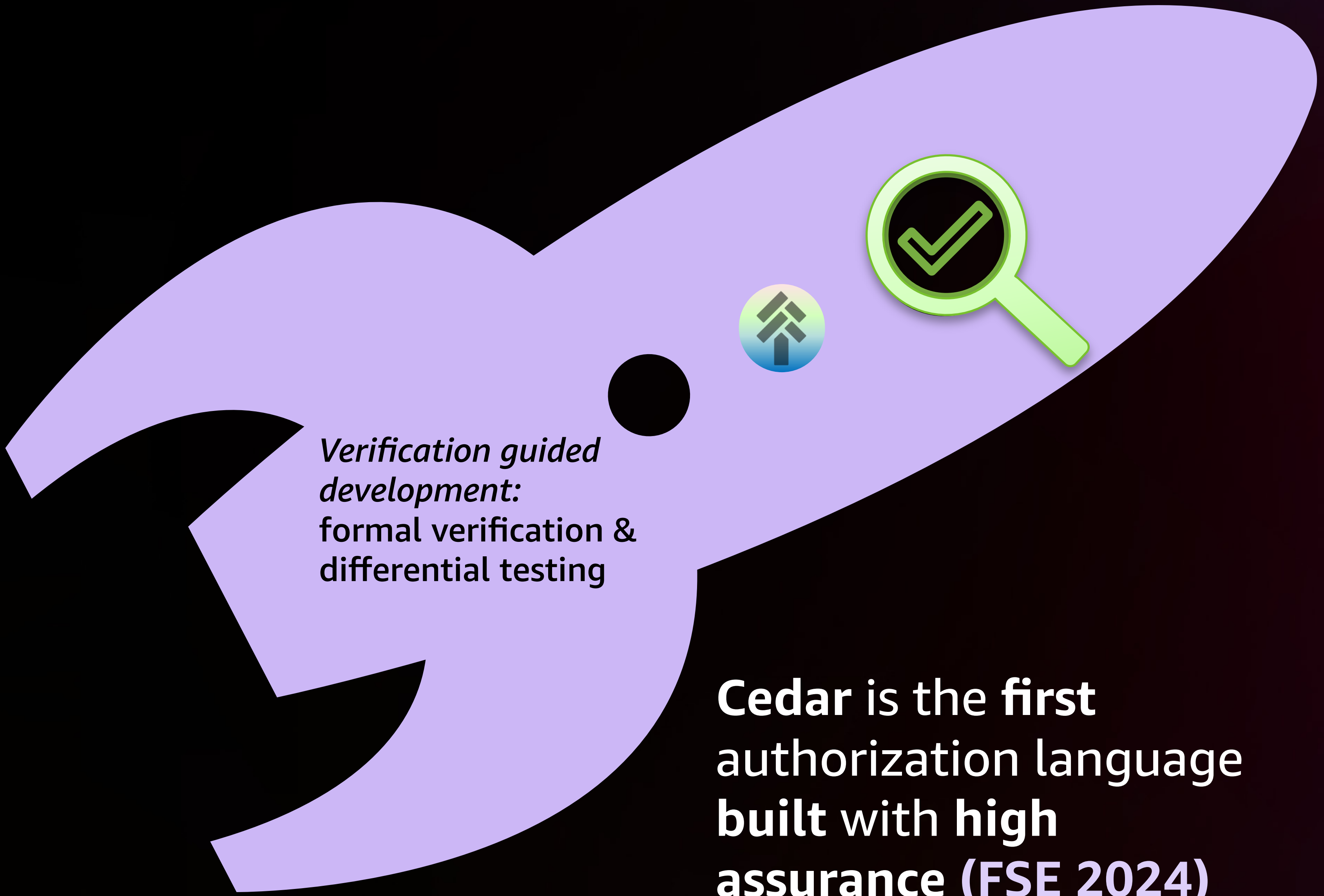
Policies written in an ***authorization language***

Cedar: a new authorization language

Powers Amazon Verified Permissions and AWS Verified Access

Open source at https://github.com/cedar-policy

What is unique about Cedar?



Verification guided development:
formal verification &
differential testing

Ergonomics

Expressiveness

Safety

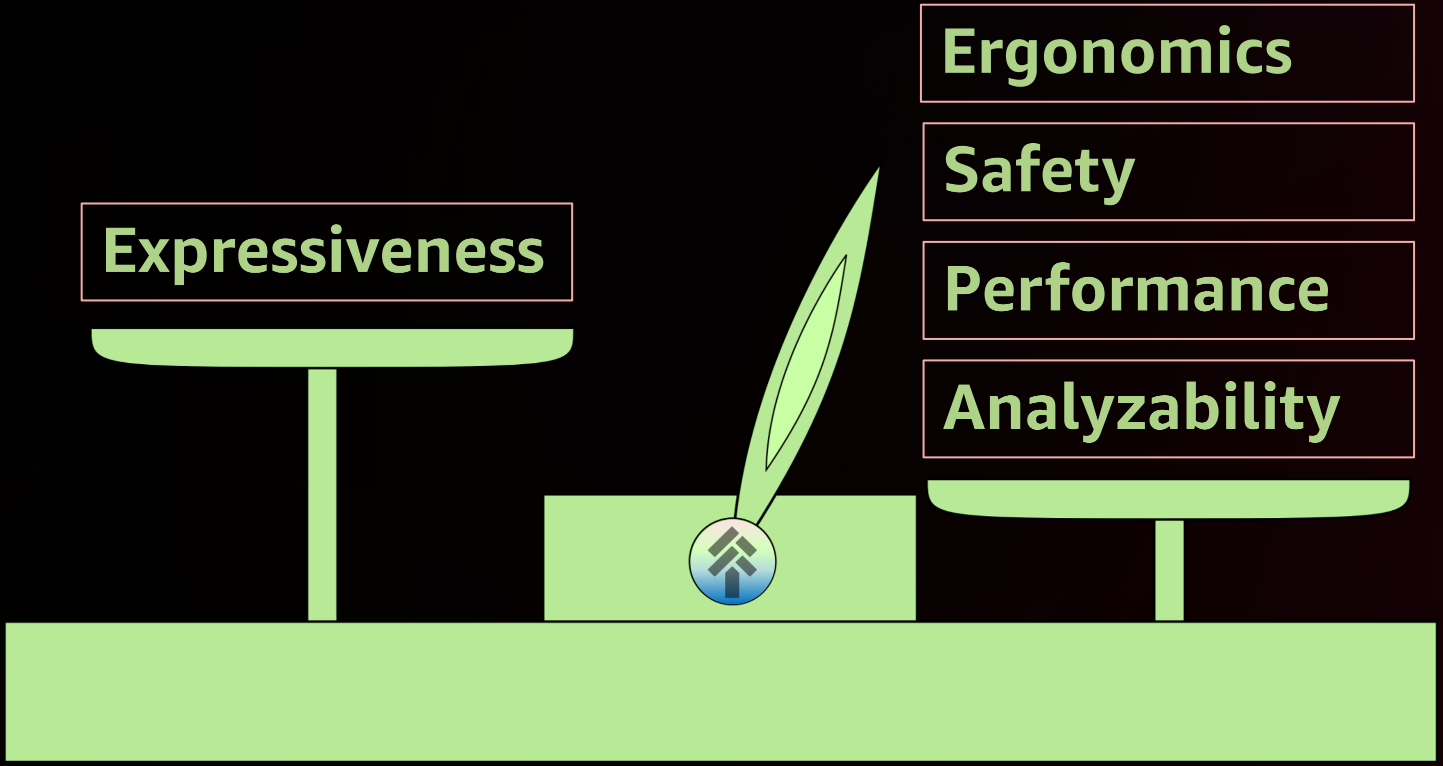
Performance

Analyzability

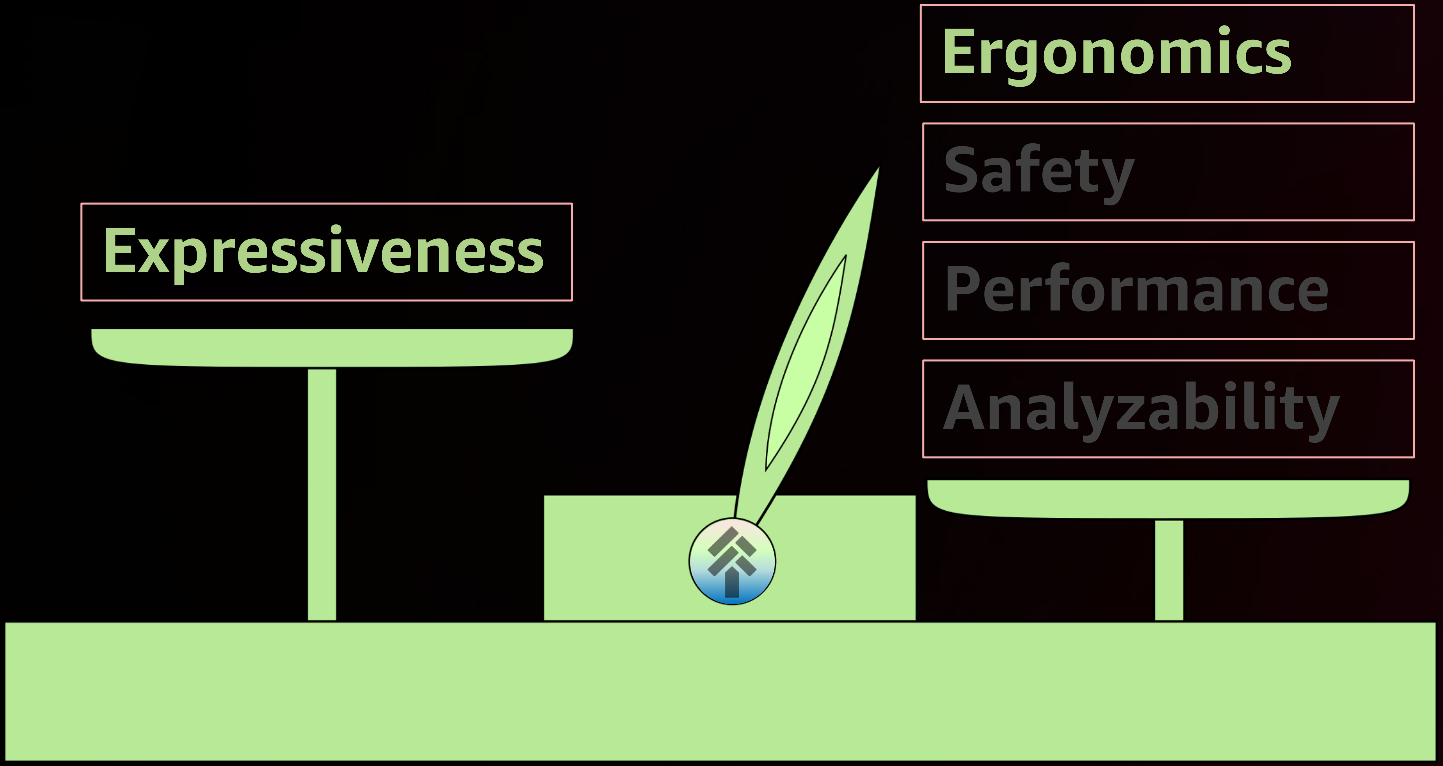
Cedar is the **first** authorization language **built** with **high assurance** (FSE 2024)

Cedar offers a **new way** to **balance** these criteria to achieve **analyzability** (OOPSLA 2024)

Cedar: design & development highlights



Cedar: design & development highlights



Expressiveness

Ergonomics

Safety

Performance

Analyzability

Syntax

Policy

```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
```

Effect: either `permit` or `forbid`

Scope: (optionally) constrains the `principal`, `action`, and `resource` using == and `in`

Condition(s): boolean expression prefixed by `when` or `unless` that further constrains access

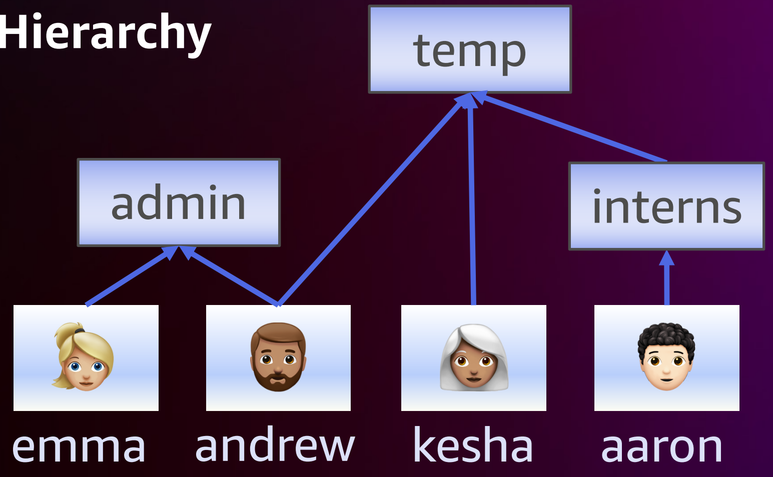
Syntax, data model

Policy

```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
```

Application ***entities*** with ***hierarchy*** and ***attributes***

Entities: Hierarchy



Entities: Attributes

List123

name: “Demo”
owner: User::"aaron"
editors: Team::”interns”
readers: Team::”temp”
tasks: […]

Syntax, data model

Policy

```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
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};
```
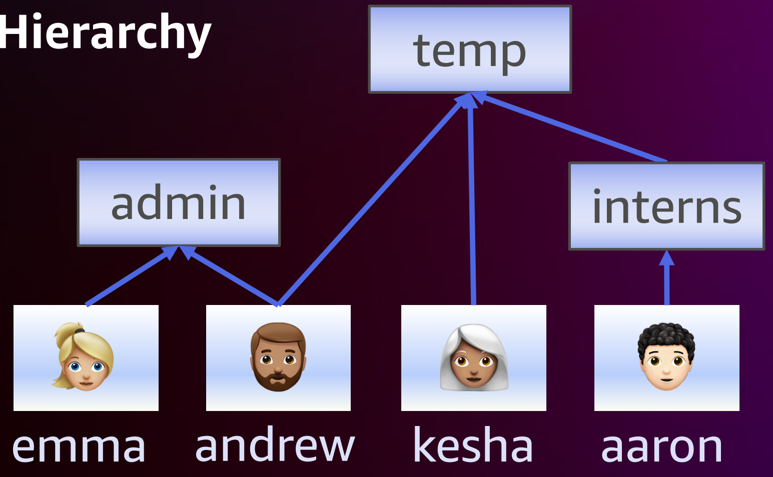
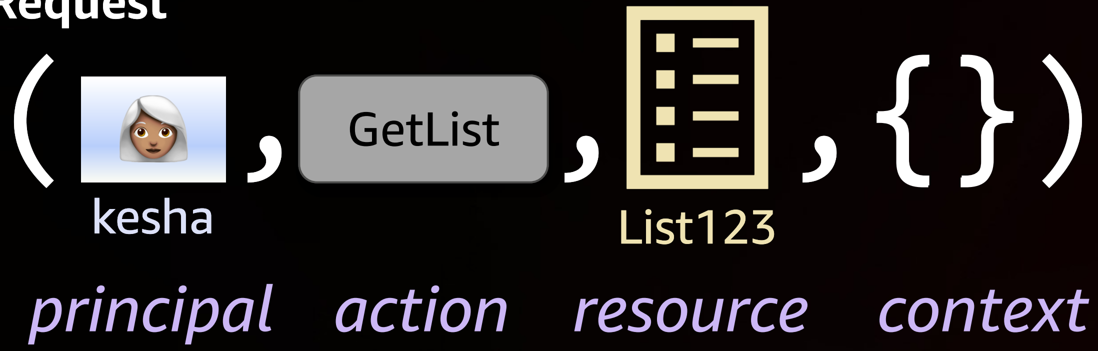

Entities: Hierarchy



Request



Entities: Attributes

List123

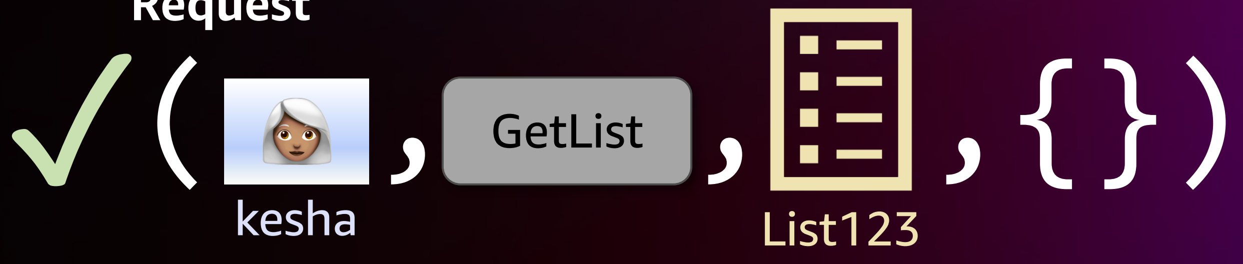
name: “Demo”
owner: User::"aaron"
editors: Team::”interns”
readers: Team::”temp”
tasks: […]

Syntax, data model, and semantics

Policy

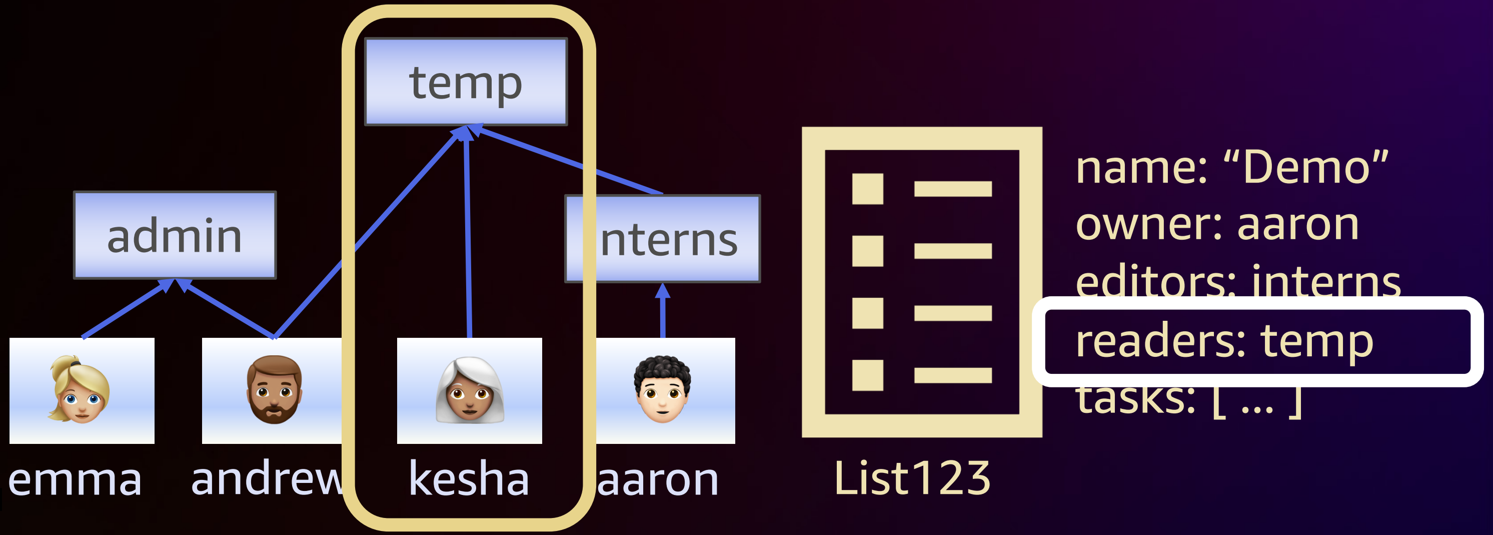
```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
```

Request



Request allowed when:

- it satisfies *at least one* **permit**
- and *no* **forbid** policies



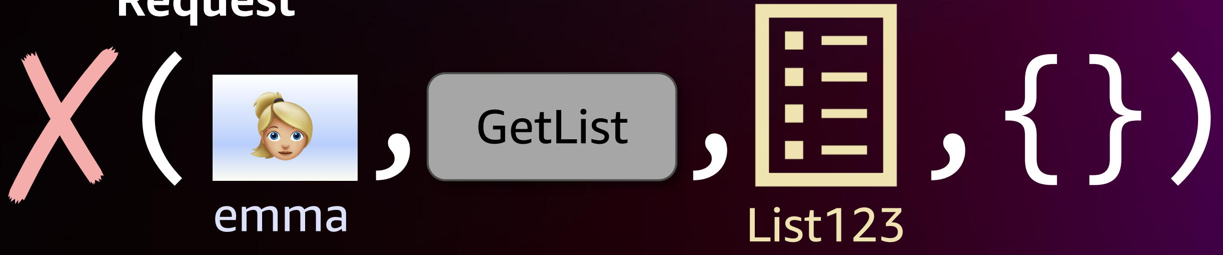
name: “Demo”
owner: aaron
editors: interns
readers: temp
tasks: […]

Syntax, data model, and semantics

Policy

```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
```

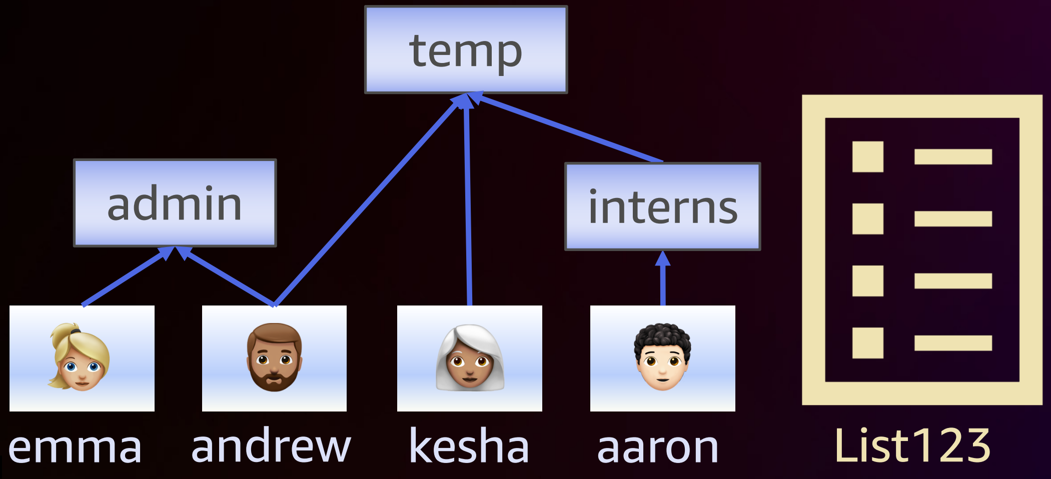
Request



(Default deny)

Request allowed when:

- it satisfies *at least one* **permit**
- and *no* **forbid** policies



name: “Demo”
owner: aaron
editors: interns
readers: temp
tasks: […]

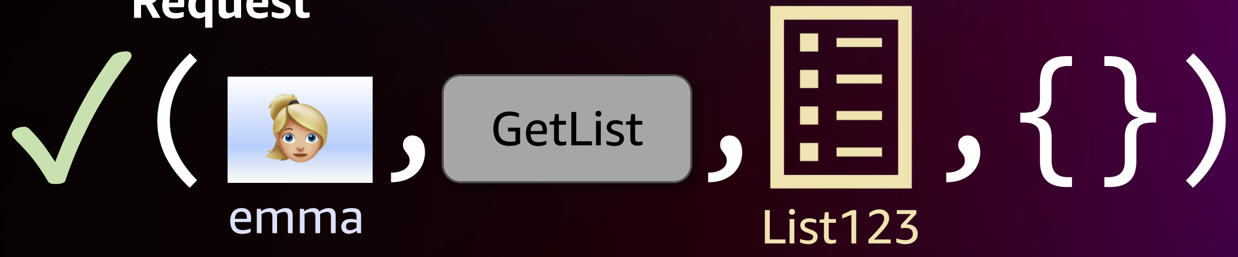
Syntax, data model, and semantics

Policy

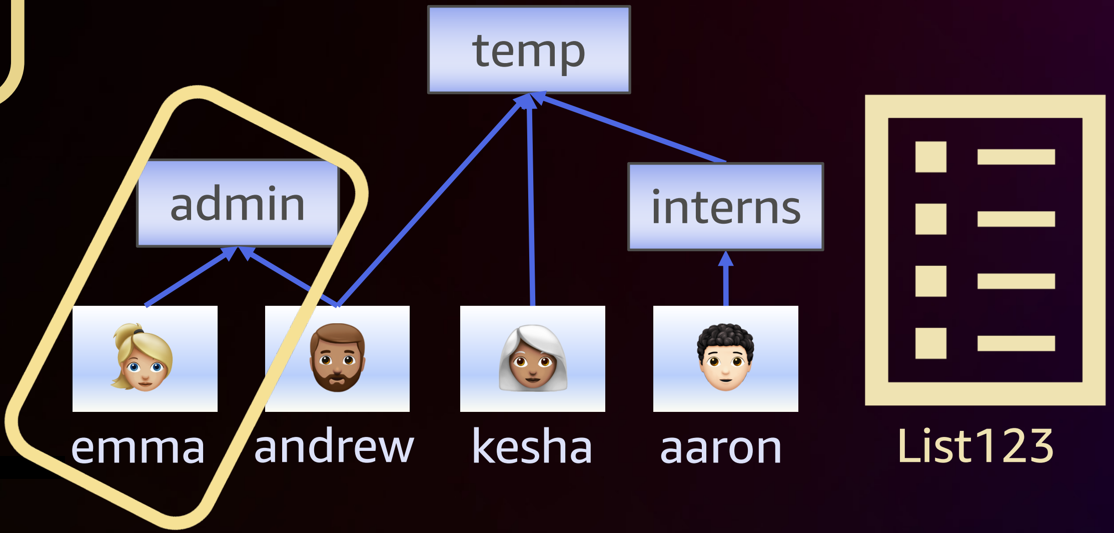
```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
```

```
permit (
  principal in Team::"admin",
  action,
  resource);
```

Request



✓ (emma , GetList , List123 , {})



temp

admin

interns

emma

andrew

kesha

aaron

List123

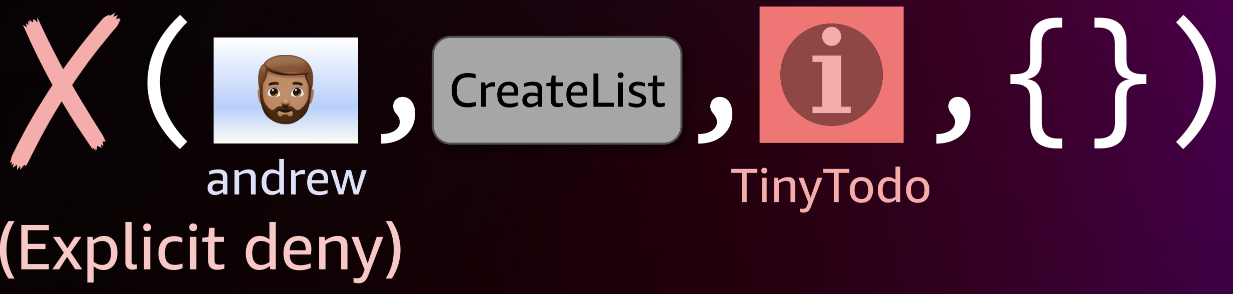
name: “Demo”
owner: aaron
editors: interns
readers: temp
tasks: […]

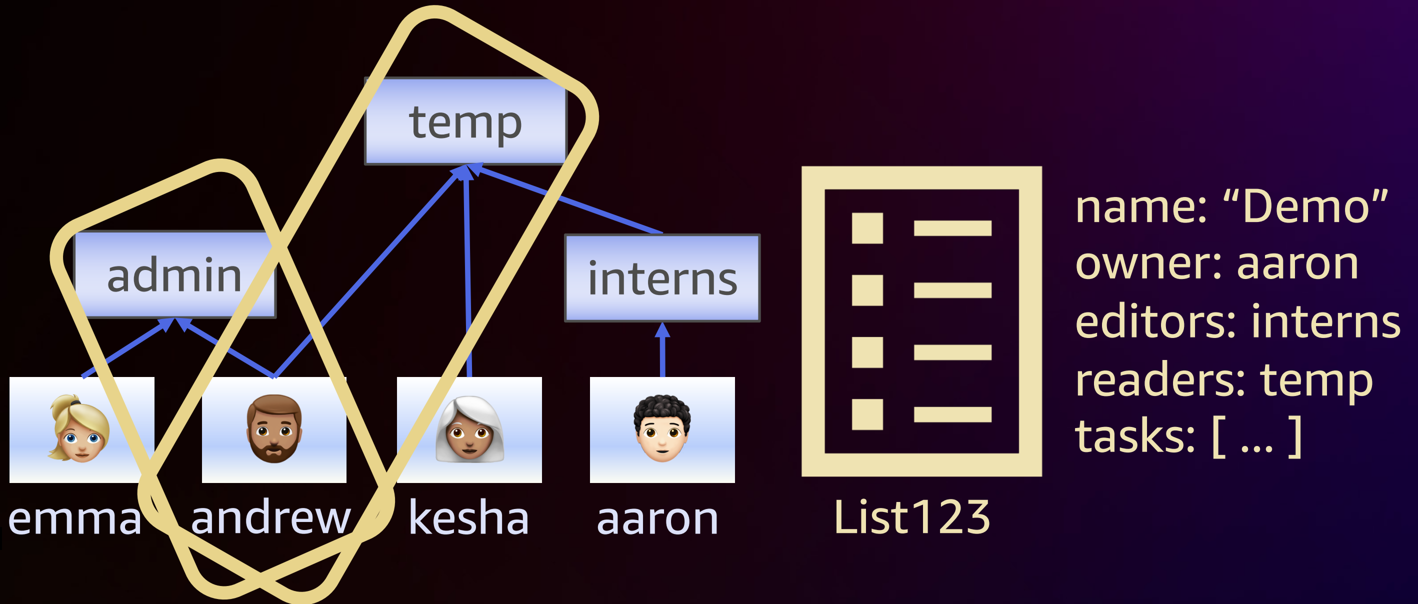
Syntax, data model, and semantics

Policy

```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
permit (
  principal in Team::"admin",
  action,
  resource);
forbid (
  principal in Team::"temp",
  action == Action::"CreateList",
  resource == Application::"TinyTodo";
```

Request





Syntax, data model, and semantics for …

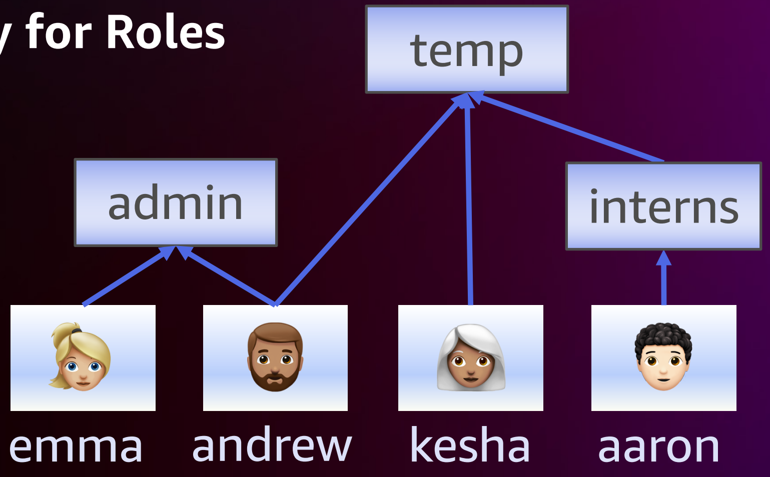
- role-based access control (RBAC)
- attribute-based access control (ABAC)
- relation-based access control (ReBAC)

Syntax, data model, and semantics: RBAC

```
permit (
  principal in Team::"admin",
  action,
  resource);

forbid (
  principal in Team::"temp",
  action == Action::"CreateList",
  resource == Application::"TinyTodo");
```

in: transitive membership

Hierarchy for Roles



Key idea for O(1) **in** checks: it operates on the *transitive closure* of the entity hierarchy, given as a map from entities to their ancestors (sets of entities).

name: “Demo”
owner: User::"aaron"
editors: Team::”interns”
readers: Team::”temp”
tasks: […]

List123

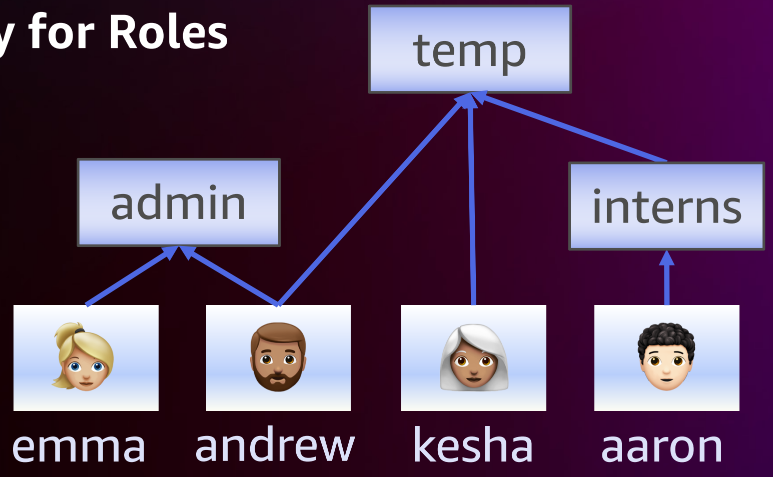
Syntax, data model, and semantics: ABAC

```
permit (
  principal,
  action,
  resource)
when {
  resource has owner &&
  resource.owner == principal
};
```

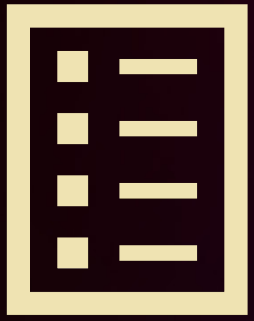
Conditions are **pure, loop-free expressions**: **==** , **in**, set membership, conditionals, **!**, **&&**, **||**, wildcard matching, …

Evaluation time **O(n)** typical, **O(n³)** worst case

Hierarchy for Roles



Attributes for Conditions

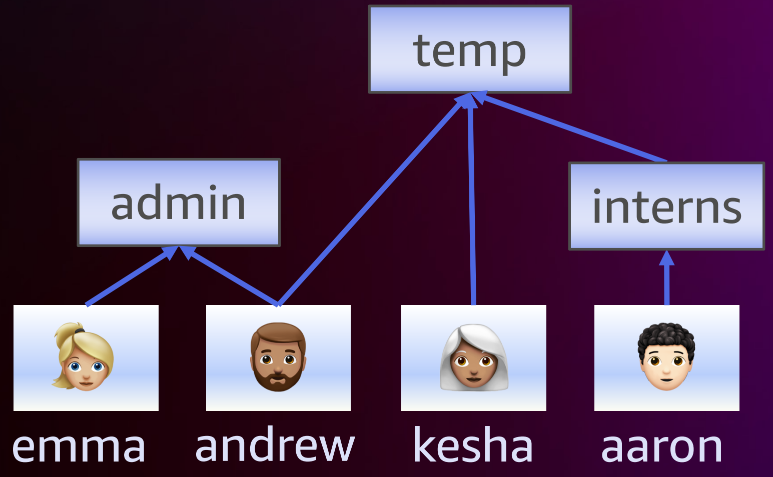


name: “Demo”
owner: User::"aaron"
editors: Team::”interns”
readers: Team::”temp”
tasks: […]

Syntax, data model, and semantics: ReBAC

```
permit (
  principal,
  action == Action::"GetList",
  resource)
when {
  principal in resource.readers ||
  principal in resource.editors
};
```

Hierarchy
+ Attributes
= Relations

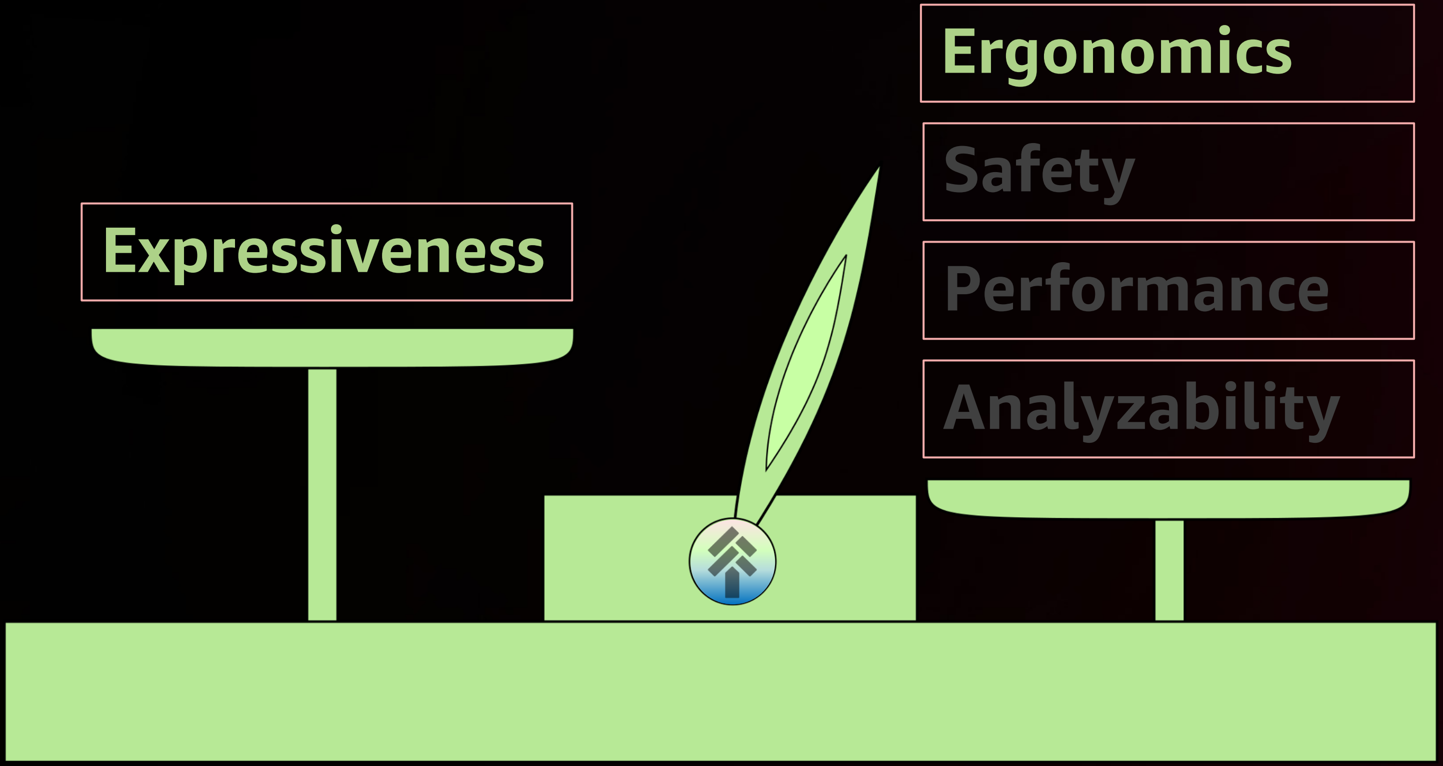


"principal *is related to* resource via the readers relation
or
principal *is related to* resource via the editors relation"

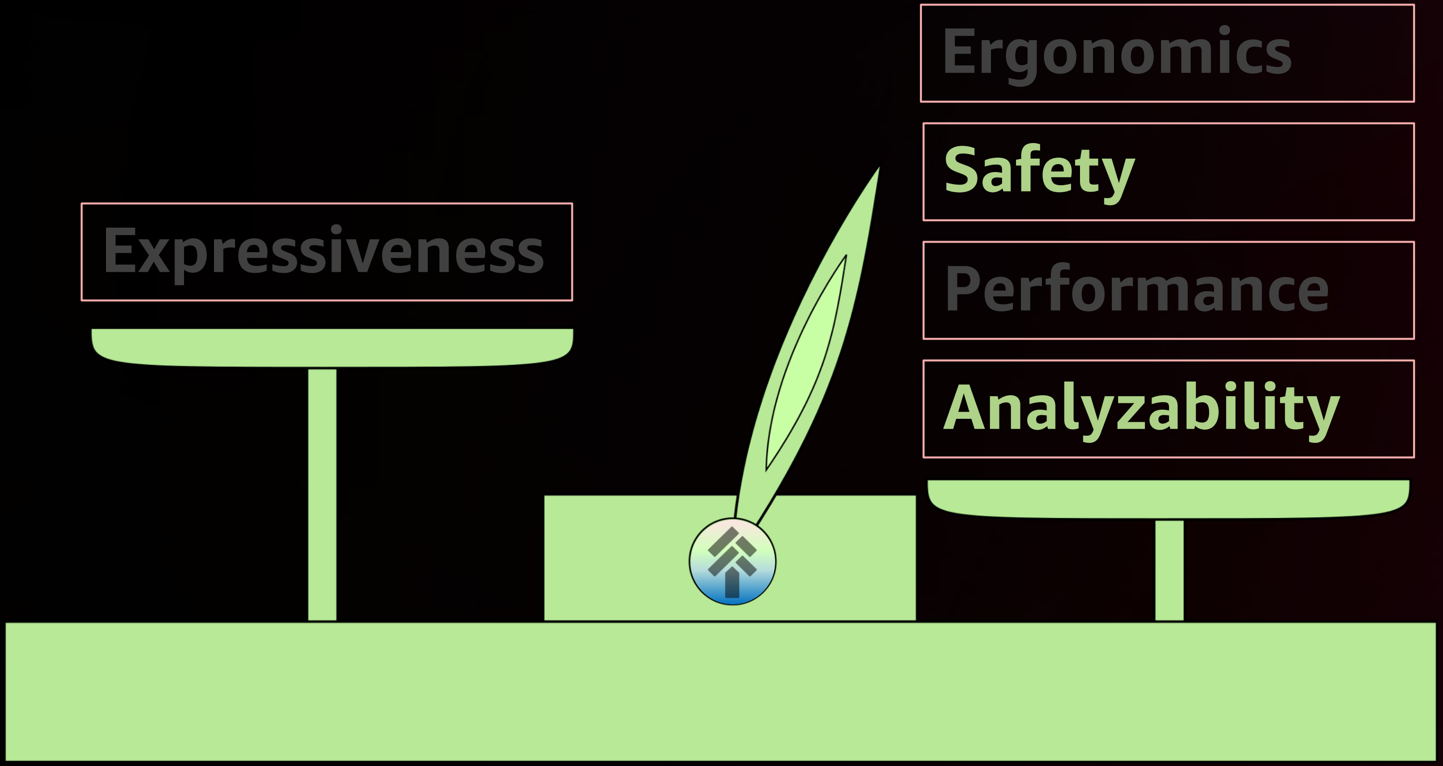
name: "Demo"
owner: User::"aaron"
editors: Team::"interns"
readers: Team::"temp"
tasks: [...]

List123

Cedar: design & development highlights



Cedar: design & development highlights



Policy validation for safety

```
permit(
 principal,
 action == Action::"GetList",
 resource)
when {
 principal in resource.readers ||
 principal in resource.editors
};
```

Valid?

```
entity Application;
entity Team, User in [Team];
entity List {
  readers: Team,
  editors: Team,
  owner: User,
  tasks: Set<Task>,
  name: String
};
action GetList appliesTo {
  principal: [User],
  resource: [List]
};
```

Schema

Can detect: improper entity relationship, misspelling of action, unrecognized attributes, illegal operations, …

Key features: path-sensitive request-type handling, flow-sensitive capability tracking, singleton types

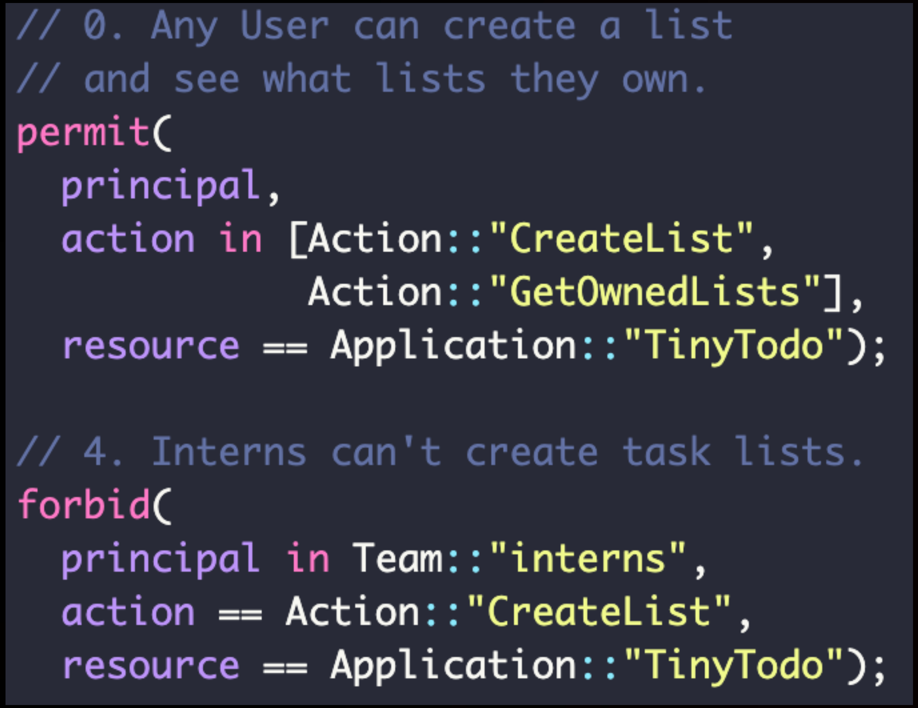
Theorem (soundness): If validation succeeds, policy evaluation will exhibit no run-time type errors.

Policy analysis for semantic reasoning

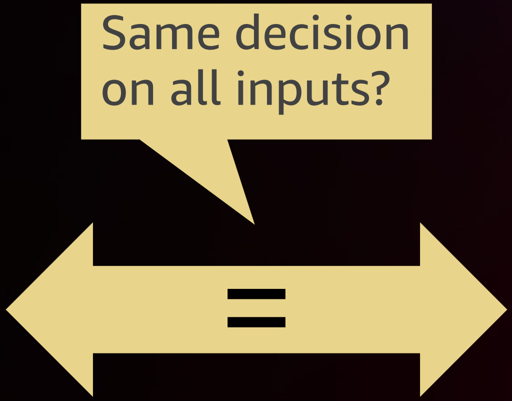
Answers ***universal*** questions about the behavior of policies on ***all*** possible inputs—all requests and entities

Example (equivalence): do two (sets of) policies produce the same decision on all inputs?

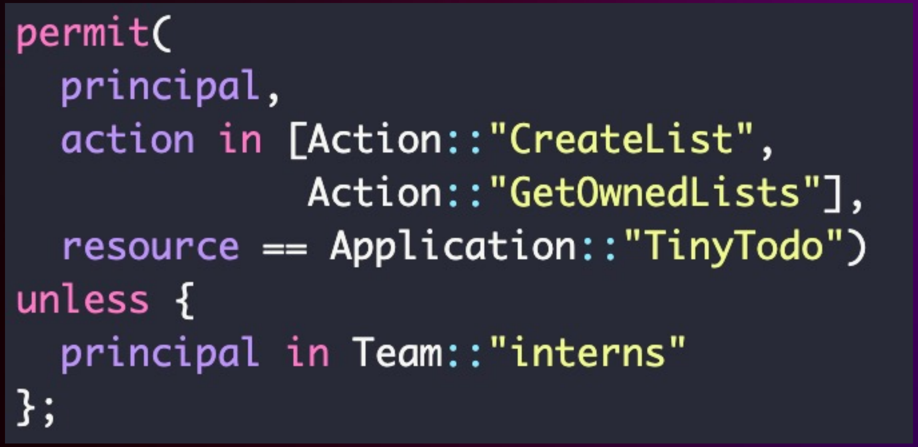
Example policy analysis: equivalence



```
// 0. Any User can create a list
// and see what lists they own.
permit(
  principal,
  action in [Action::"CreateList",
             Action::"GetOwnedLists"],
  resource == Application::"TinyTodo");

// 4. Interns can't create task lists.
forbid(
  principal in Team::"interns",
  action == Action::"CreateList",
  resource == Application::"TinyTodo");
```

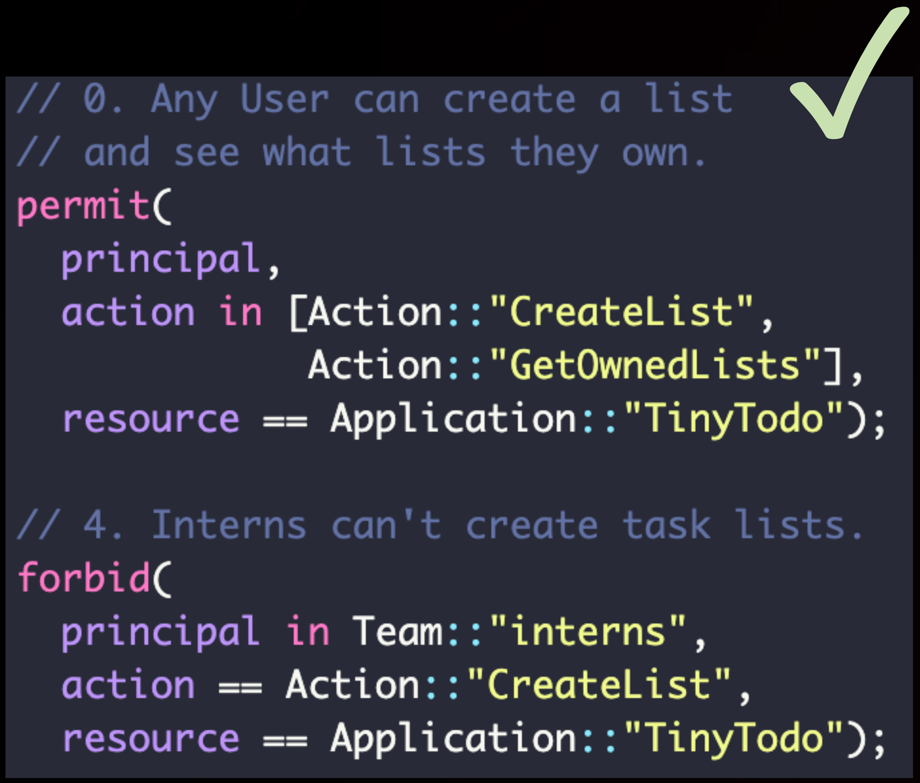


Same decision on all inputs?



```
permit(
  principal,
  action in [Action::"CreateList",
             Action::"GetOwnedLists"],
  resource == Application::"TinyTodo")
unless {
  principal in Team::"interns"
};
```

Example policy analysis: equivalence



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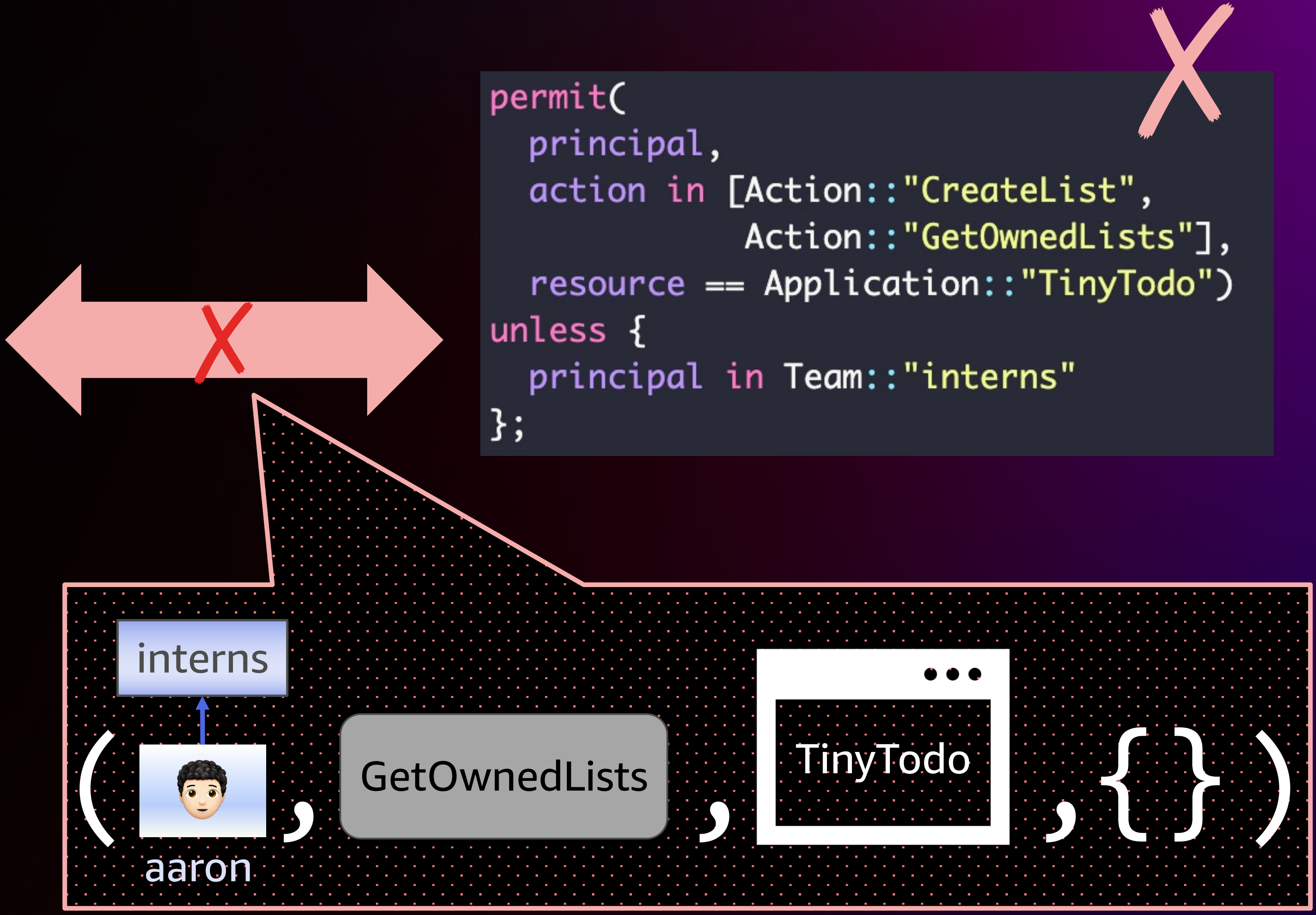

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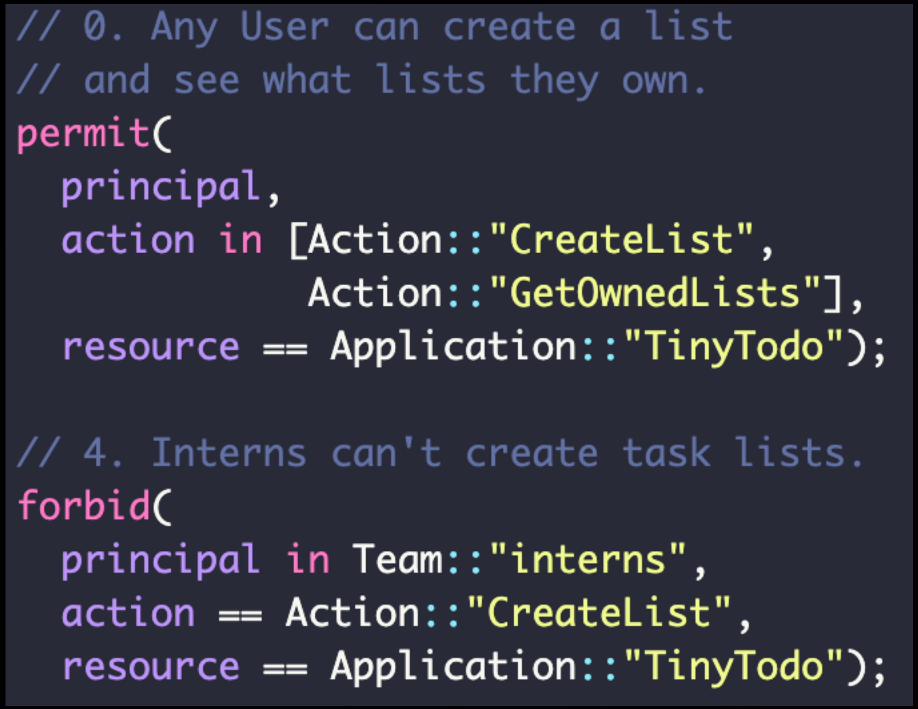
Example policy analysis: equivalence



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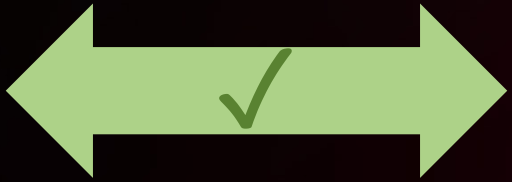
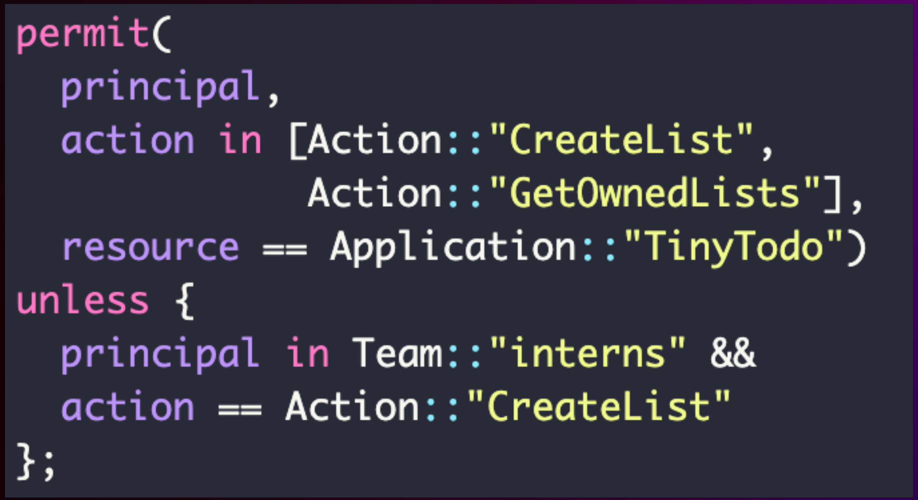




```
permit(
  principal,
  action in [Action::"CreateList",
             Action::"GetOwnedLists"],
  resource == Application::"TinyTodo")
unless {
  principal in Team::"interns" &&
  action == Action::"CreateList"
};
```

Works by **symbolically compiling** policies to logical formulas, and using an **SMT solver** to check that the negation of the desired property is unsatisfiable.

Policy analysis by symbolic compilation to SMT

Schema

Expression

$$M,\Gamma \vdash e \downarrow t$$

Symbolic environment

Symbolic term

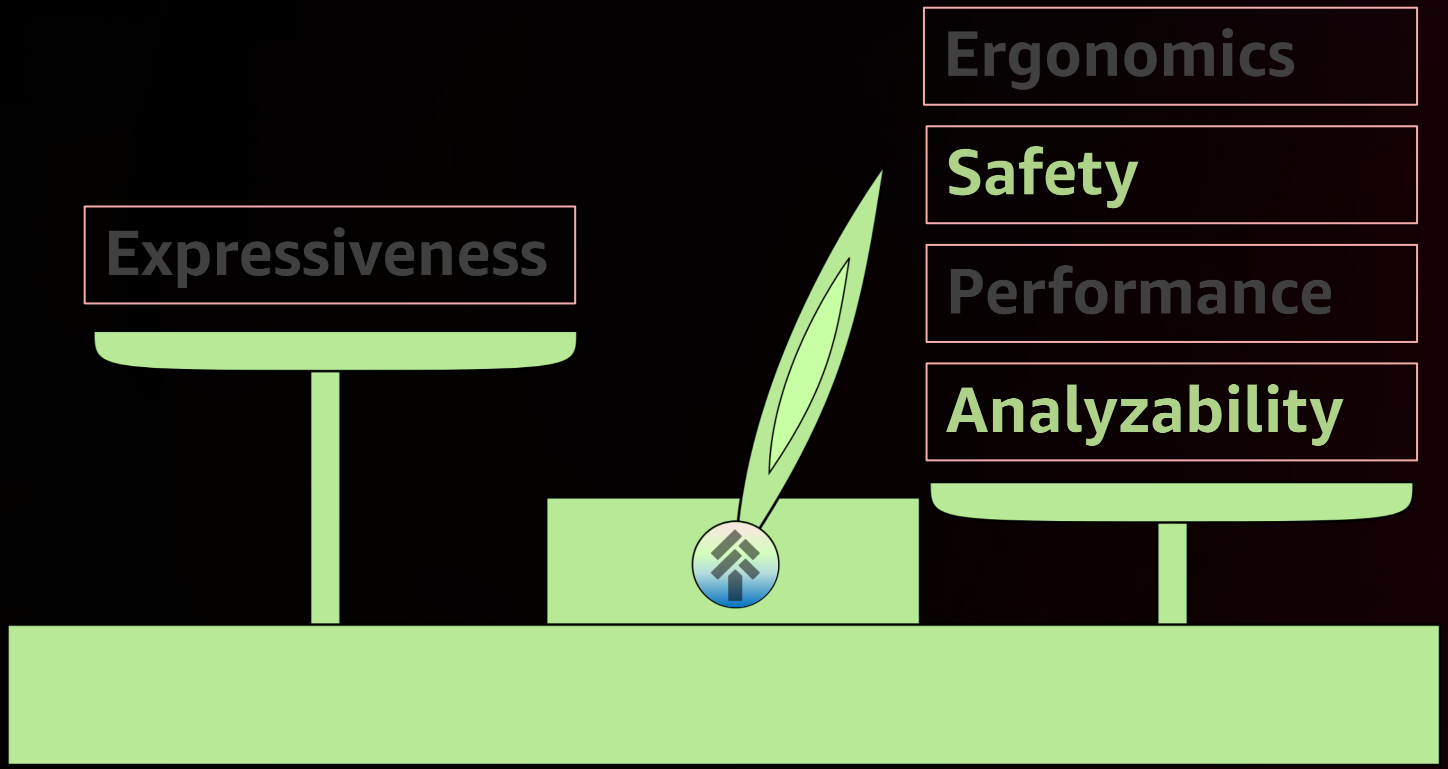
Key challenge: how to encode the fact that hierarchies are DAGs while remaining decidable (i.e., without transitive closure or quantifiers)?

Symbolic compilation: type-directed reduction to a ***decidable*** fragment of SMT (uninterpreted functions, bitvectors, strings, ADTs, and finite sets)

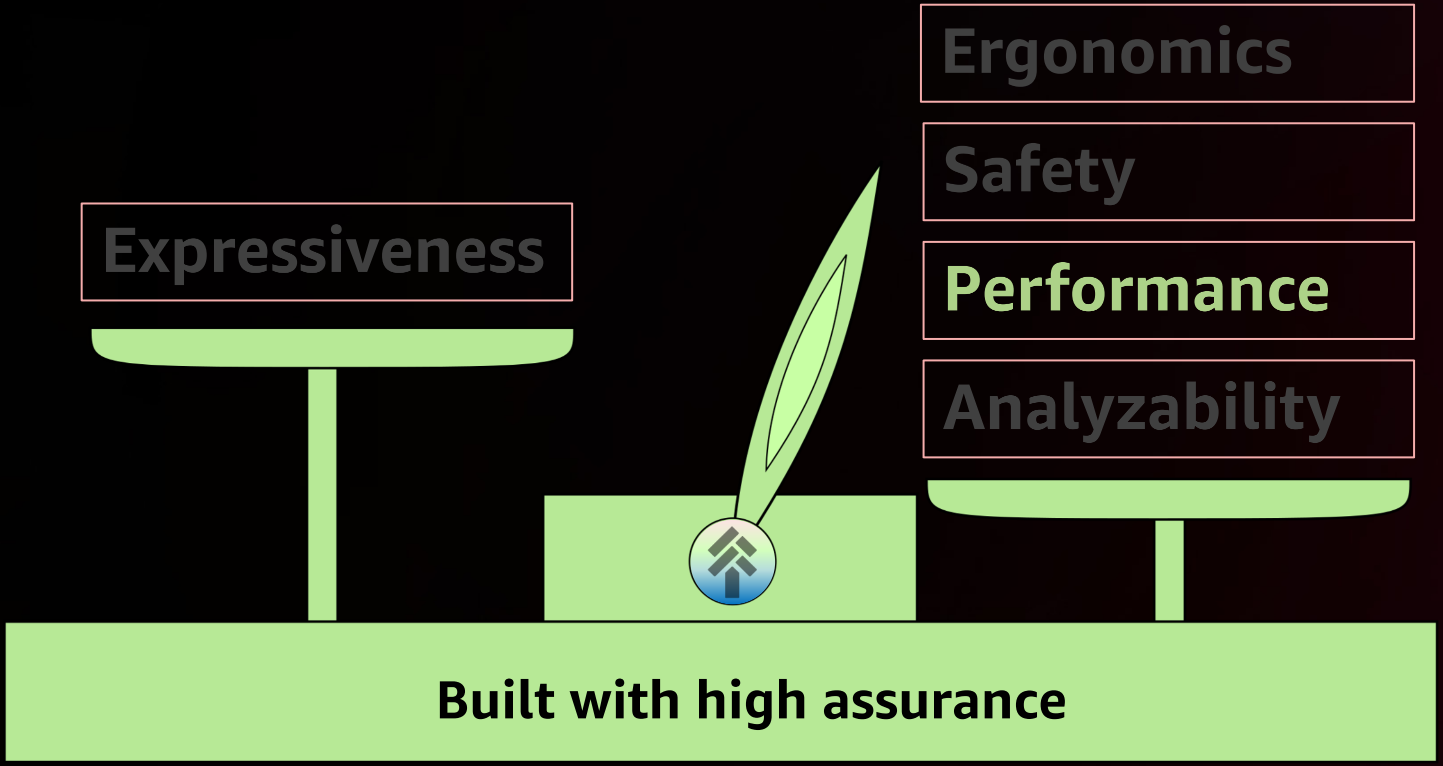
Solution: observe that an expression ***e*** can access only a finite set of entities. Compute an overapproximation of that set, and use it to ground acyclicity and transitivity constraints on hierarchies.

Theorem (soundness and completeness): policy analysis based on symbolic compilation produces no false negatives and no false positives.

Cedar: design & development highlights

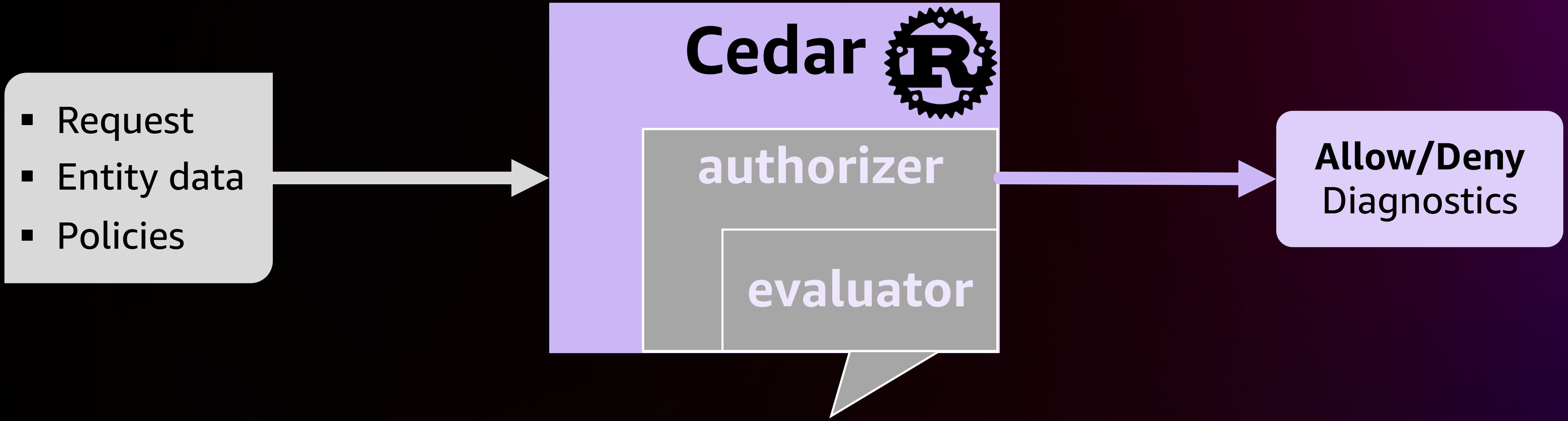


Cedar: design & development highlights



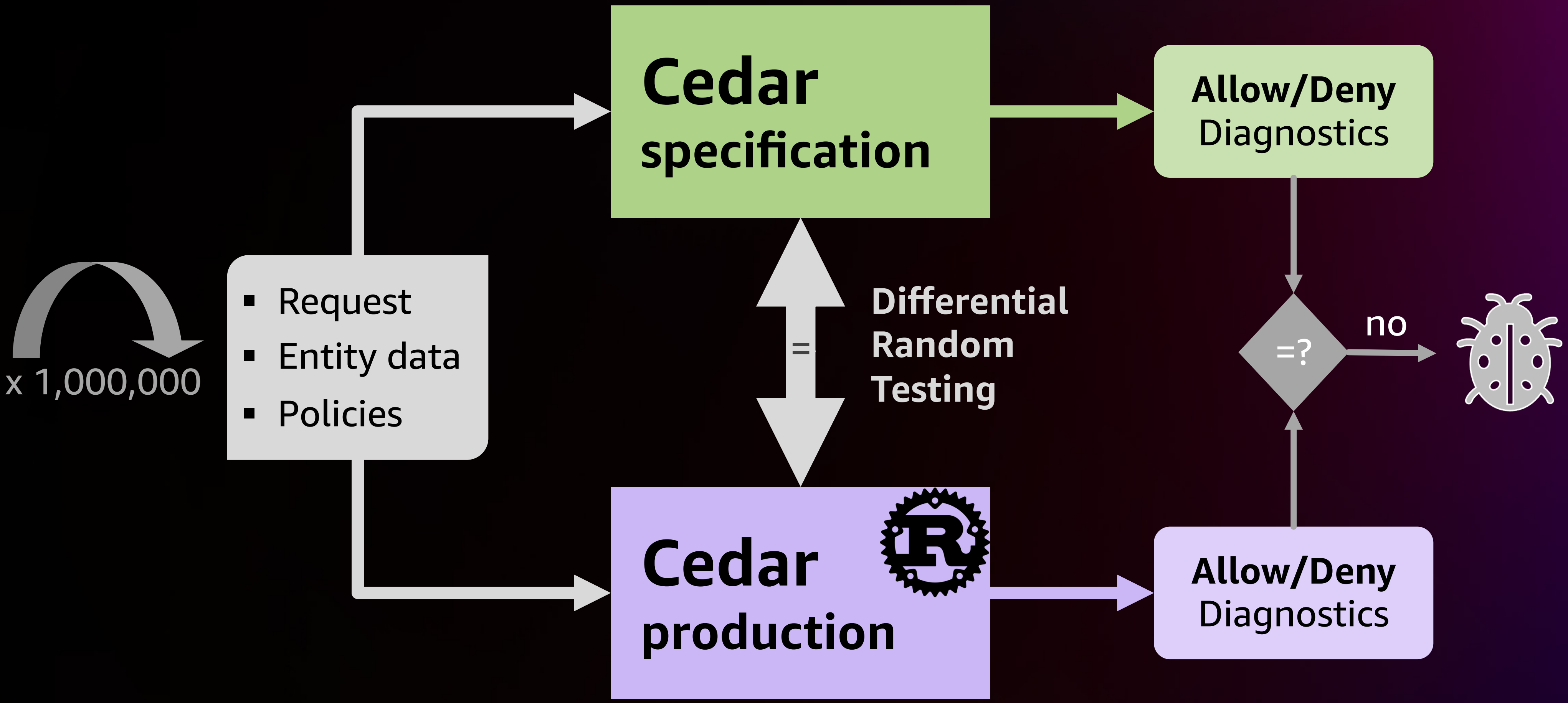
A fast runtime with Rust

42.8×-80.8× faster than OPA Rego
28.7×-35.2× faster than OpenFGA



< 10 µs for a typical input

A fast & safe runtime with Rust, DRT



x 1,000,000

- Request
- Entity data
- Policies

Cedar specification

Cedar production

=

Differential Random Testing

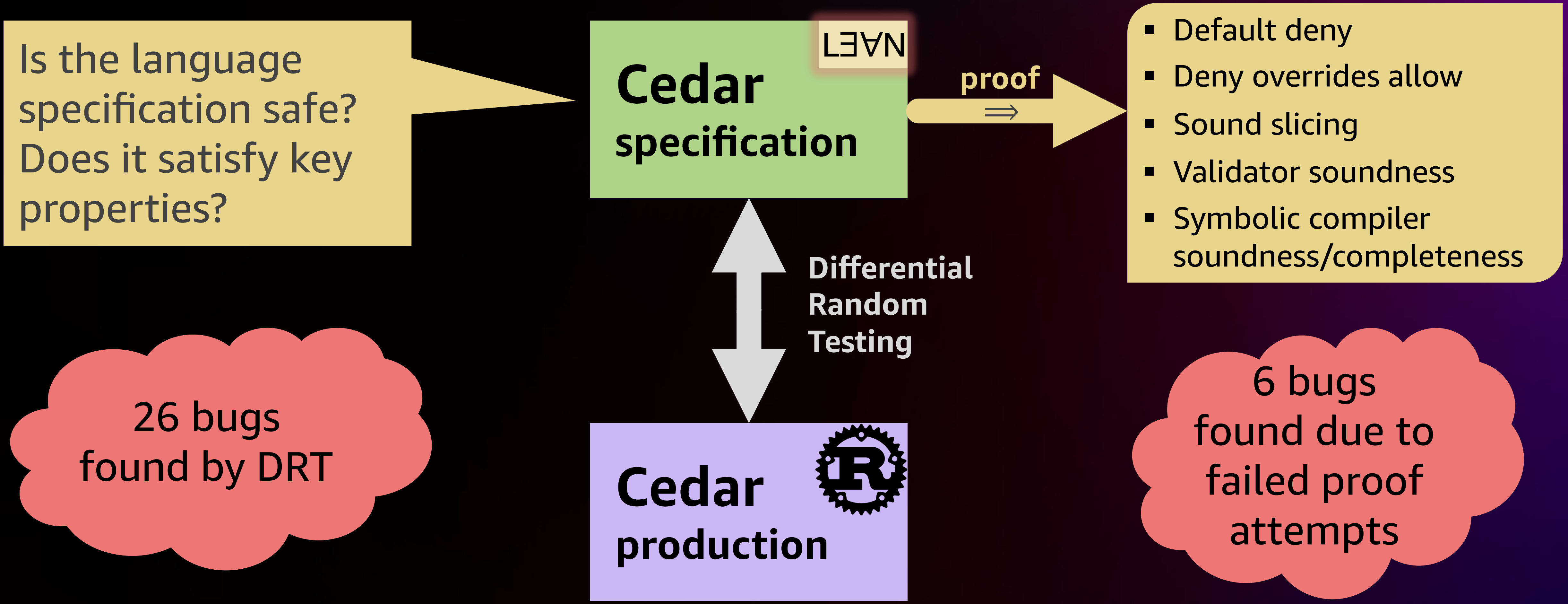
Allow/Deny Diagnostics

Allow/Deny Diagnostics

=?

no

A fast & safe runtime with Rust, DRT, and Lean



Is the language specification safe? Does it satisfy key properties?

Cedar specification

proof ⟹

- Default deny
- Deny overrides allow
- Sound slicing
- Validator soundness
- Symbolic compiler soundness/completeness

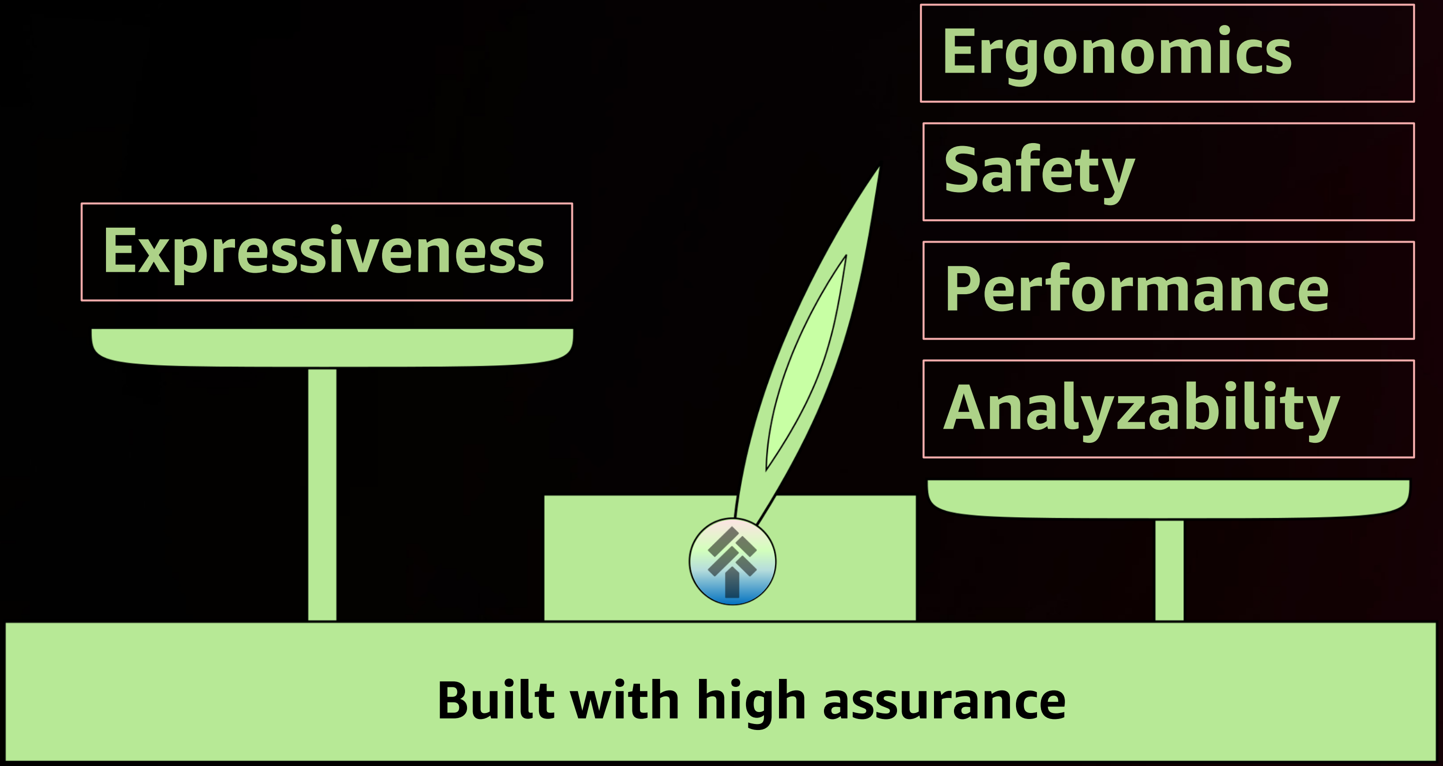
Differential Random Testing

Cedar production

26 bugs found by DRT

6 bugs found due to failed proof attempts

Cedar: expressive, fast, safe, analyzable authz


Expressiveness

Ergonomics

Safety

Performance

Analyzability

Built with high assurance

https://github.com/cedar-policy