Blockaid

Data-access Policy Enforcement for Web Applications

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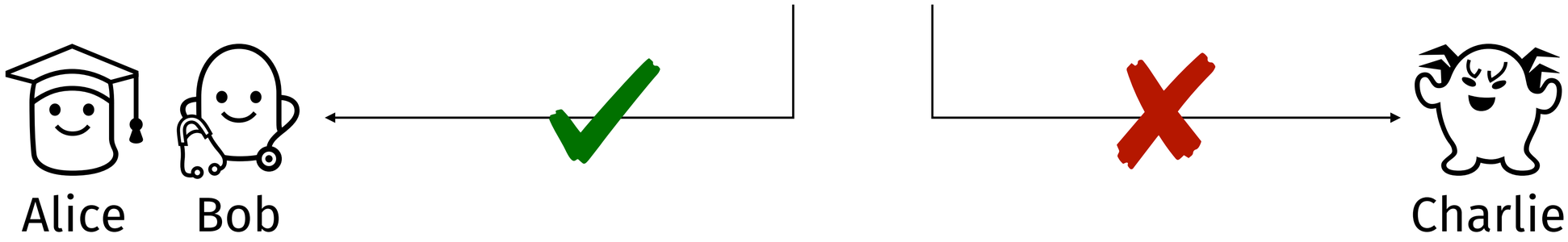
NETSYS

Web Applications Are Everywhere

Web Applications Serve Sensitive Information

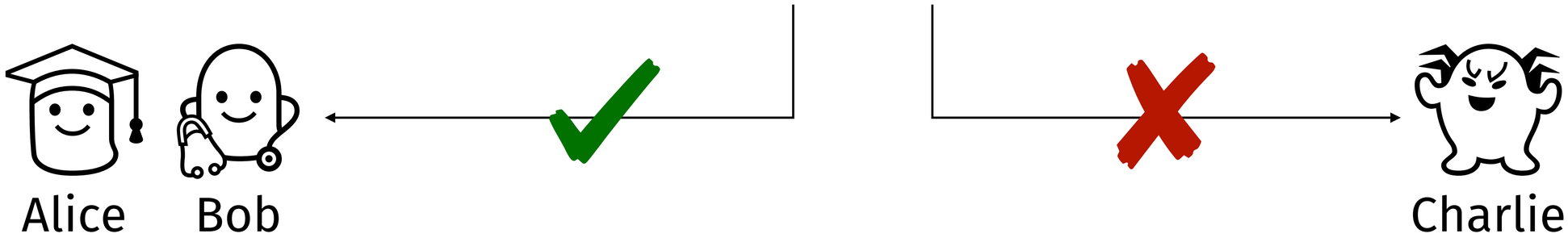
Private Message

From: Alice
To: Bob
Content:
Here’s my little secret…



Web Applications Serve Sensitive Information

Sensitive information be released
only to parties that should have access to it



What information can be accessed by which users?

Data-access Policy

- A **direct message** is accessible only to its **participants**.
- ...

Data-access Policy

Enforced using access checks

- A **direct message** is accessible only to its **participants**.
- ...

Every time a message is displayed...

```
⋮
if not message.has_participant(curr_user):
    return "Error"

return message.content
⋮
```

Access Checks Are Hard to Get Right

Missing/incorrect checks ➡ inadvertent data leaks in production software

How to systematically ensure an application reveals only information allowed by its data-access policy?

How to systematically ensure
an application reveals only information
allowed by its data-access policy?

Blockaid

Run-time data-access policy enforcer for web applications

Coming Up Next...

1. Overview and goals.
2. Policy specification.
3. Policy enforcement.
4. Evaluation.

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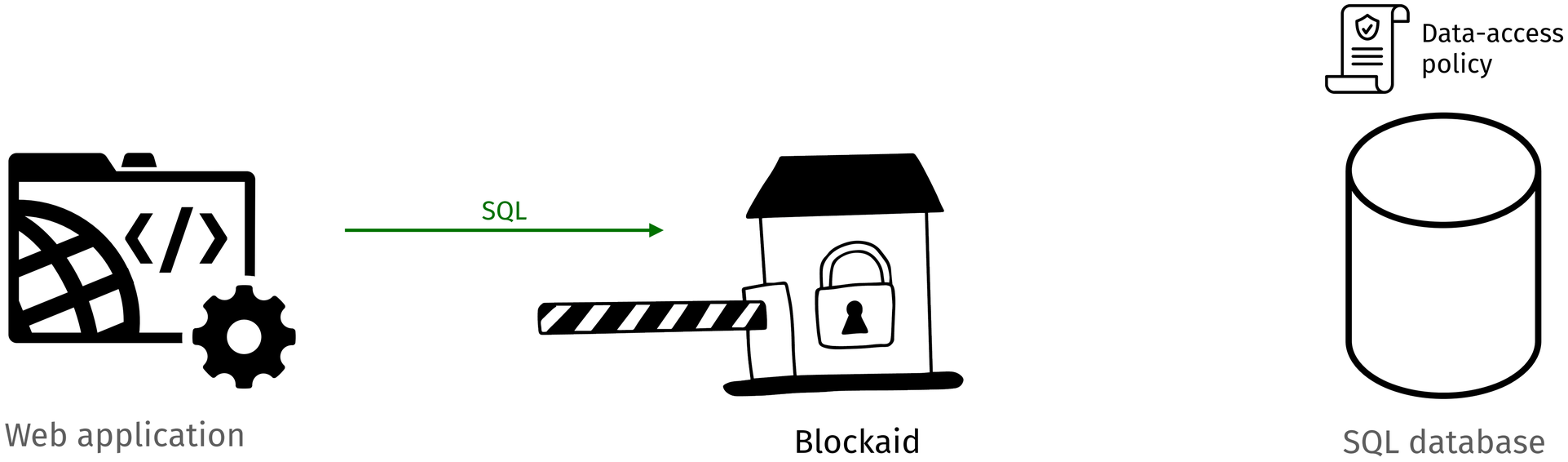
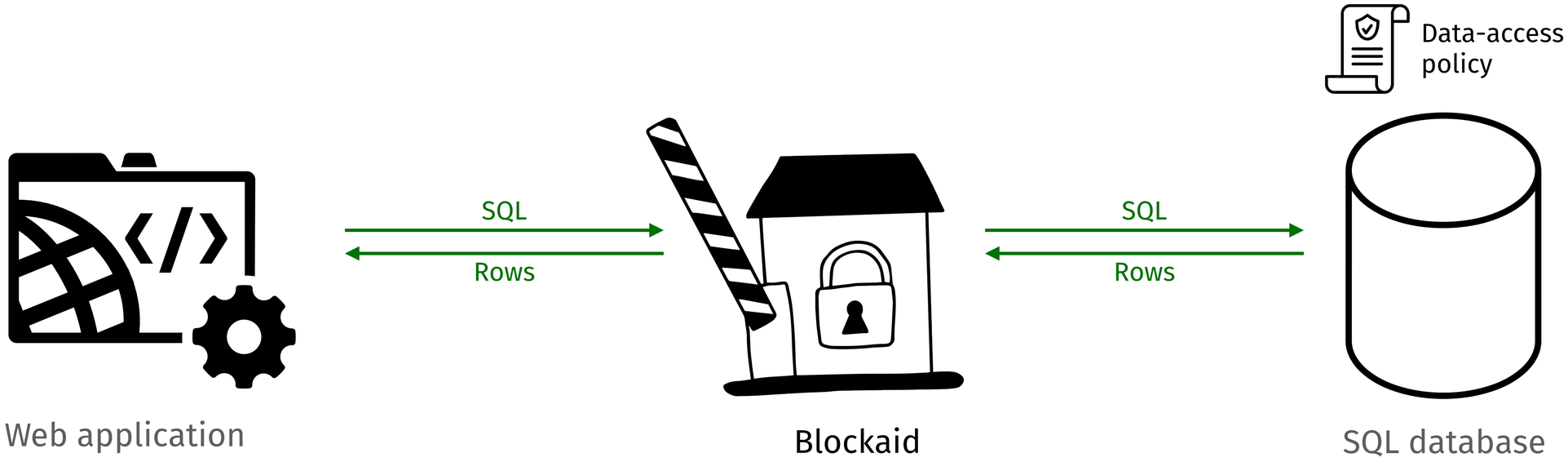
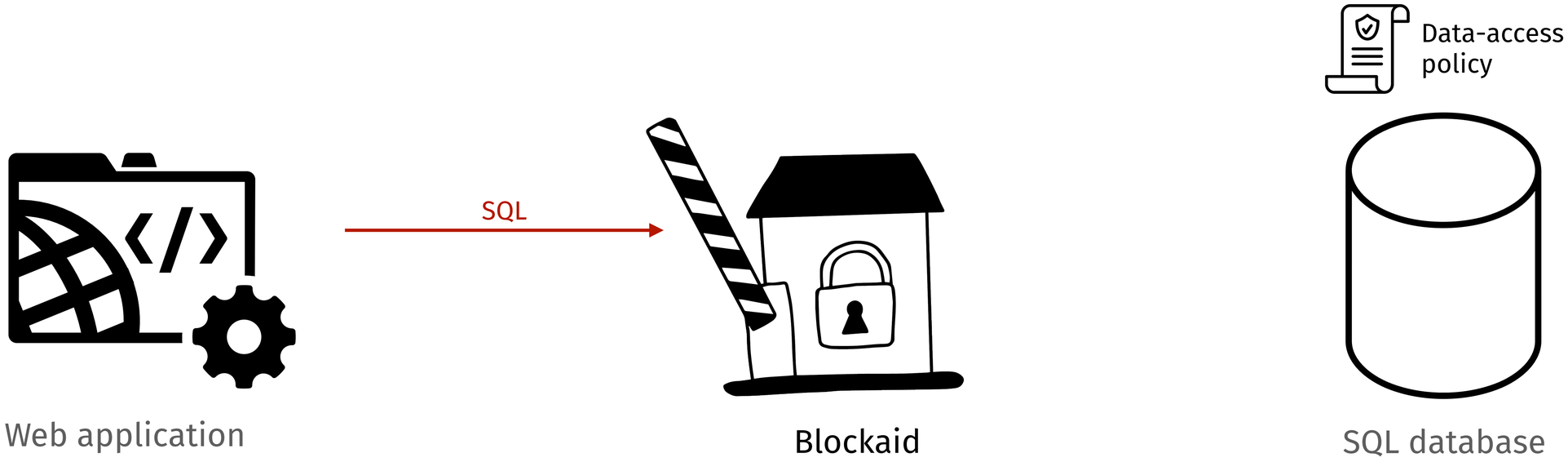
Blockaid: Overview



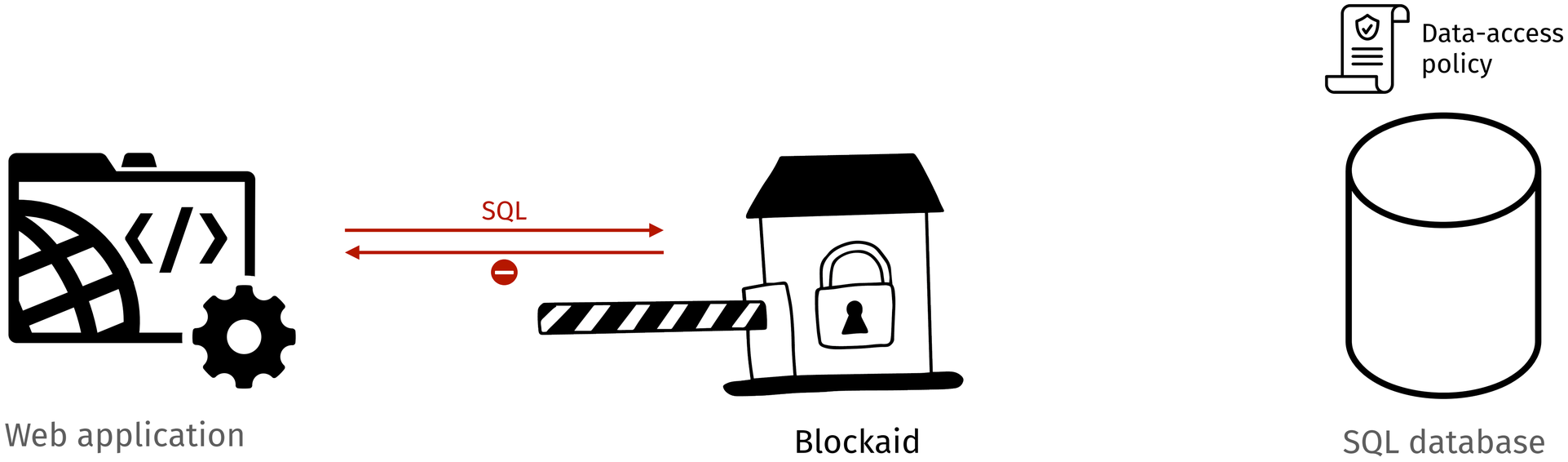
Blockaid: Overview



Blockaid: Overview



Blockaid: Overview



Goals

Ensure application reveals only information that the policy allows the user to access.

1. Policy expressiveness.
2. Compatibility with existing frameworks.
3. Semantic transparency.

   Complies with policy ➡ Maintain application behavior.

   Violates policy ➡ Raise error **visibly**.
4. Low performance overhead.

No Prior System Satisfies All Four Goals

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Prior Systems Don't Meet Both Goals

Query Modification

Limiting Disclosure in Hippocratic Databases

Qapla: Policy compliance for database-backed systems

Towards Multiverse Databases

Precise, Dynamic Information Flow for Database-Backed Applications

Jean Yang — Carnegie Mellon University and Harvard Medical School, USA
Travis Hance — Dropbox, USA
Thomas H. Austin — San Jose State University, USA
Armando Solar-Lezama — Massachusetts Institute of Technology, USA
Cormac Flanagan — University of California, Santa Cruz, USA
Stephen Chong — Harvard University, USA

✅ Compatible with existing frameworks

❌ **Not** semantically transparent

Static Verification

Static Checking of Dynamically-Varying Security Policies in Database-Backed Applications

Adam Chlipala
Impredicative LLC

STORM: Refinement Types for Secure Web Applications

Nico Lehmann — *UC San Diego*
Rose Kunkel — *UC San Diego*
Jordan Brown — *Independent*
Jean Yang — *Akita Software*
Niki Vazou — *IMDEA Software Institute*
Nadia Polikarpova — *UC San Diego*
Deian Stefan — *UC San Diego*
Ranjit Jhala — *UC San Diego*

✅ Semantically transparent

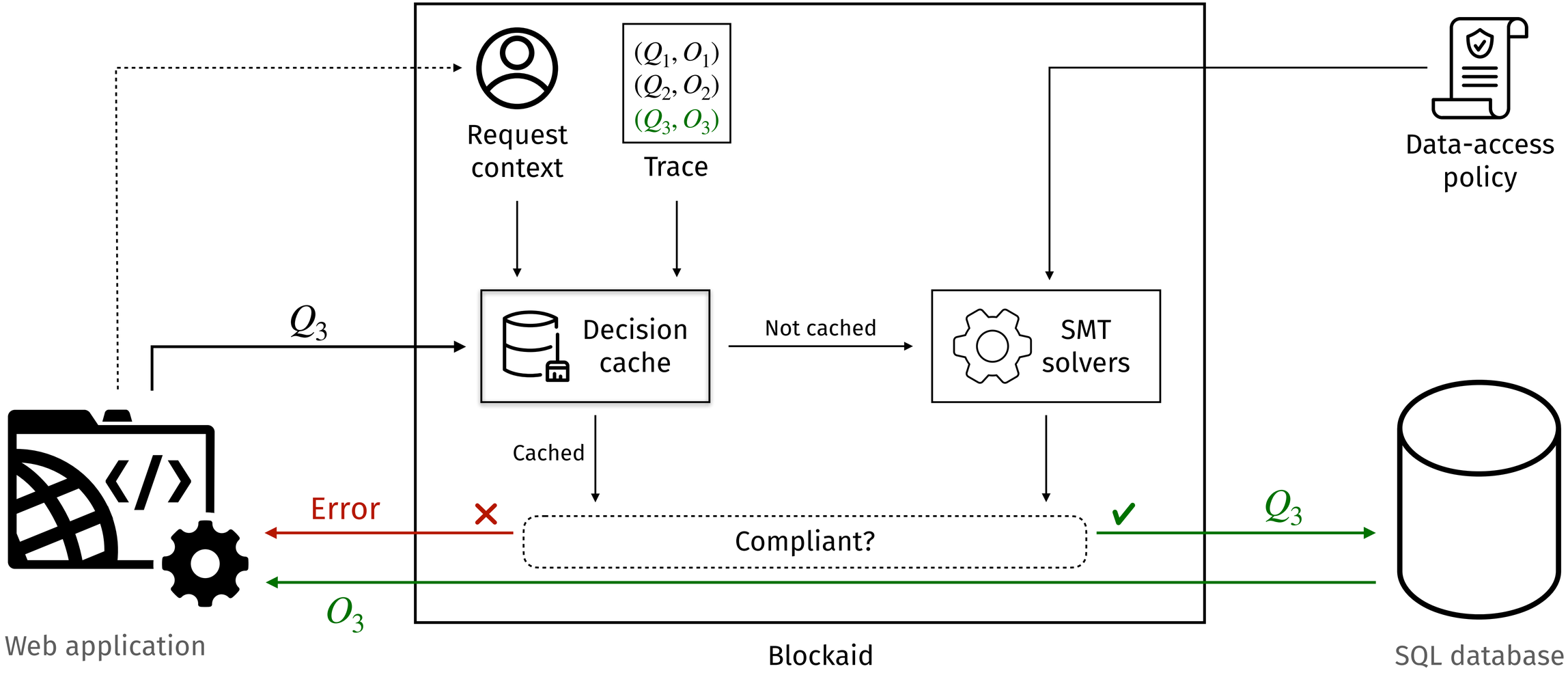
❌ **Incompatible** with existing frameworks

Blockaid

Run-time data-access policy enforcer for web applications

- ✅ Compatible with existing frameworks
- ✅ Semantically transparent
- ✅ Supports expressive policies
- ✅ Incurs low performance overhead

Blockaid: A Close Look



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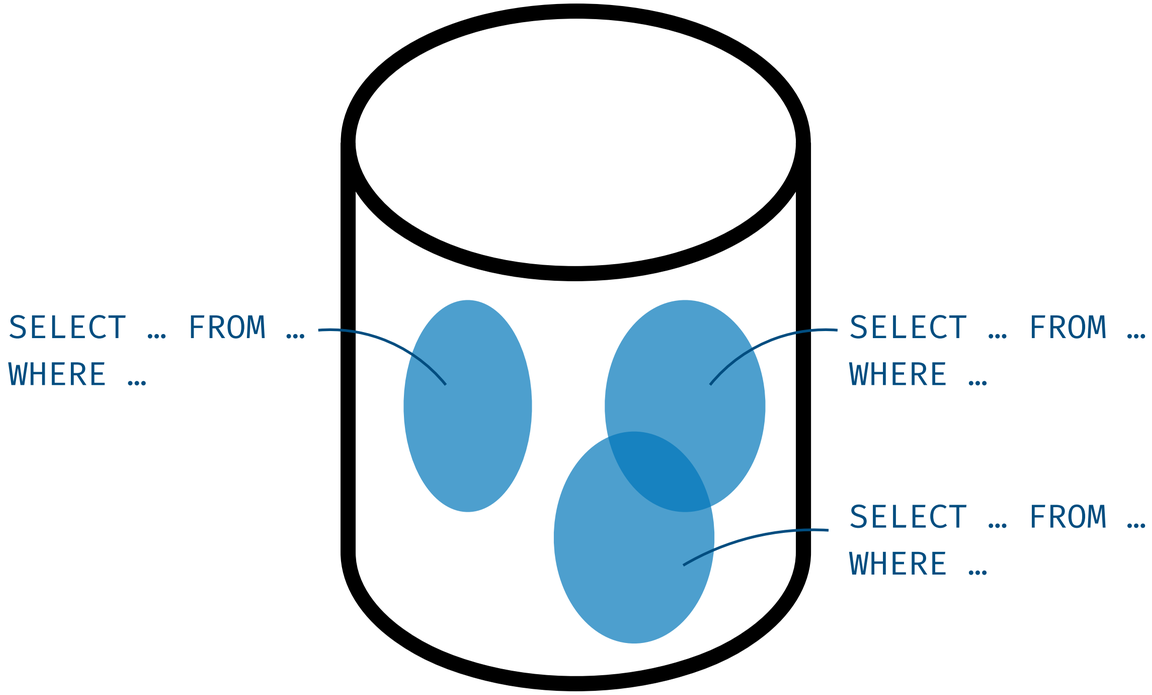
Specify Policy Using Database Views

Views: **SQL SELECT statements** defining data accessible to a user.



Example: Calendar Application

```
Users(UId, Name)
Events(EId, Title, Date)
Attendance(UId, EId)
```

1. `SELECT * FROM Users`

   Each user can view information on all users.

2. `SELECT EId FROM Attendance WHERE UId = ?MyUId`

   Each user can view IDs of events they attend.

3.
```
SELECT *
  FROM Events e
  JOIN Attendance a ON e.EId = a.EId
 WHERE a.UId = ?MyUId
```

   Each user can view details of events they attend.

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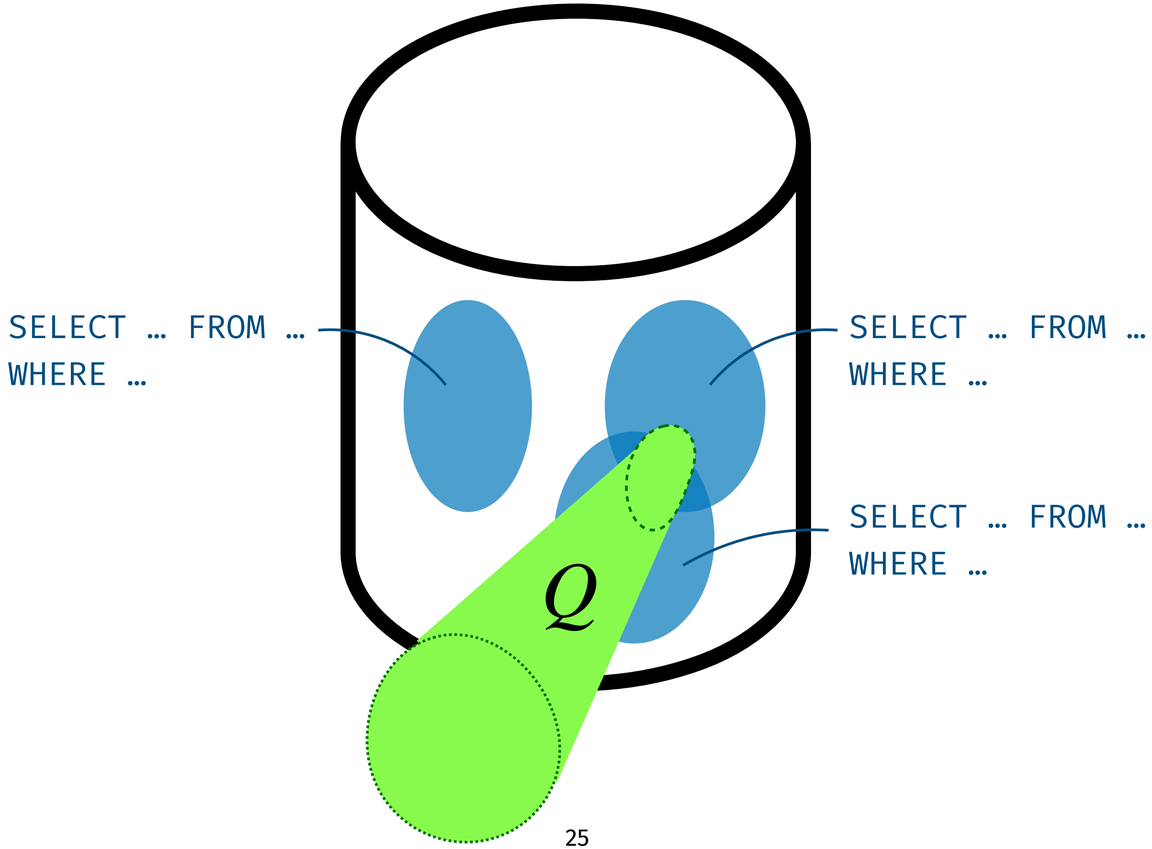
Query Compliance

A **compliant query** reveals only information exposed by the views.



Example: Calendar Application

```
Users(UId, Name)
Events(EId, Title, Date)
Attendance(UId, EId)
```

1. `SELECT * FROM Users`

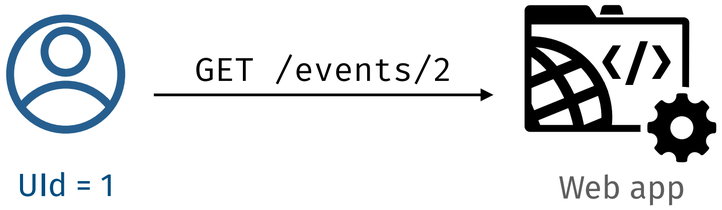
   Each user can view information on all users.

2. `SELECT * FROM Attendance`
   `WHERE UId = ?MyUId`

   Each user can view which events they attend.

3. `SELECT *`
   `FROM Events e`
   `JOIN Attendance a`
   `ON e.EId = a.EId`
   `WHERE a.UId = ?MyUId`

   Each user can view information on events they attend.



1. `SELECT * FROM Attendance`
   `WHERE UId = 1 AND EId = 2`

   ✅ Covered by View 2.

   ↩ Returns one row.

2. `SELECT * FROM Events`
   `WHERE EId = 2`

   ✅ Covered by View 3 *given Query 1 & result.*

Query Compliance, Formally

Given:

- A set $\mathscr{V}$ of views (for the current request context),
- A trace of query-result pairs: $(Q_1, O_1), \ldots, (Q_n, O_n)$,

We say query Q is **compliant** if for every *pair of databases* D, D':

Consistent with the observed trace $\quad Q_i(D) = Q_i(D') = O_i \qquad \forall 1 \leq i \leq n$

Contain the same accessible information $\quad V(D) = V(D') \qquad \forall V \in \mathscr{V}$

$$\Downarrow$$

$$Q(D) = Q(D')$$

Checking Compliance

$$\underbrace{\begin{array}{c} Q_i(D) = Q_i(D') = O_i \\ V(D) = V(D') \end{array}}_{\Downarrow \; Q(D) = Q(D')}$$

Compliance definition

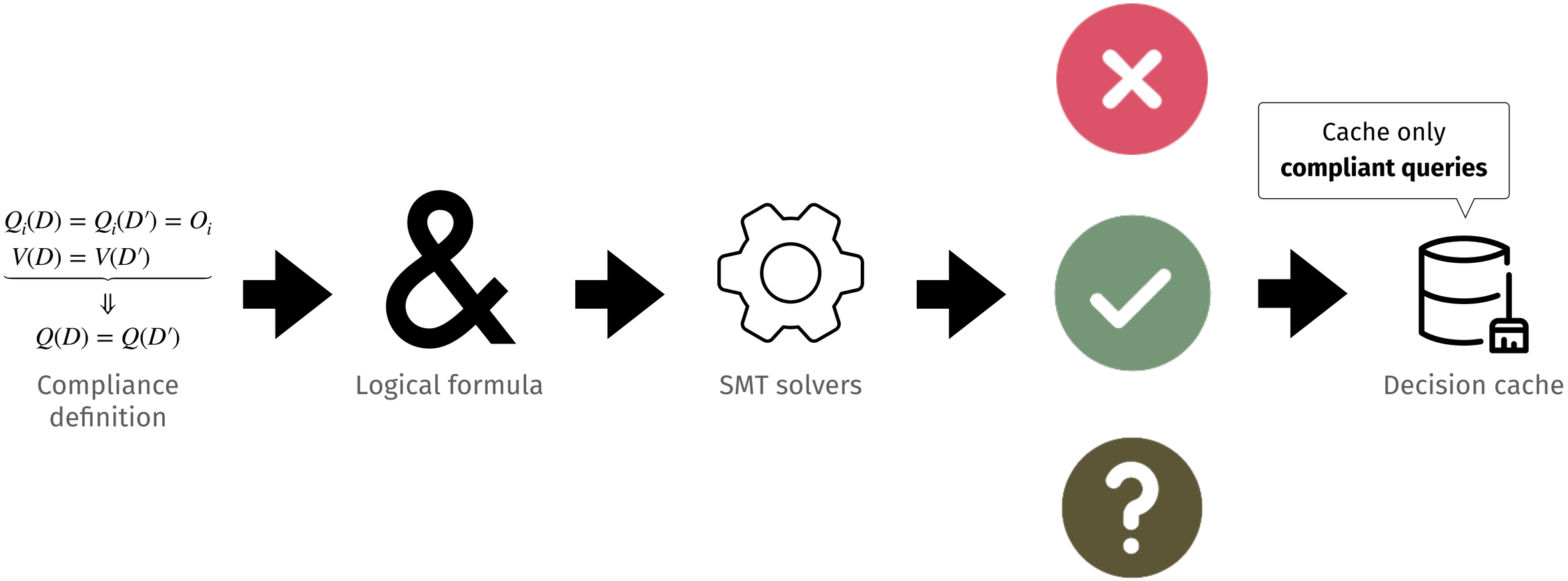
Translate SQL into first-order logic
via Codd's Theorem + approximation.

Logical formula

SMT solvers

SMT solvers can be **slow**!
100 ms per query ⇝ seconds per page

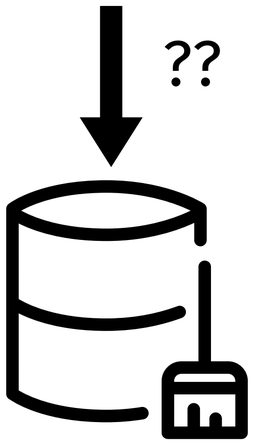
Checking Compliance Fast



Naive Caching ⇝ Low Cache Hit Rate

Assuming fixed database schema and policy...

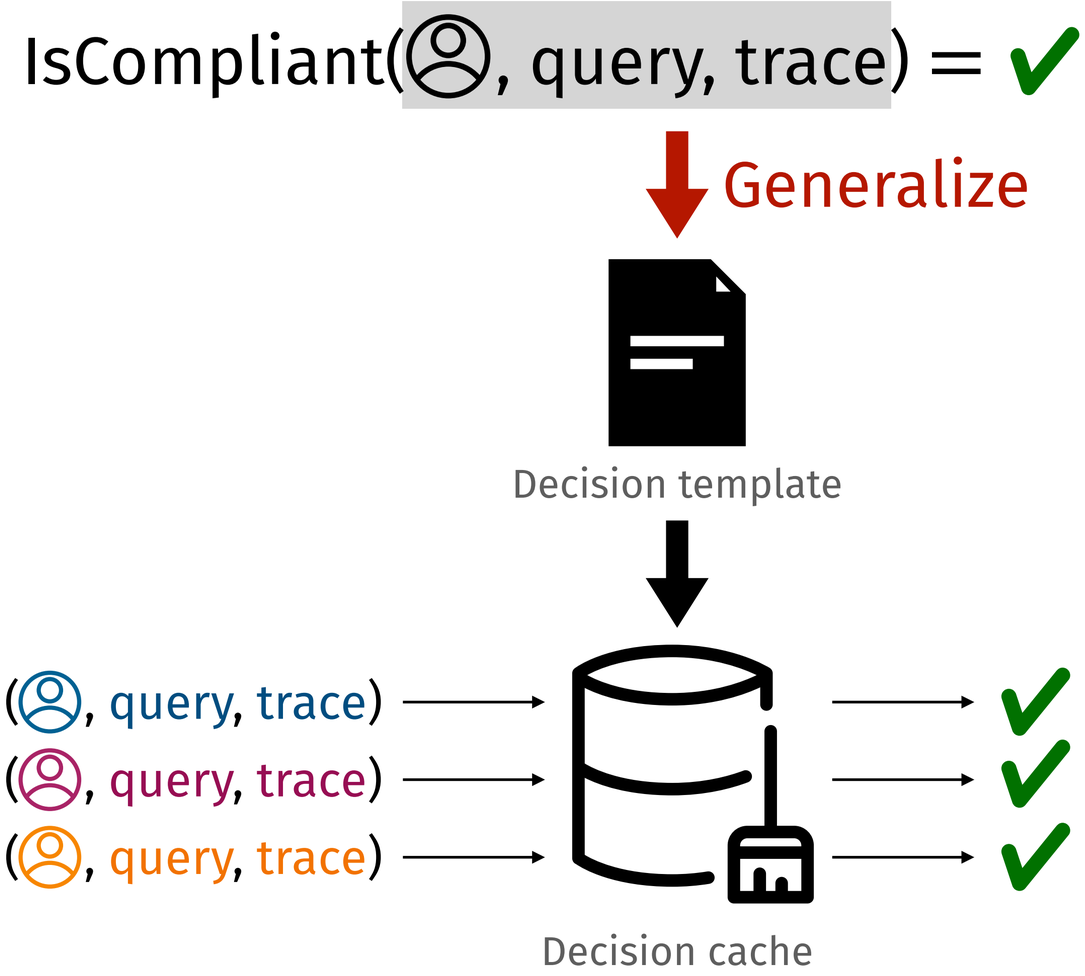
IsCompliant(👤, query, trace) = ✔



Decision cache

Each entry specific to user & URLs visited!

Blockaid Generalizes Compliance Determinations

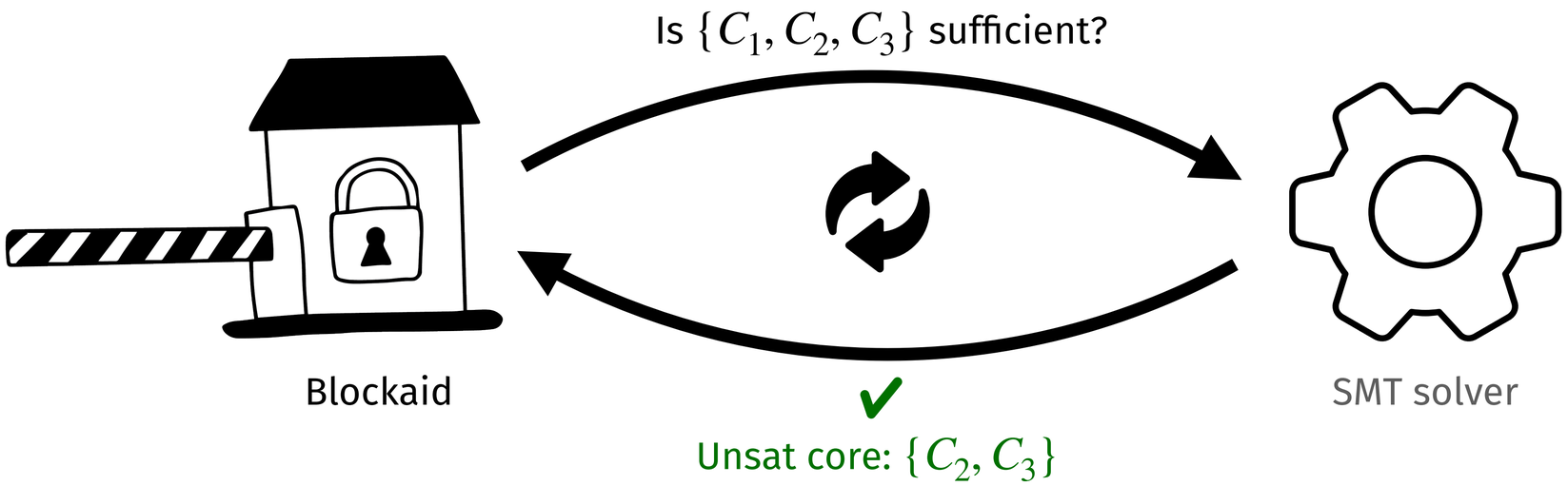


How Are Templates Generated?

Find a small set of constraints

on the request context, query, & trace

that is sufficient to guarantee compliance



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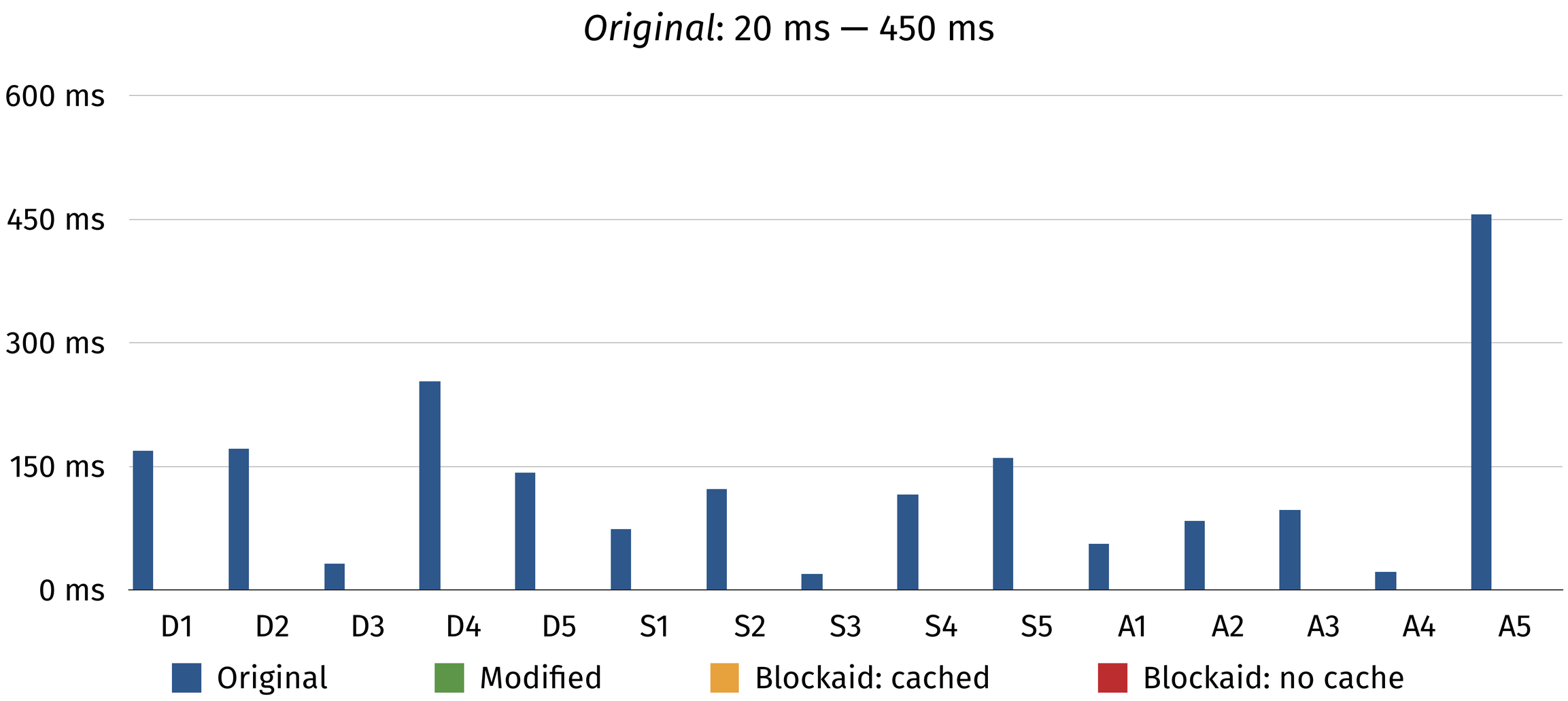
Setup

- Implemented Blockaid as **JDBC driver** wrapping a database connection.
- Applied Blockaid to **three applications** (with hand-crafted policies).

diaspora* spree AUTØLAB

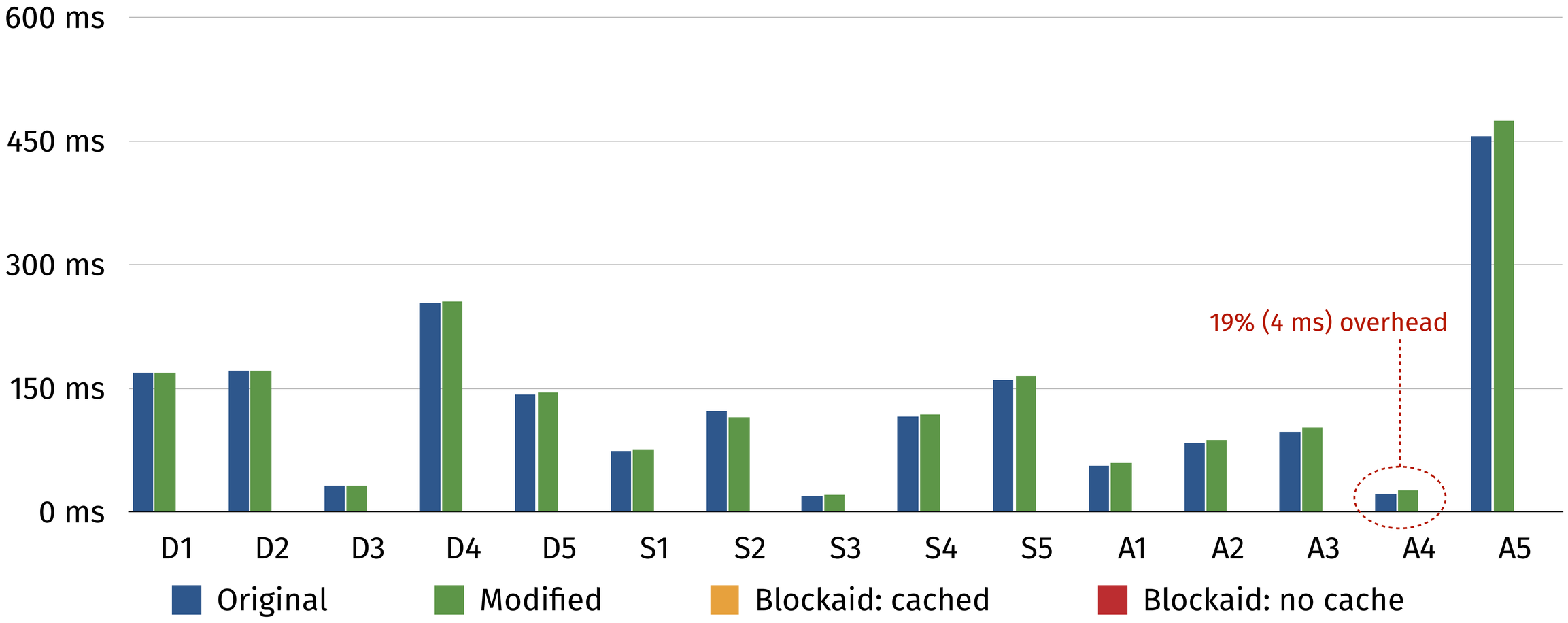
- Measured **page load time** of 5 URLs per application.
- Modified **~20 — 100 lines** of code per application.
  - To fetch only data that **can be revealed** to the user.

Page Load Times (median)



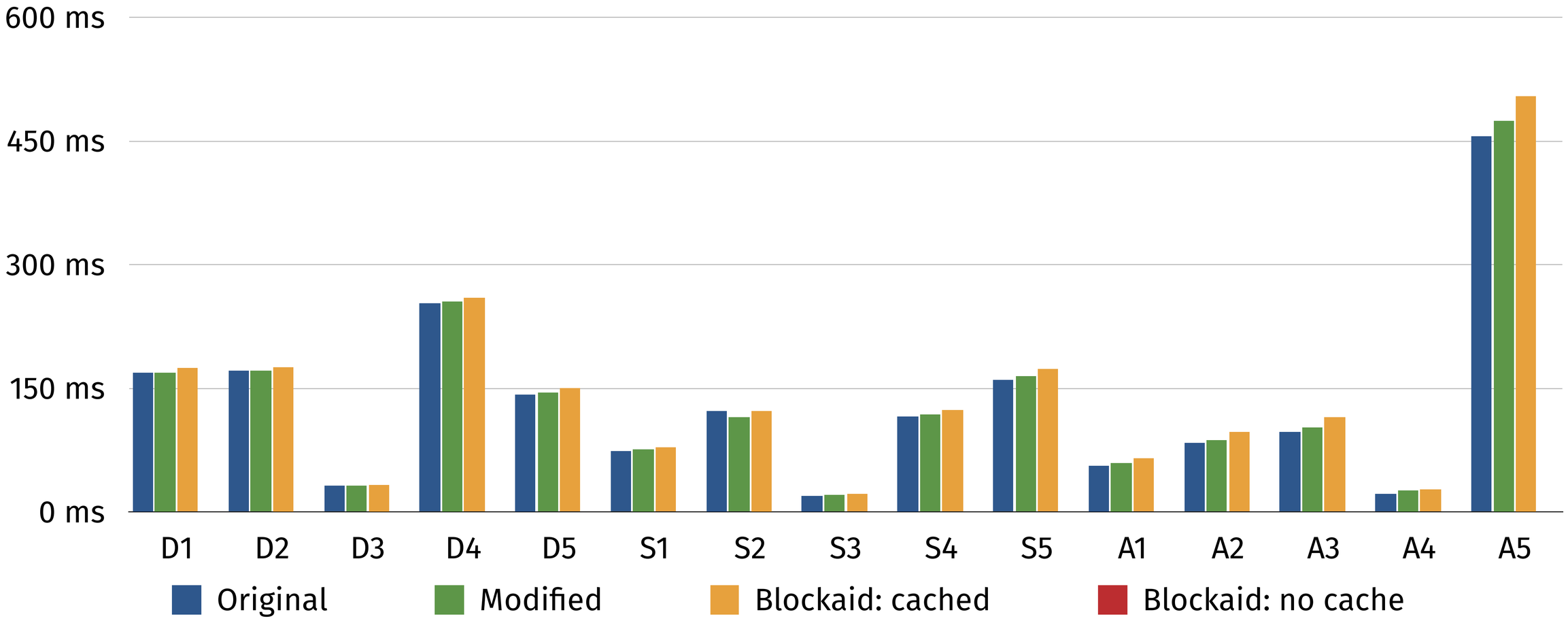
Page Load Times (median)

Modified: up to 6% overhead for all but one page



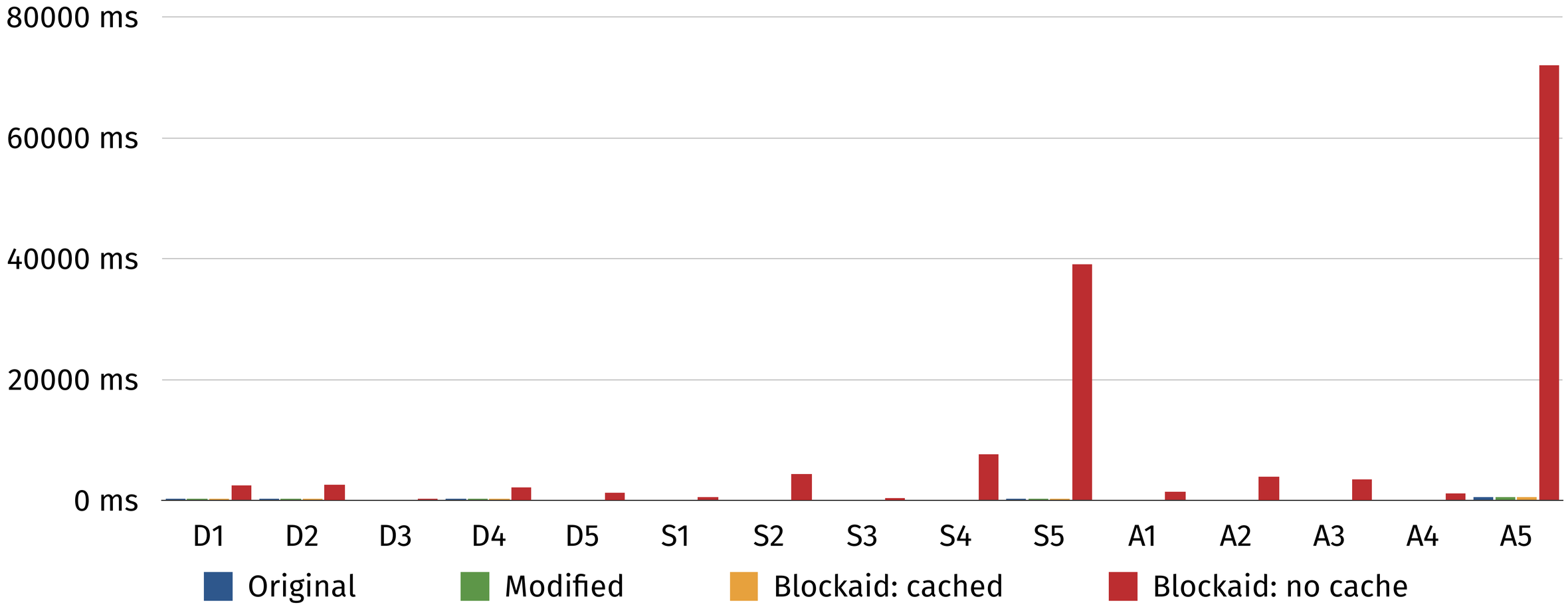
Page Load Times (median)

Cached: **up to 12% overhead** over *modified*



Page Load Times (median)

No cache: **up to 236x overhead** over *modified*



More Evaluation in the Paper

- Breakdown of page load times.
- Solver performance.
- Template generalization case study.

Blockaid

Data-access Policy Enforcement for Web Applications

- Compatible with existing frameworks ✚ semantically transparent.
- Uses SMT to verify query compliance with view-based policy.
- Generalization-based caching through decision templates.

https://github.com/blockaid-project/

ARTIFACT EVALUATED usenix ASSOCIATION AVAILABLE

ARTIFACT EVALUATED usenix ASSOCIATION FUNCTIONAL

ARTIFACT EVALUATED usenix ASSOCIATION REPRODUCED