Transparent DIFC: Harnessing Innate Application Event Logging for Fine-Grained Decentralized Information Flow Control

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Data Breaches Are Alarmingly Common

"We have recently notified all affected users of a security breach in Freepik Company, affecting Freepik and Flaticon. The security breach was due to a **SQL injection** in Flaticon that allowed an attacker to get some user's information from our database." [1]

Data of 8.3M users was stolen by one attacker!

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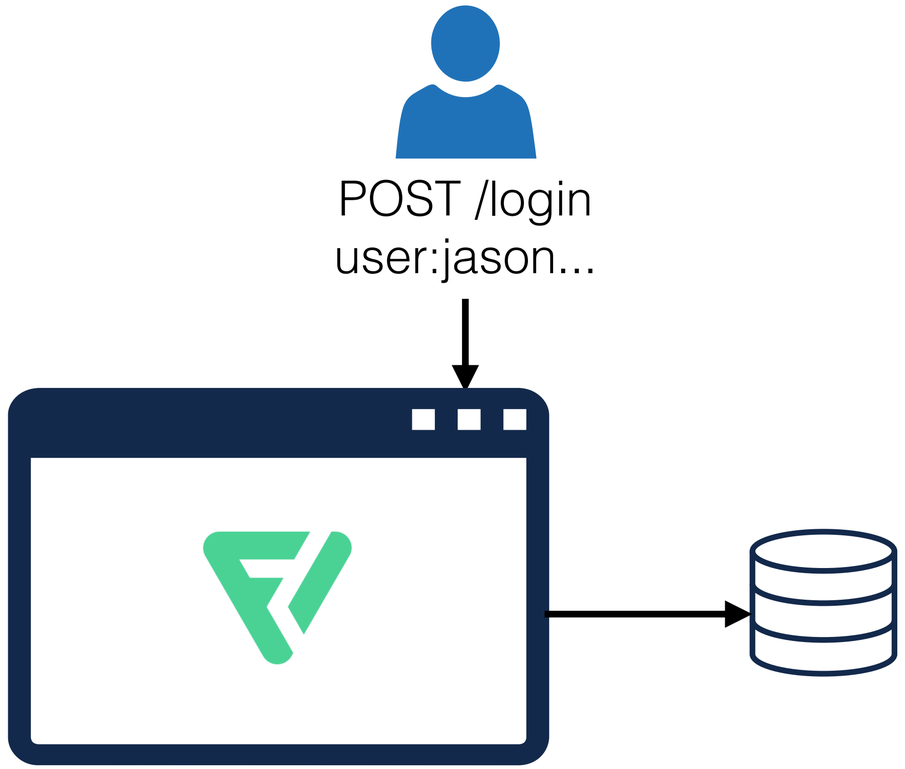

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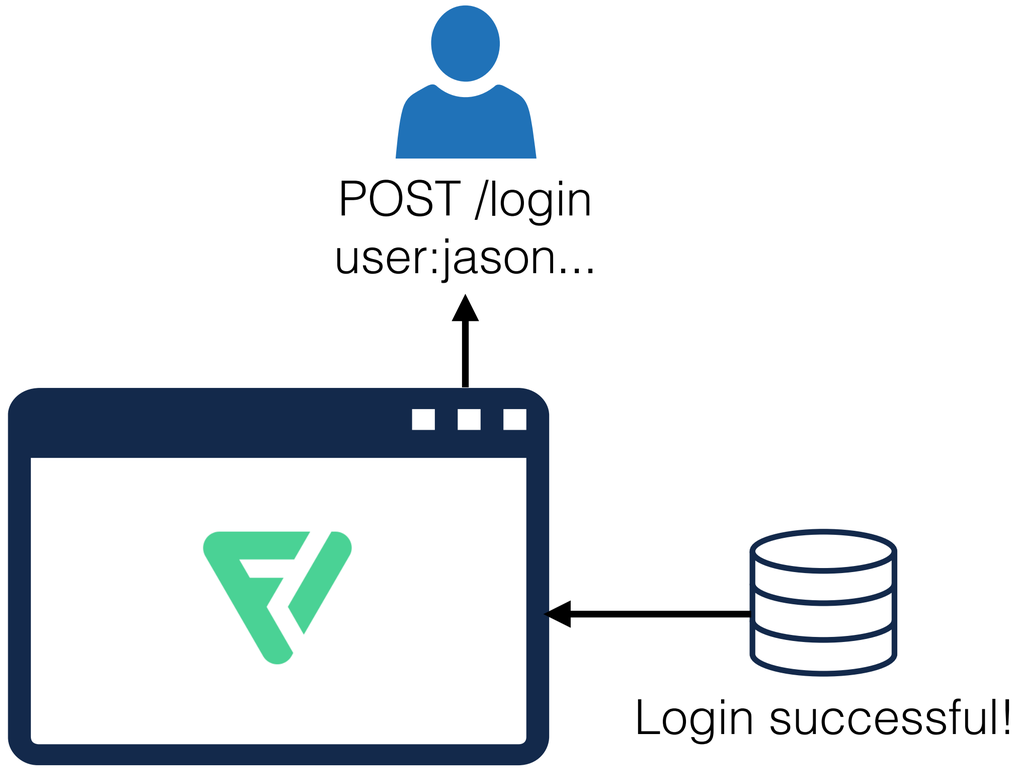

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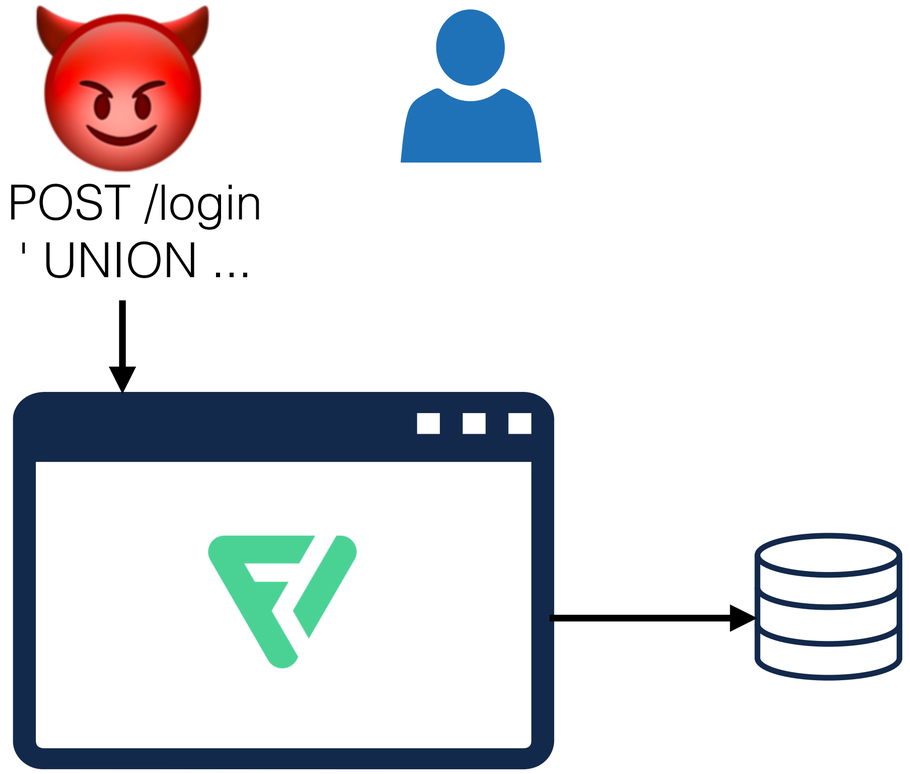

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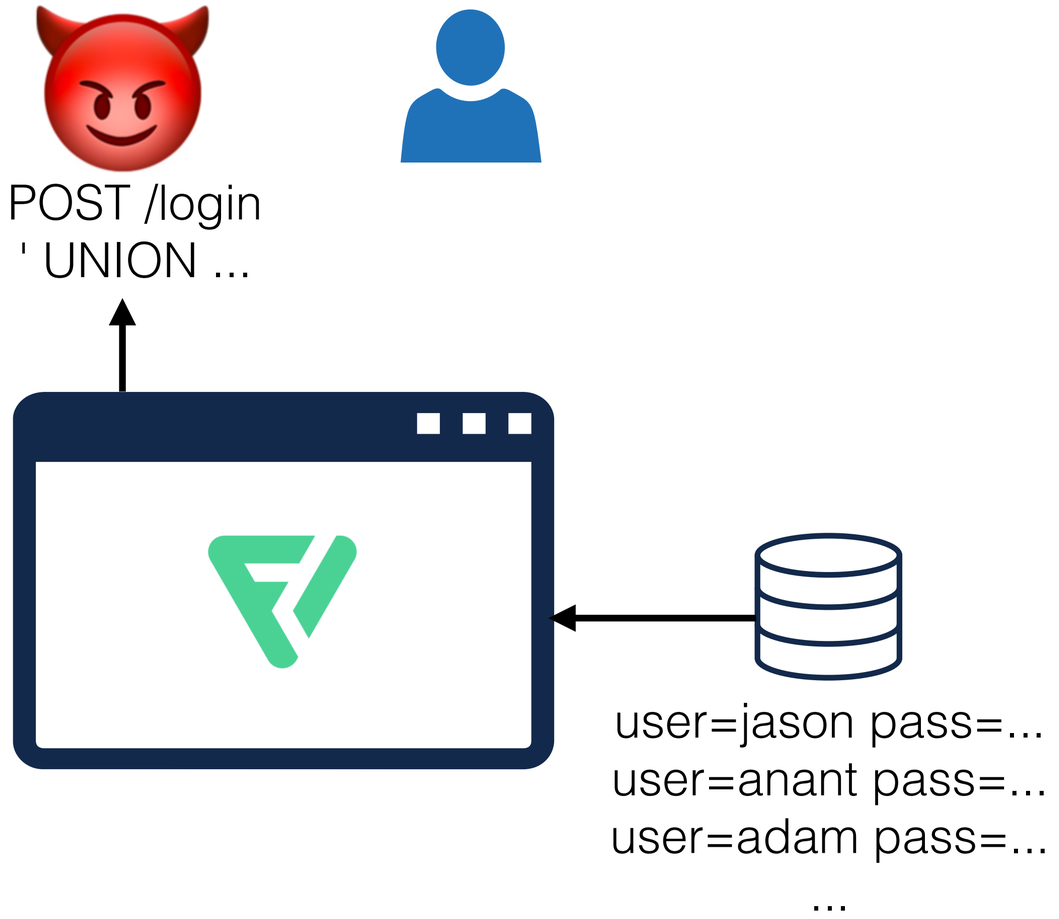

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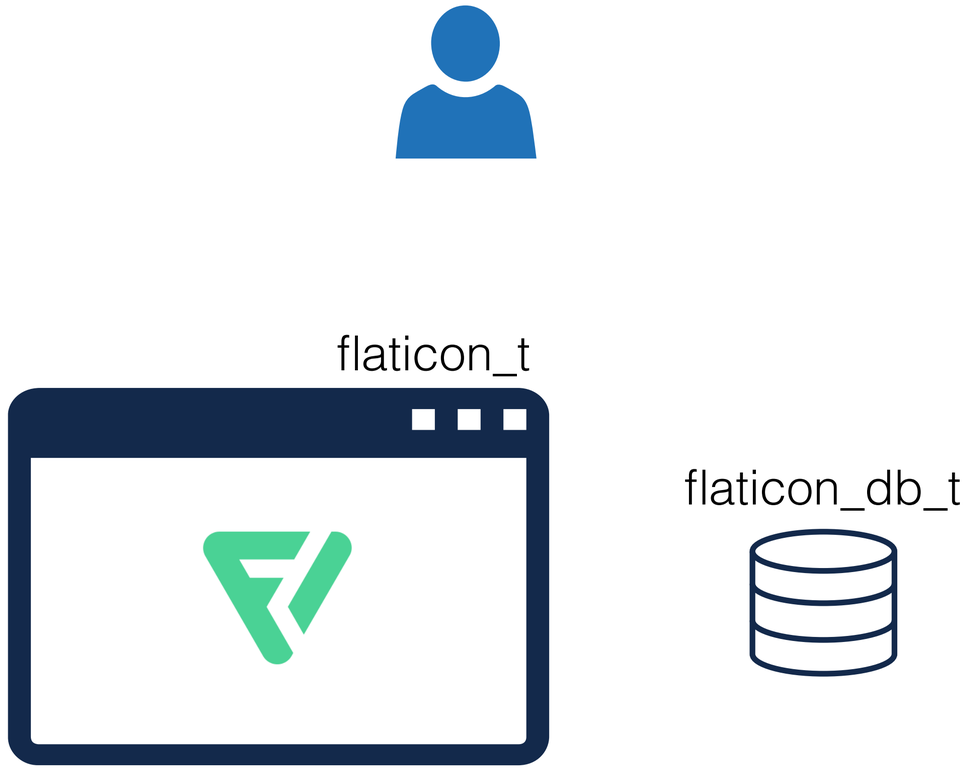
What Went Wrong?

- Data confidentiality from MAC
  - e.g., SELinux, AWS IAM
- `allow flaticon_t flaticon_db_t:db_table *;`
- Traditional MAC cannot distinguish application-level users or data!



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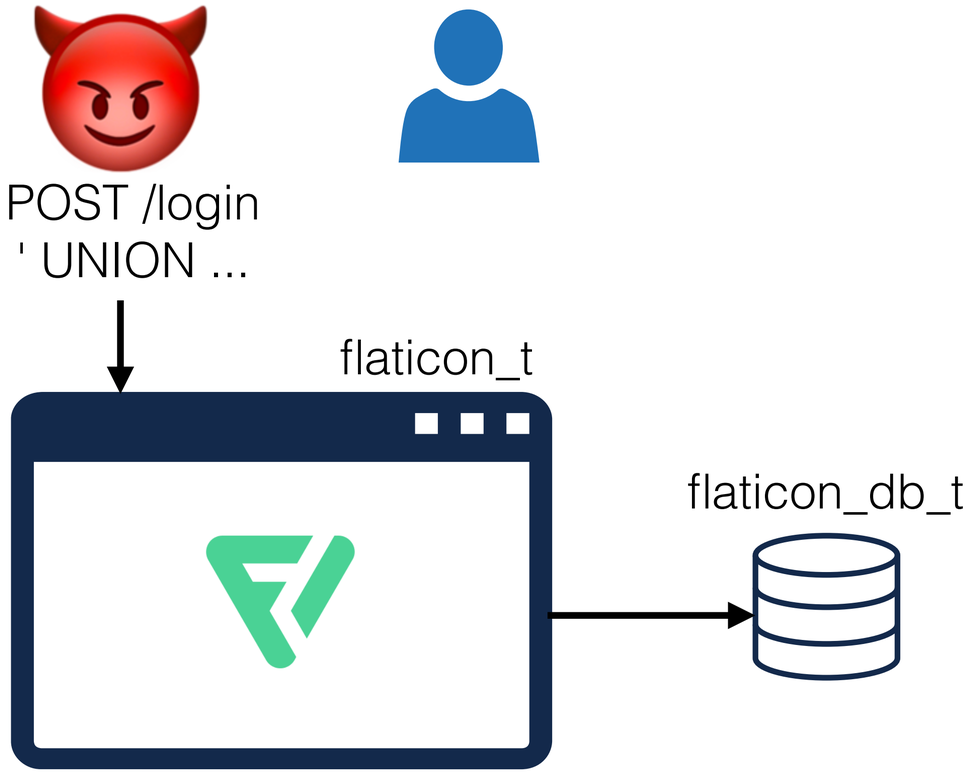

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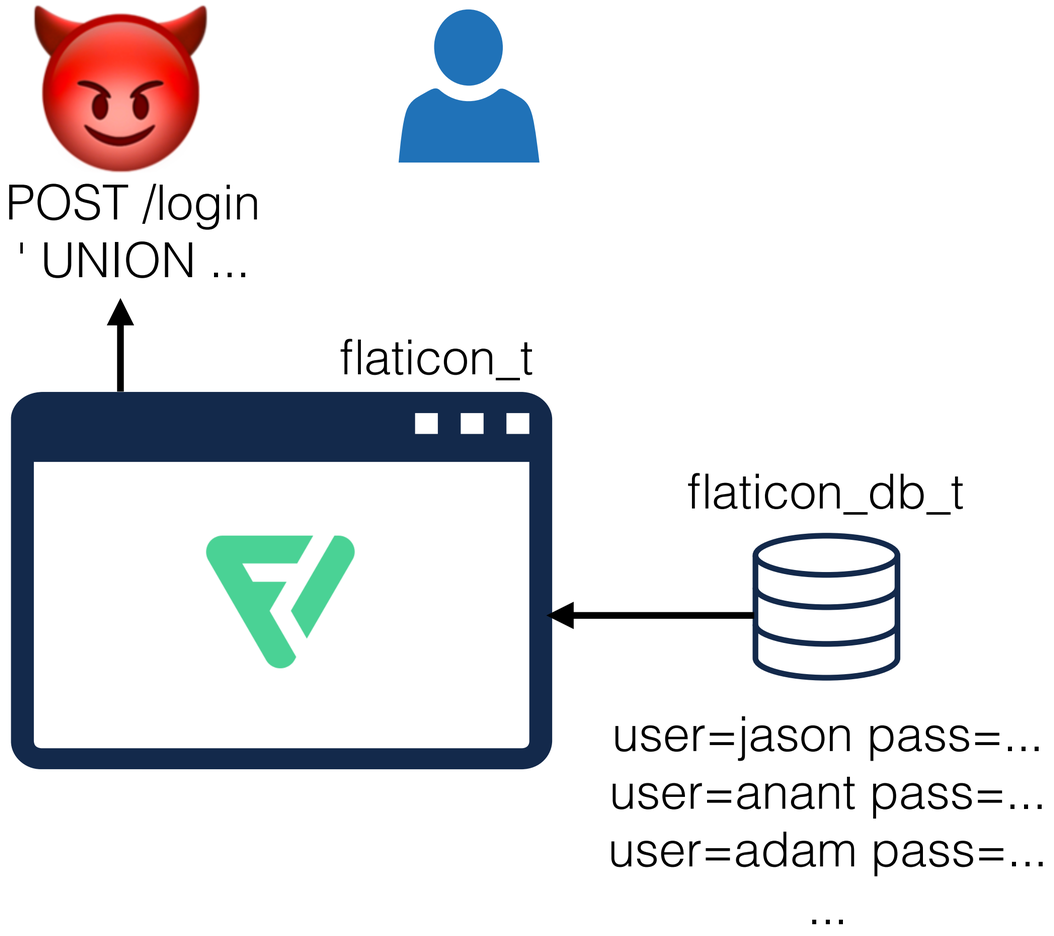

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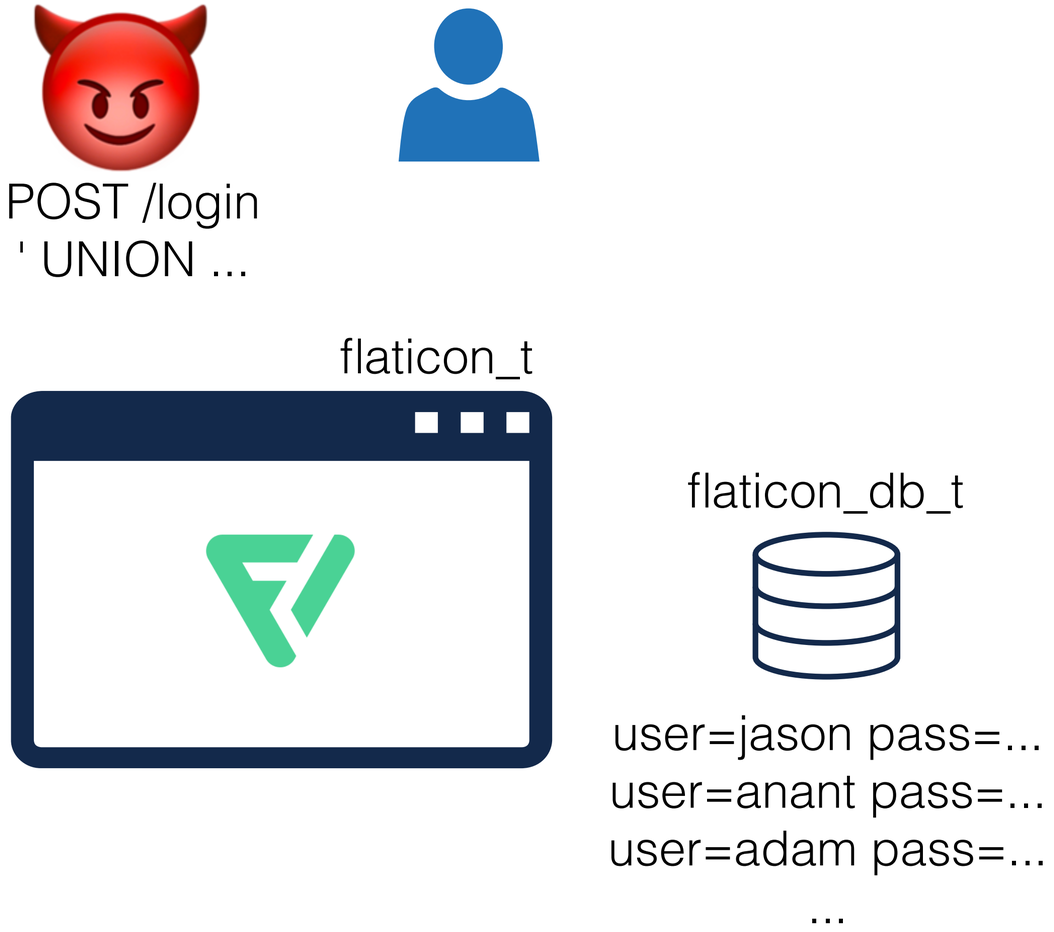
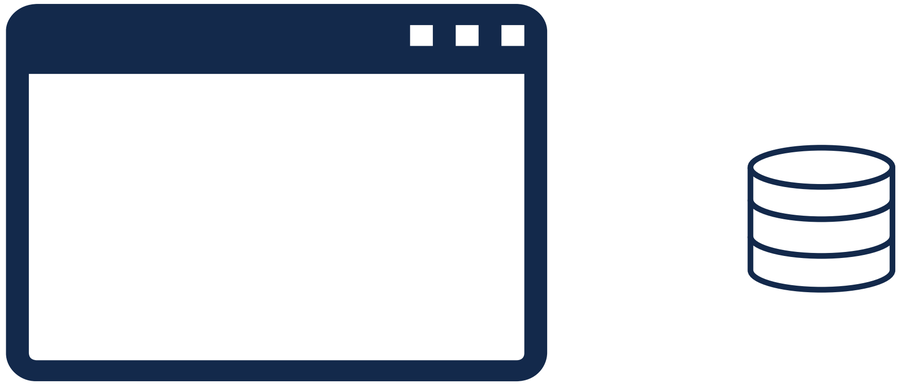
Actually, this problem was already solved in 1997...



DIFC: Application-Level Security

- Decentralized Information Flow Control (DIFC): applications can define flow control rules
  - Finer-grained labeling of application-level users and data



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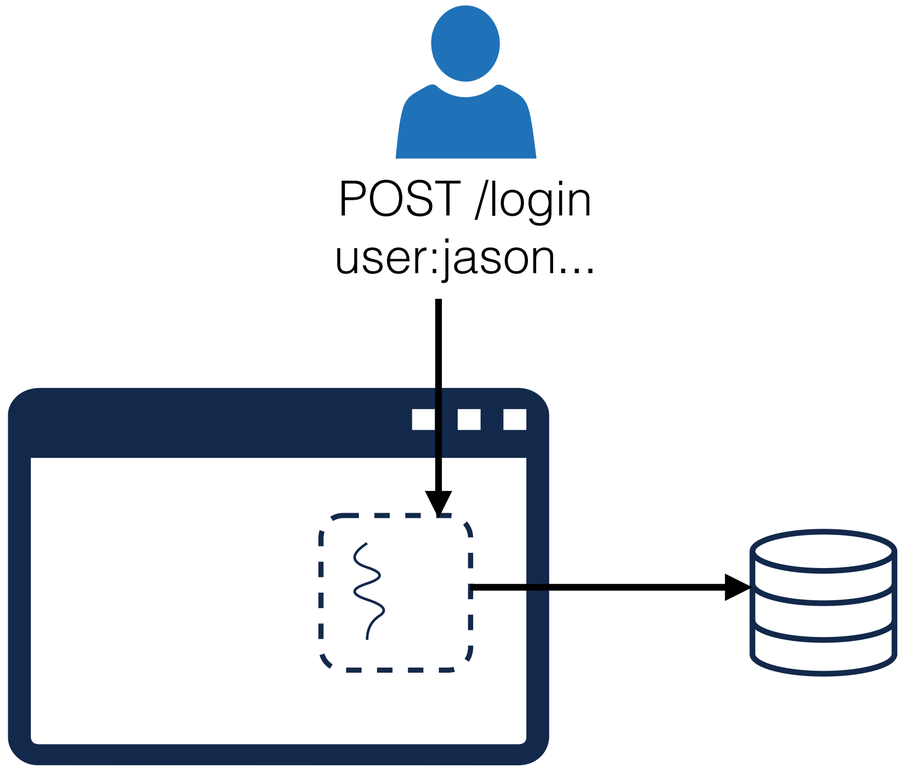

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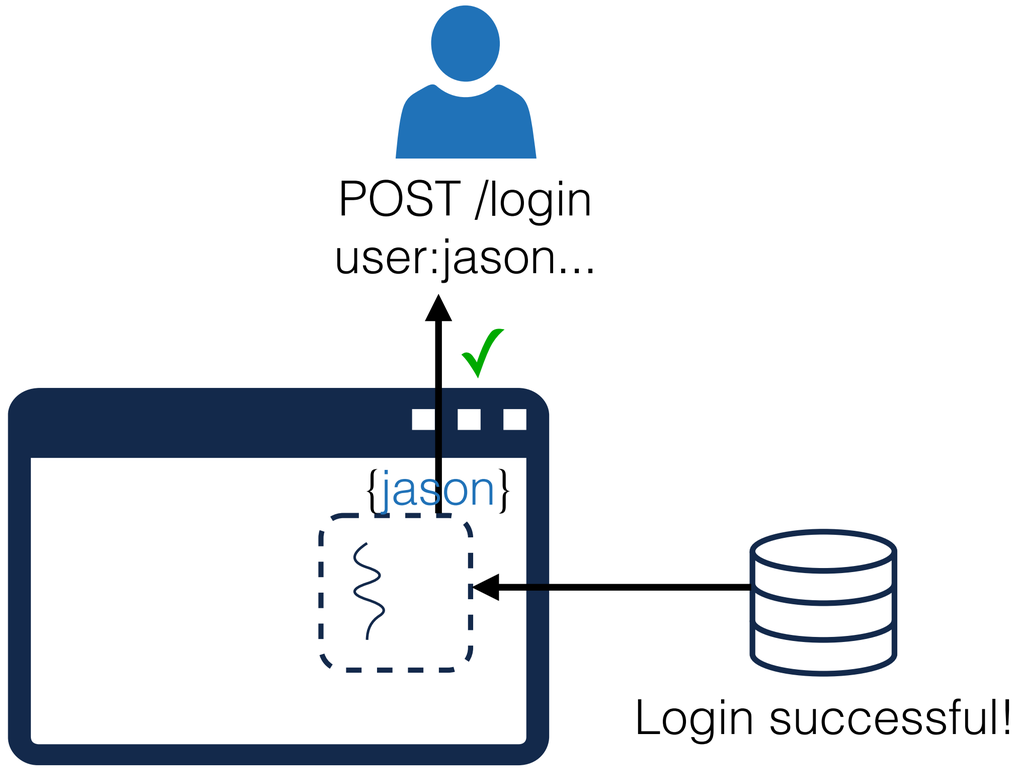

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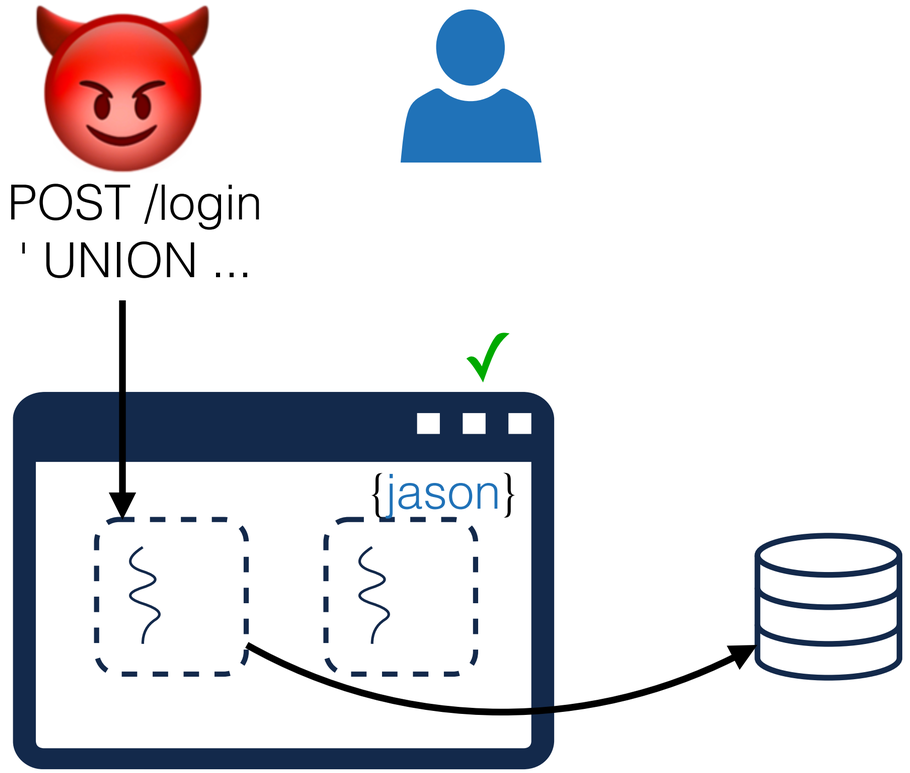

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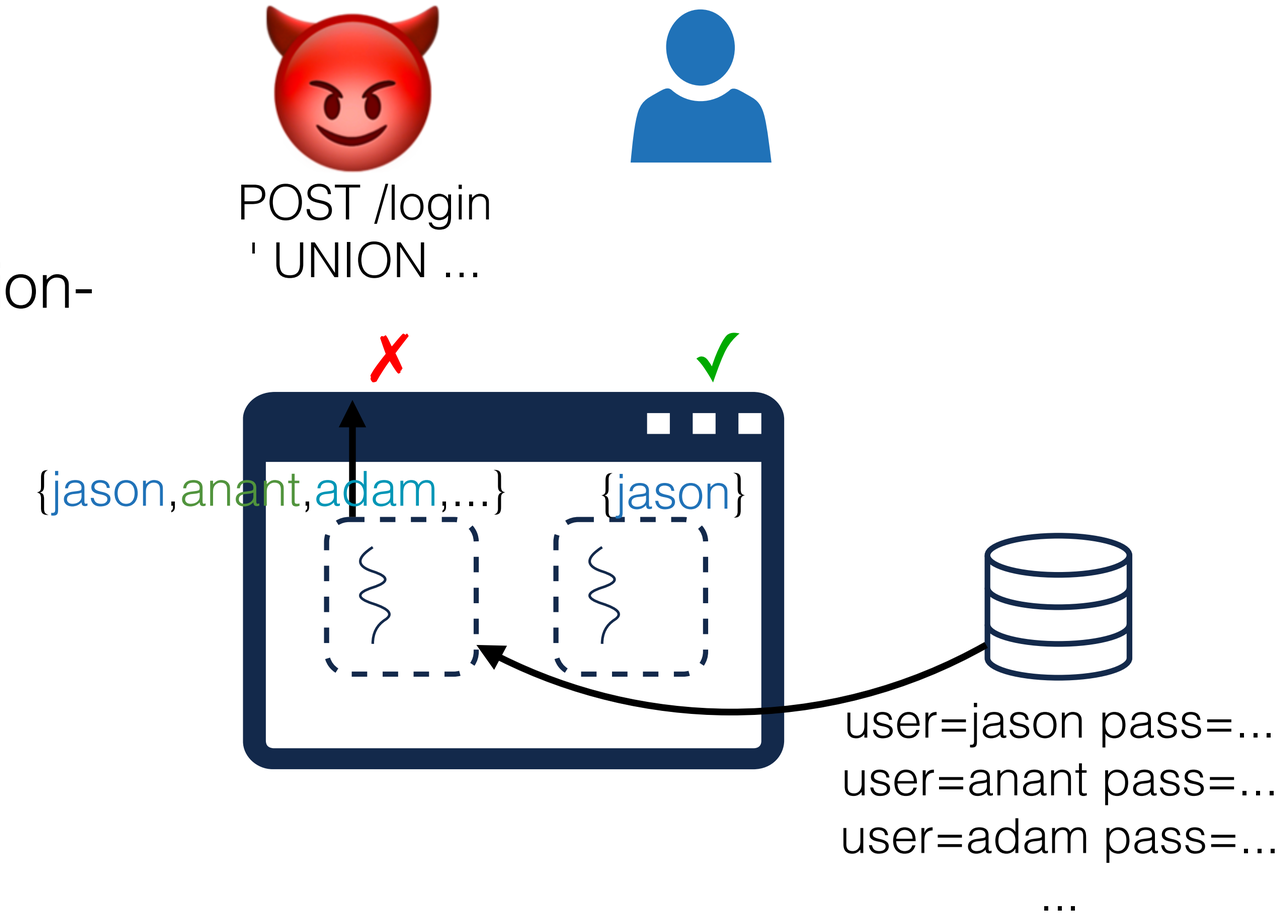

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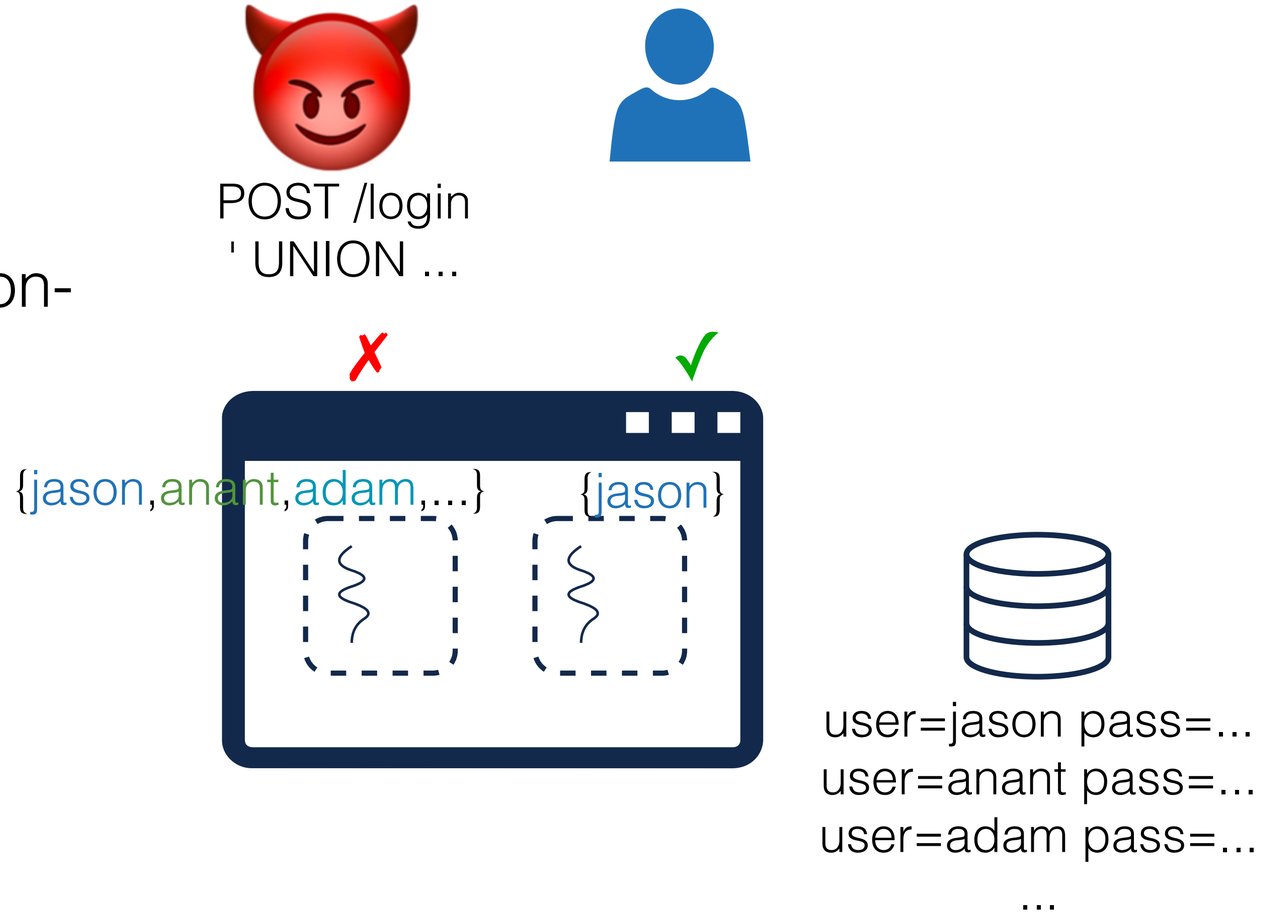
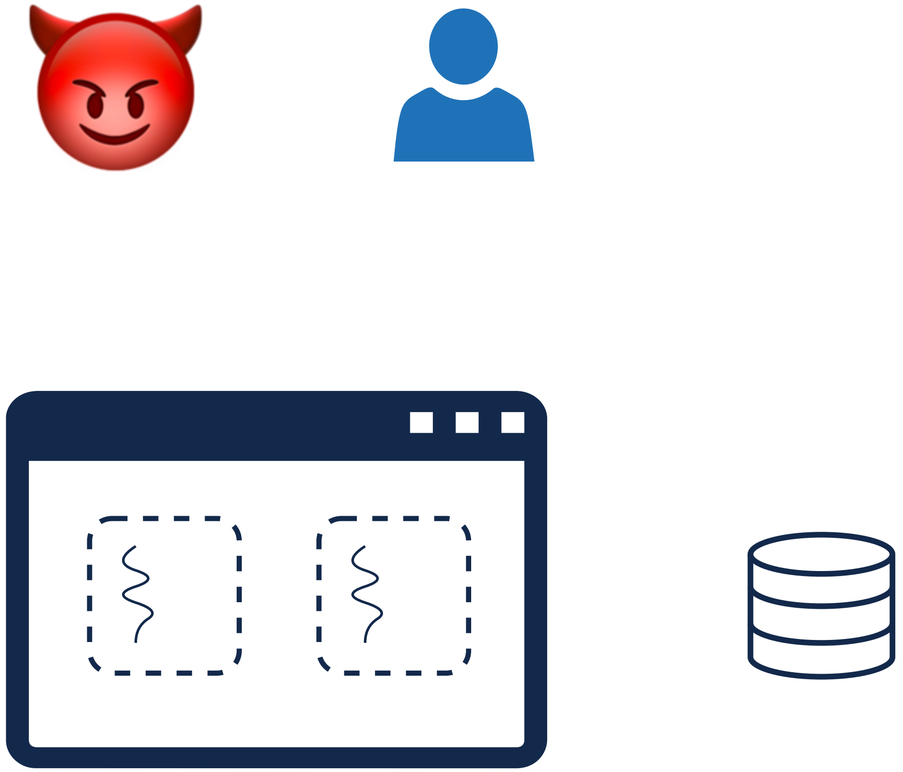


Why does DIFC remain unused despite its advantages?

DIFC Requirements

- Modify code to:
  - Label threads and data
  - Specify allowable flows
  - Declassify data safely



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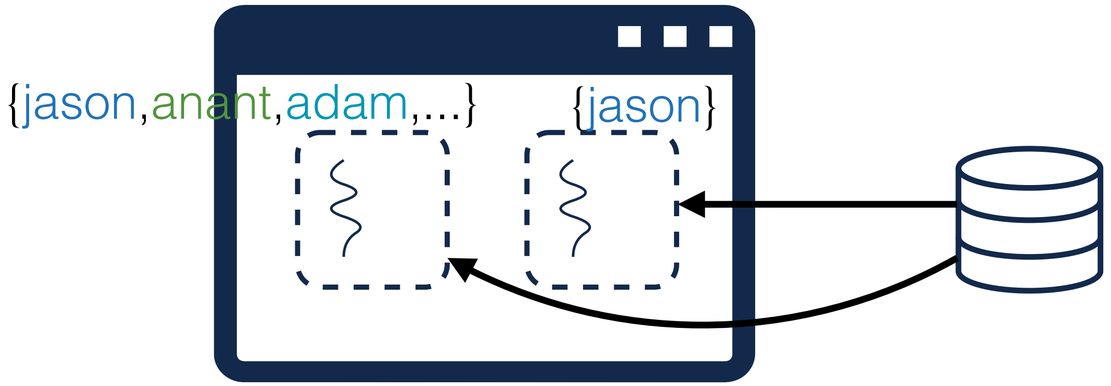

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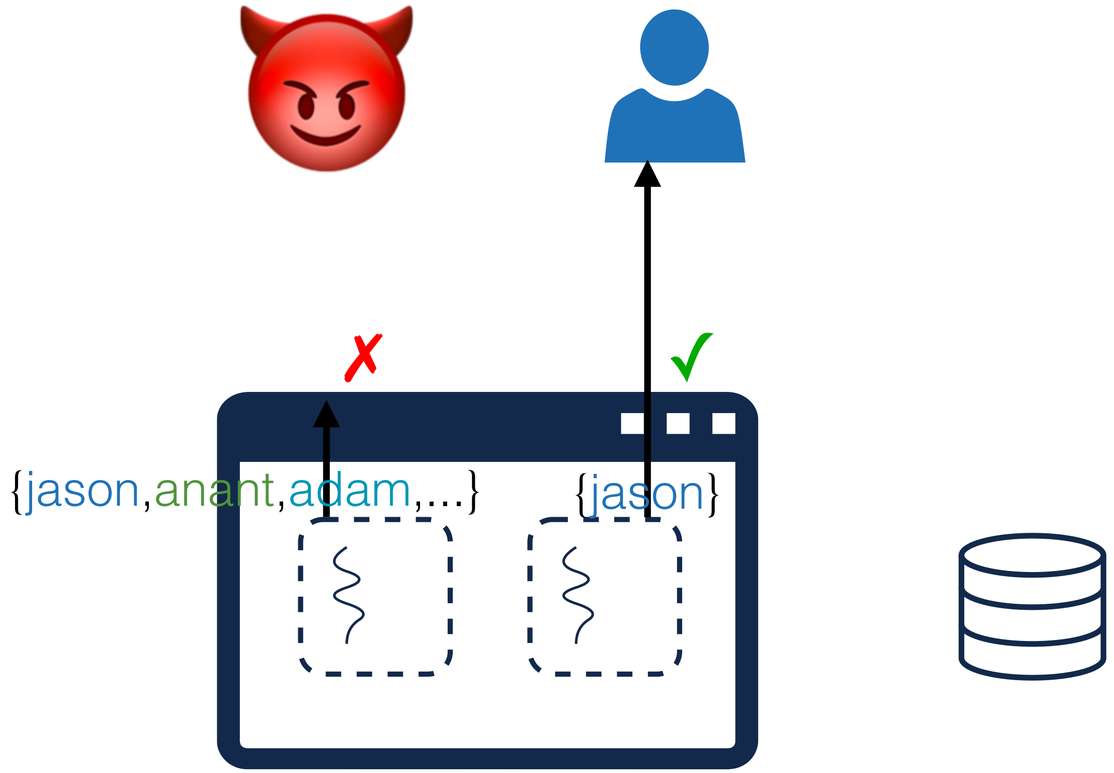

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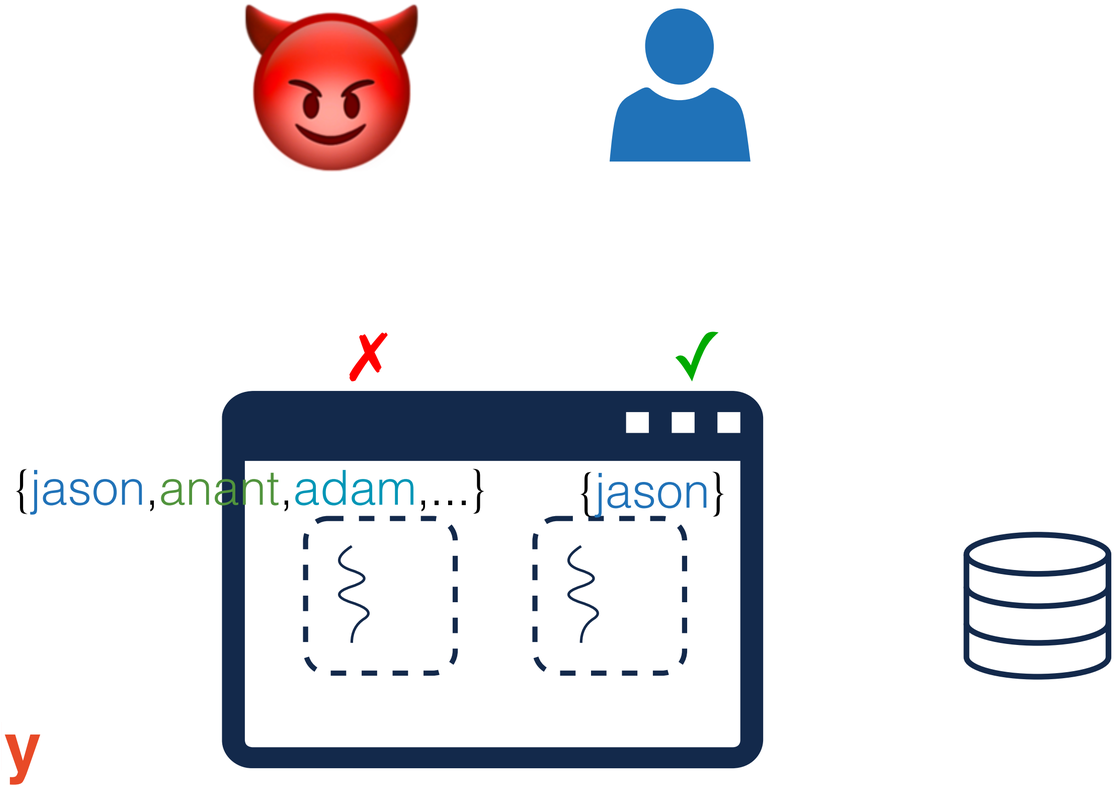
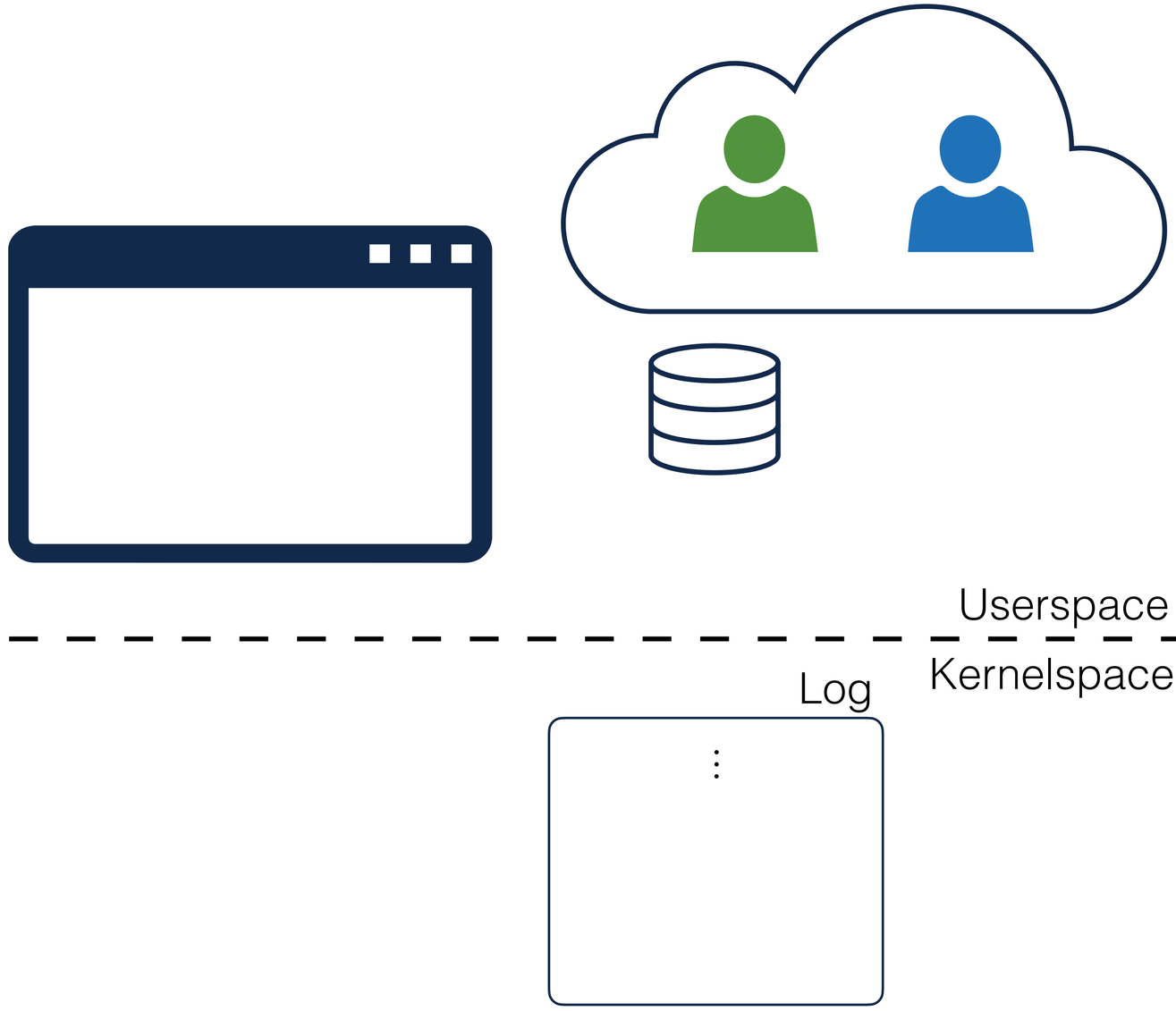


Such code changes are too costly to justify widespread deployment

Can we enforce DIFC policies transparently?

Devs Have Already Done (Some of) the Work

- Best practices dictate logging key events
- Logs contain application-level information
  - Including threading!
- Applications convey this to the reference monitor via write syscalls



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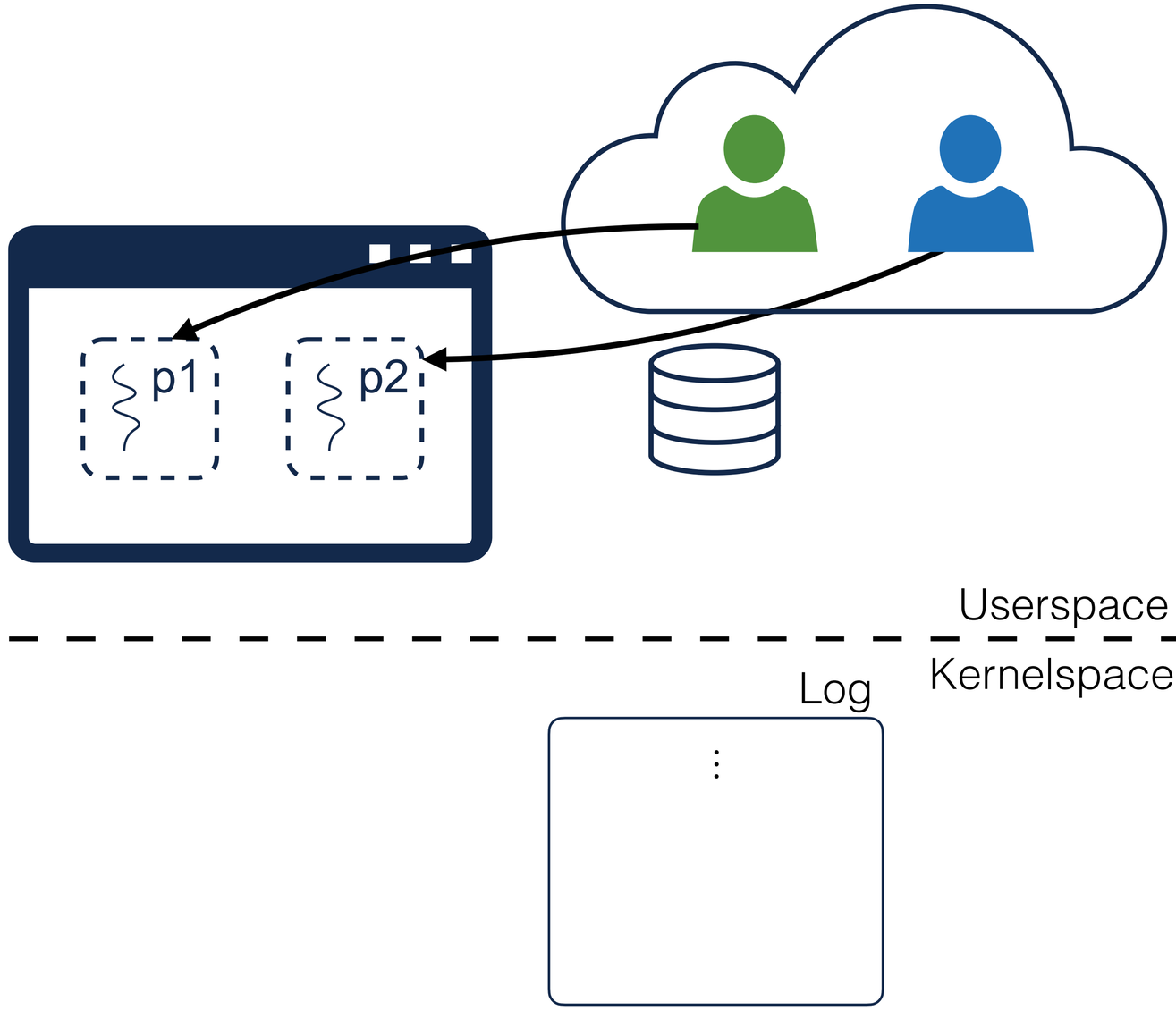

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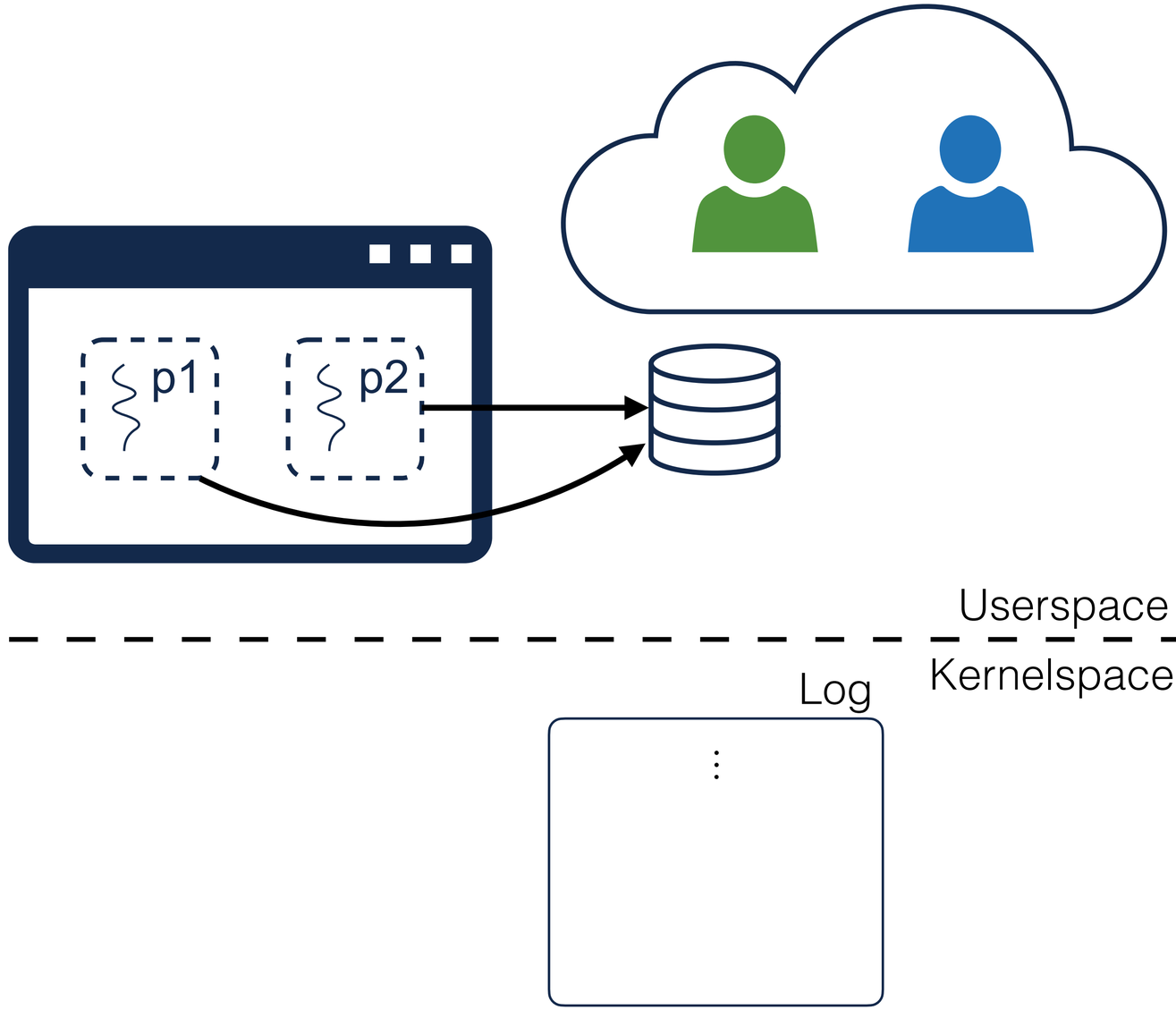

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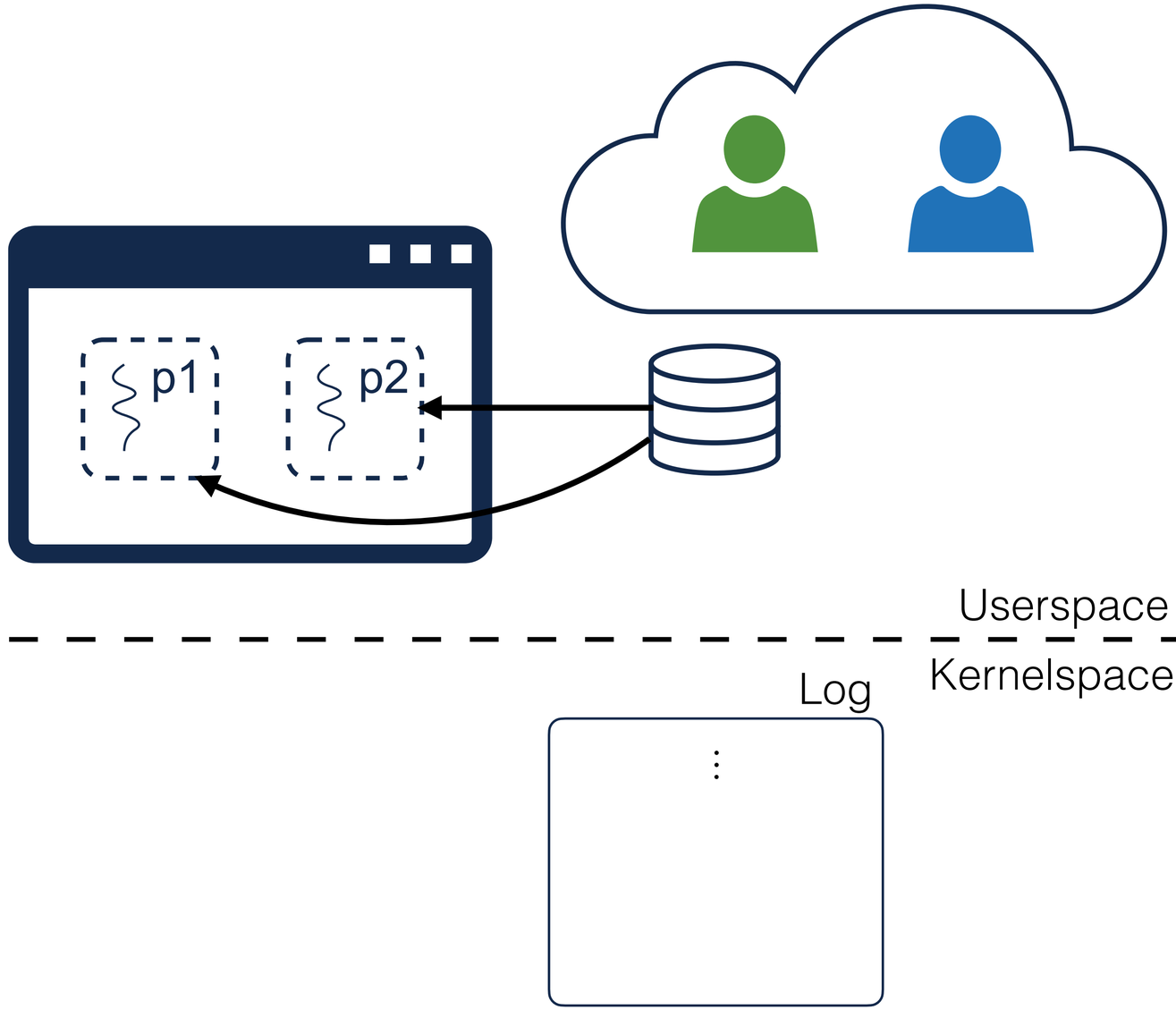

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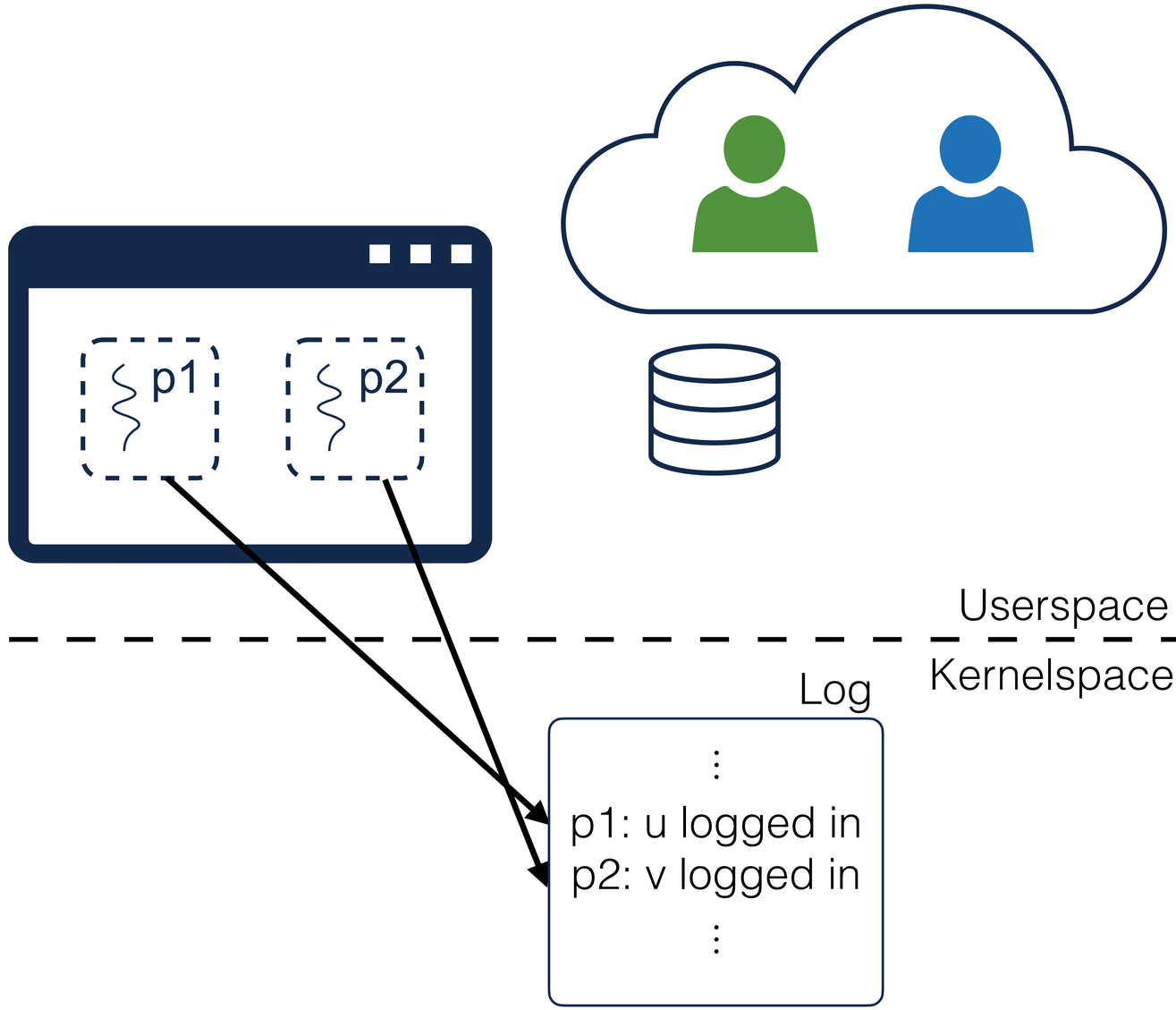

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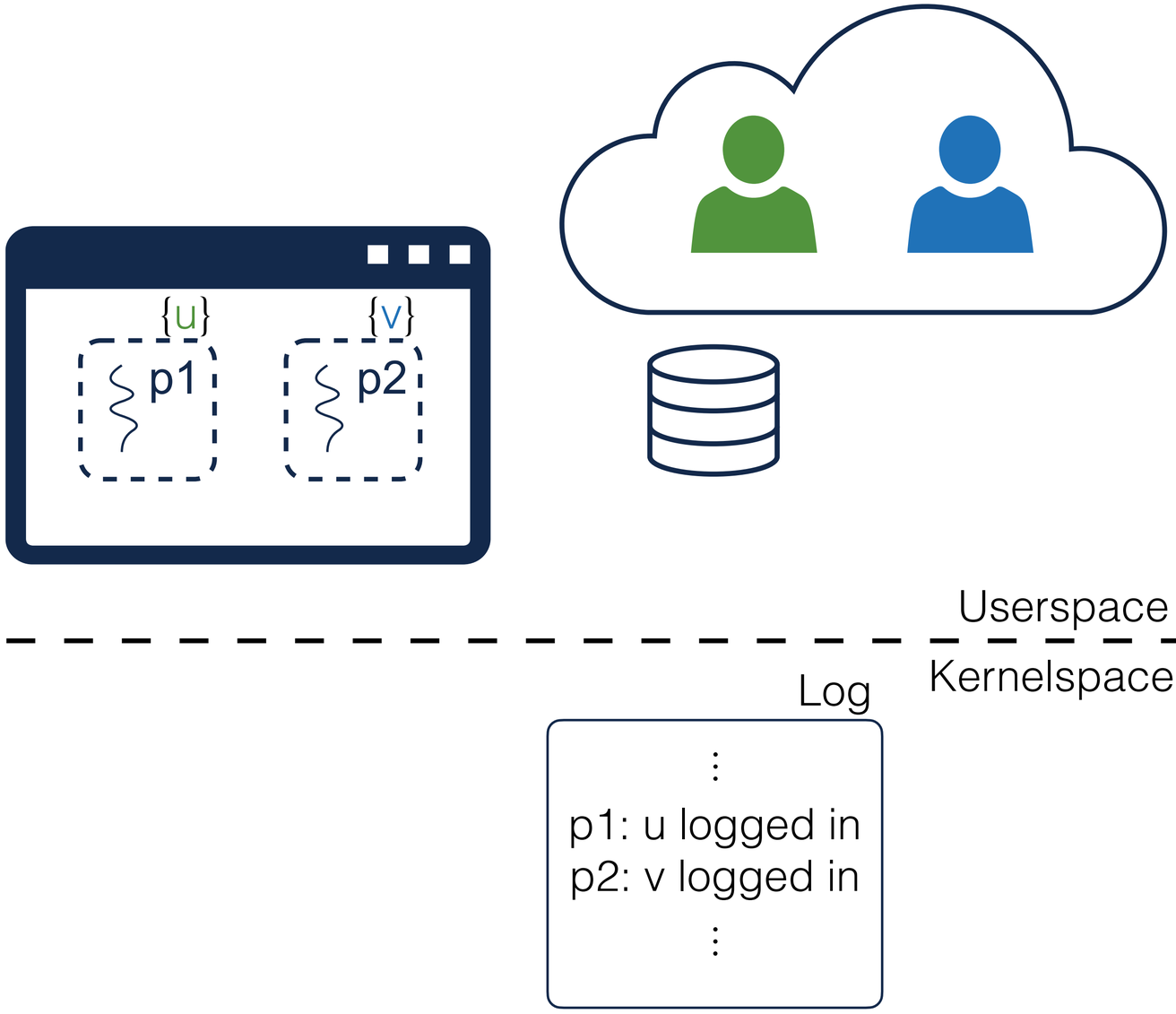
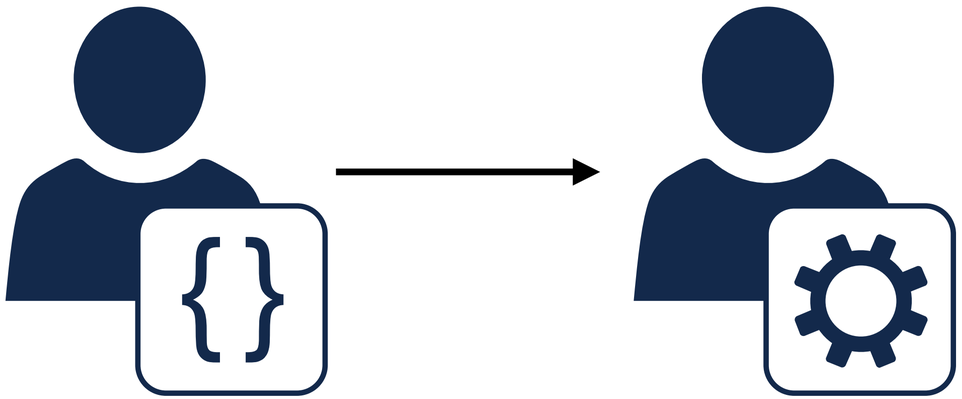


From Devs to SysAdmins



- Only need to create policies for programs when required
- Can specialize policies to exact needs & deployments
- Easy to write policies spanning multiple programs

T-DIFC Overview

Userspace

Kernelspace

Log

Label Propagation & Permissions

Log Interception

T-DIFC Overview

Configure
External Policy

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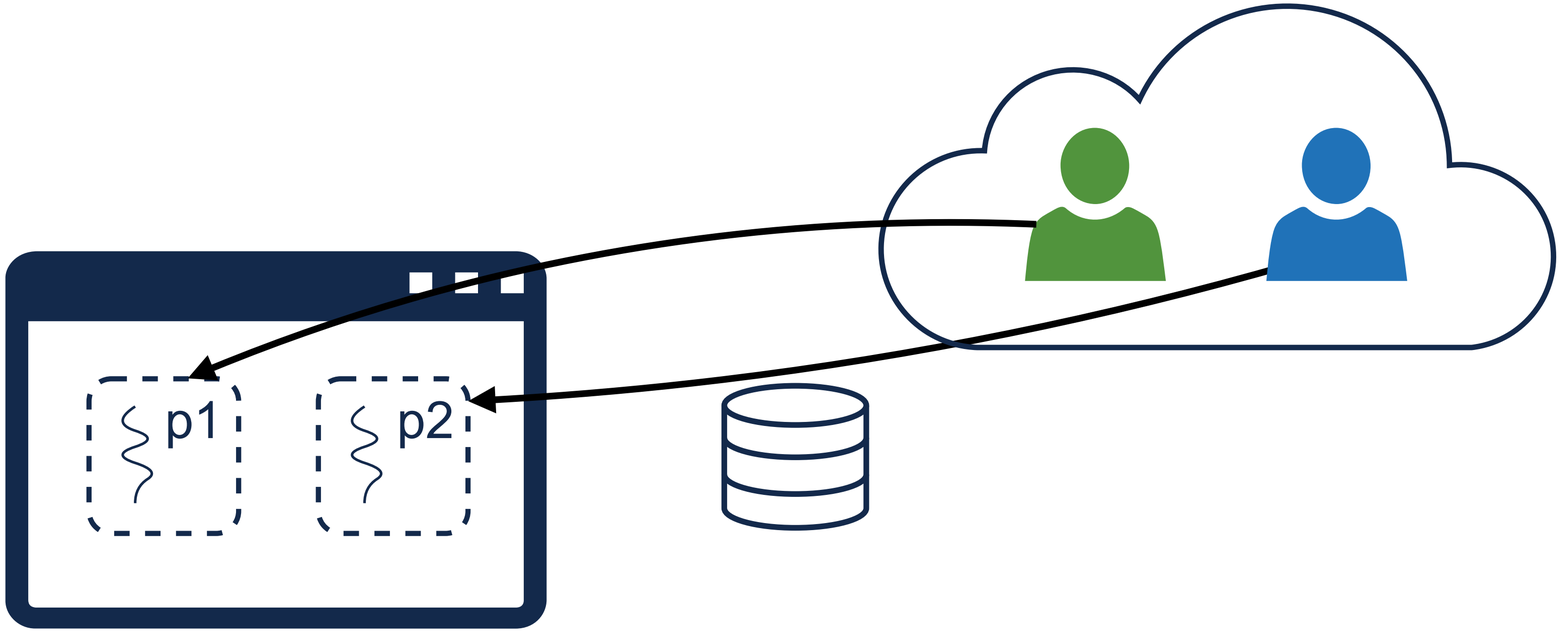

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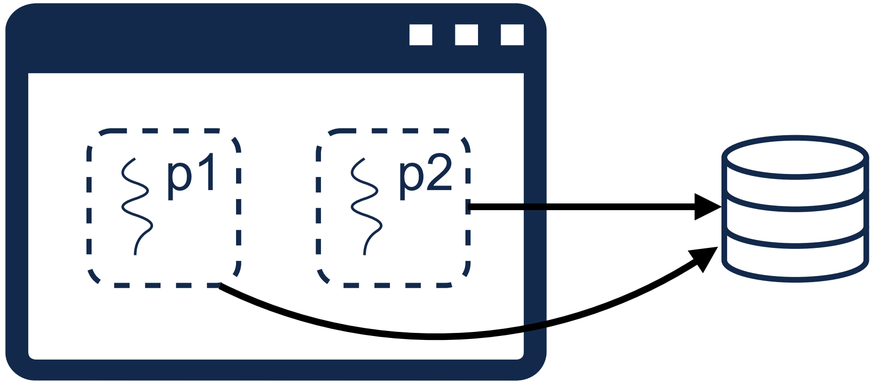

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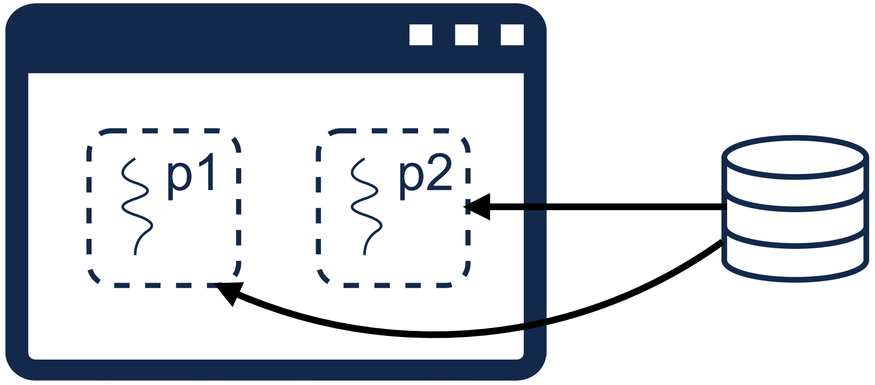

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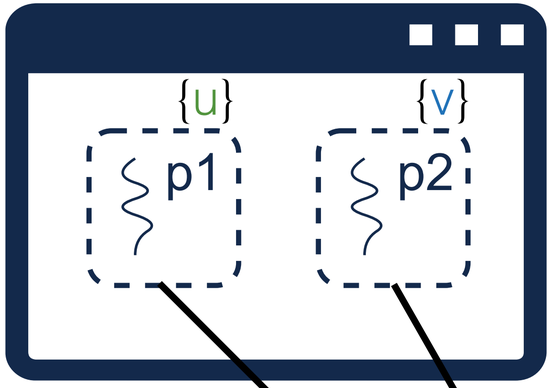

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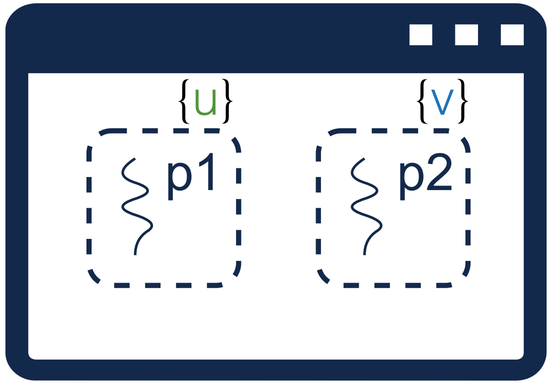

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p2: v logged in
⋮

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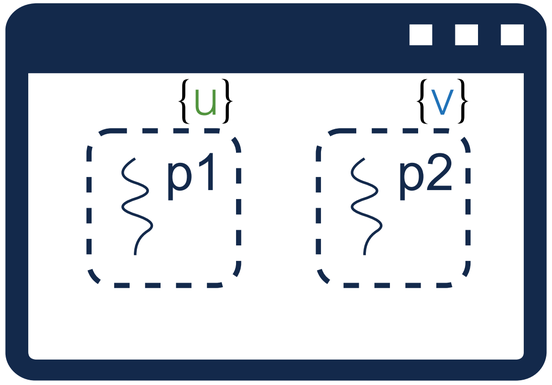

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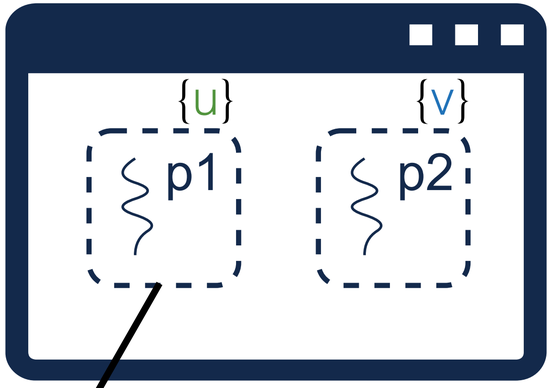

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{v} {u}

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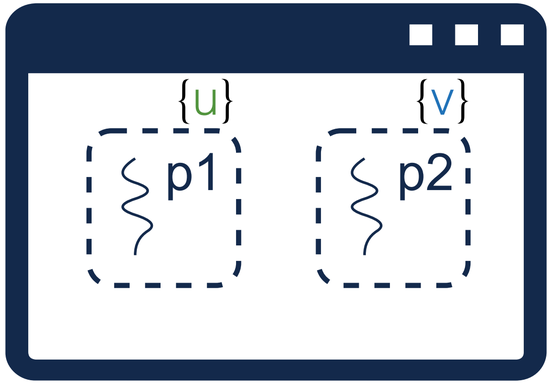

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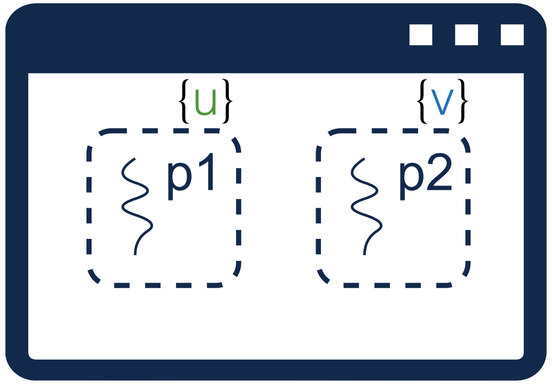

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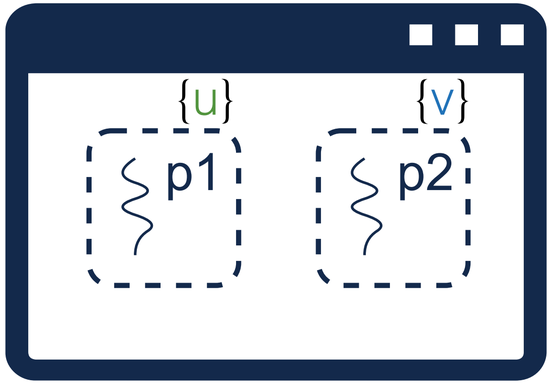

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Labeling

```
match "<p[0-9]+>: <.+> logged in" {
   process <1> {
      settags tag(<2>);
   }
}
```

- Extract PID of current thread (`<p[0-9]+>`)
- Extract user as tag (`<.+>`)

Log Interception

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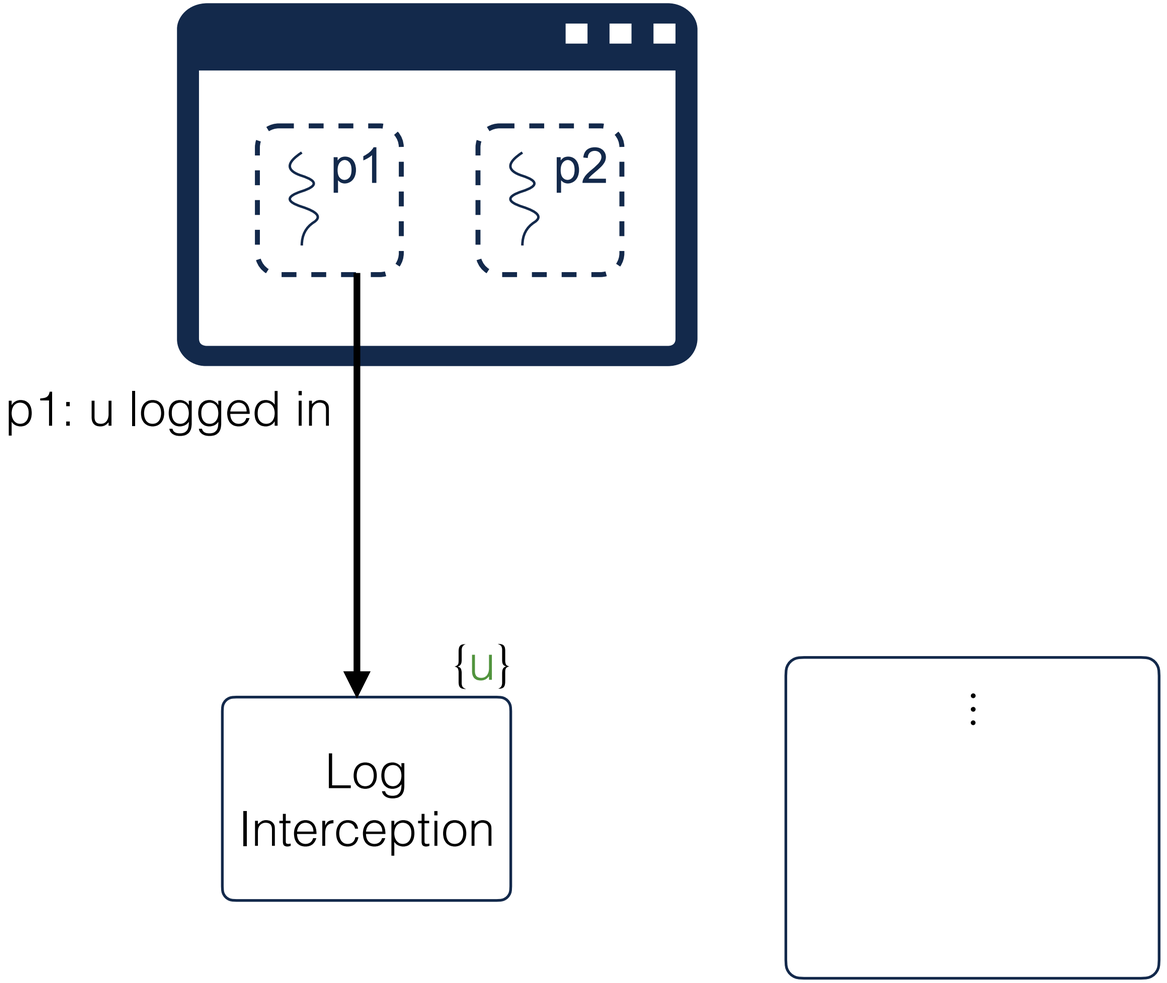

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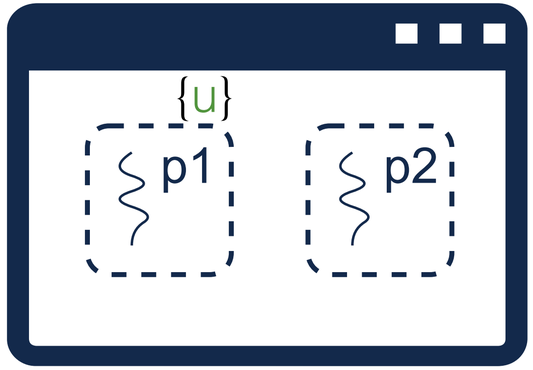

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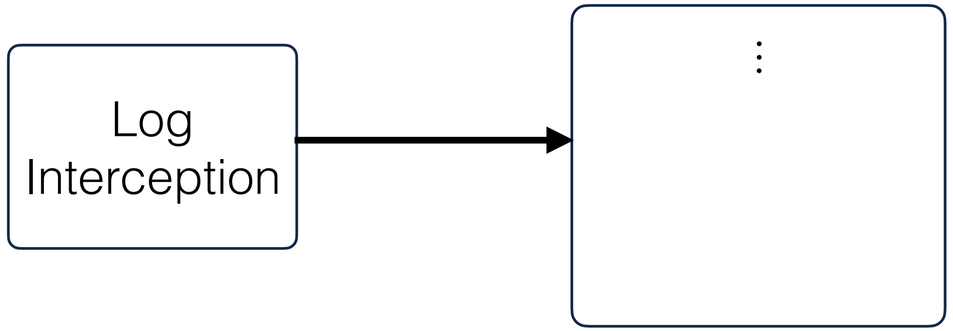

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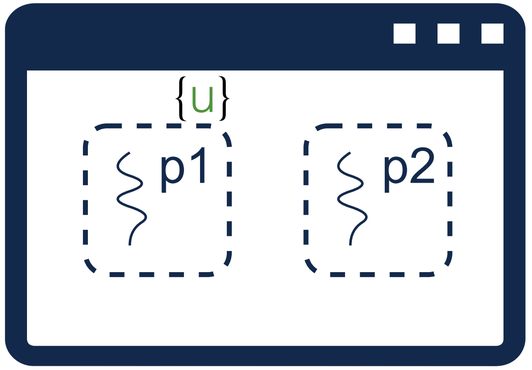

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Log Interception

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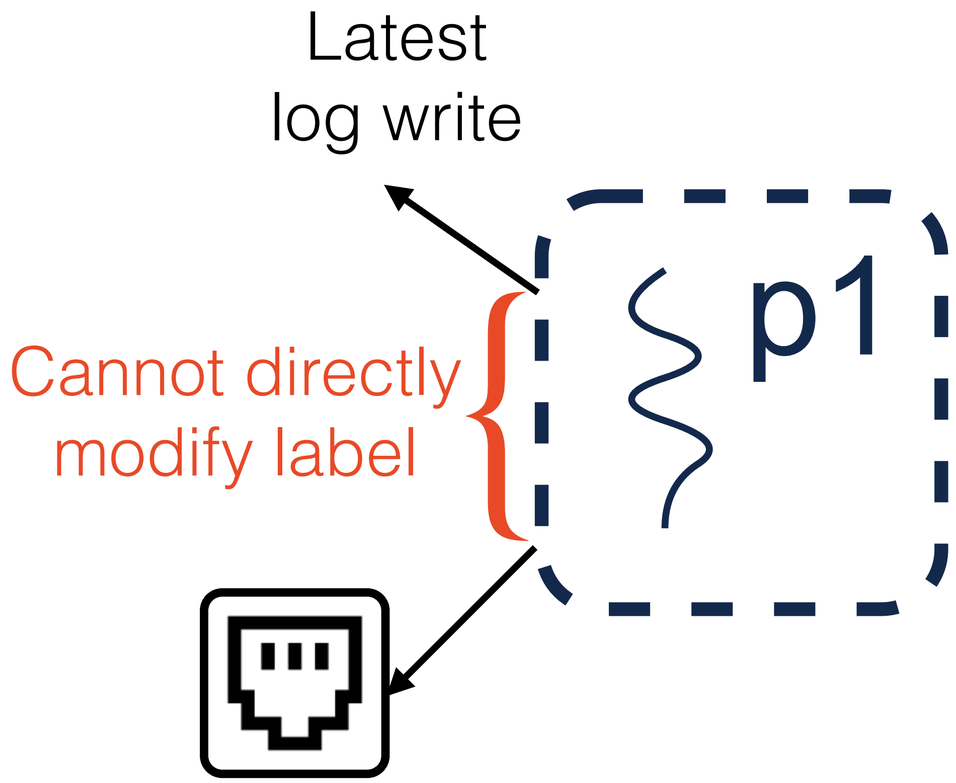
Declassification

- Unlike existing systems, T-DIFC can only directly manipulate labeling state at **specific code locations** (logs)
- Allow specific implicit declassification using an **external policy rule**
  - Only declassify if label is small enough
  - Prevents smash-'n-grab attacks



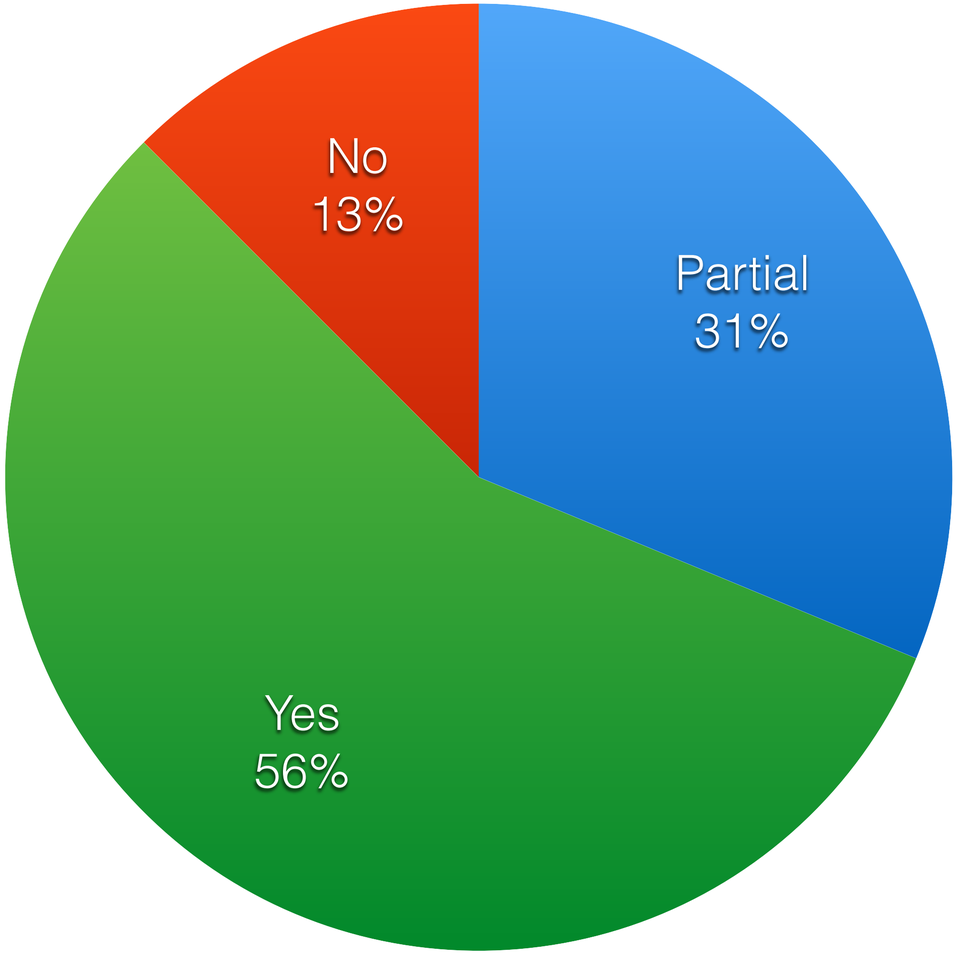
Evaluation Takeaways

Category	"Useful" Policy?	Sample Log
HTTP Servers	3/3	*host - user ...*
Other Servers	3/3	USER *user*: Login successful.
Load Balancing	0/1	Connect from *addr:port* to ...
Web Applications	2*/2	... Login for *user* succeeded ...
Databases	3*/3	... "get" "*key*"
Web Clients	3/4	Logging in as *user*... Logged in!

*Insufficient data partitioning

ProFTPD case study:
~154% overhead per log write
Negligible data transfer overhead

Surveyed Applications with Useful Policies



Open Challenges

- Difficulty in creating correct policies for a specific program
  - Translating high-level security policies to DIFC policies
  - Handling implementation details, e.g., fork before/after logging?
- Finer-grained partitioning for complex data structures (e.g., monolithic file-based or in-memory databases)
- Effectiveness on varying workloads

Conclusion

- One factor limiting DIFC is lacking compatibility with existing software
- Application logs can be used to partition processes and generate tags
  - We can express DIFC policies from most existing applications' logs
- We create T-DIFC, an OS-level DIFC system leveraging logs to achieve transparent DIFC

Thank you!

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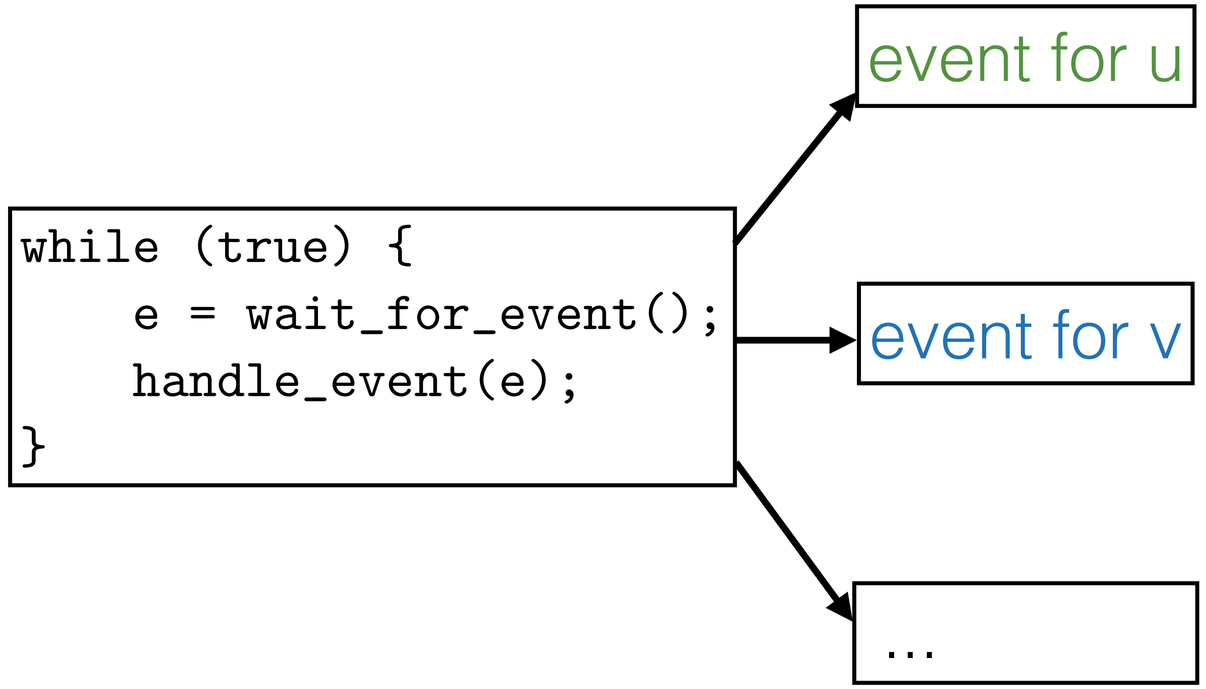
Finer-Than-Process Granularity

- "Event process" abstraction from Asbestos [1]
- Can divide many servers into handlers for different user requests
  - Each handler is typically one iteration of an event-handling loop



[1] Efstathopoulos et al.. Labels and Events in the Asbestos Operating System. *SOSP '05.*

ProFTPD Example

```
id 21;
namespace unique;
logfile "/var/log/proftpd/proftpd.log";

max_process_label 1;

match ".*proftpd\[<[0-9]+>\].*:
    USER <[^:]+>: Login successful.\n" {
  process <1> {
    settags tag(<2>);
  }
}
```