Fabric

A Platform for
Secure Distributed Computation and Storage

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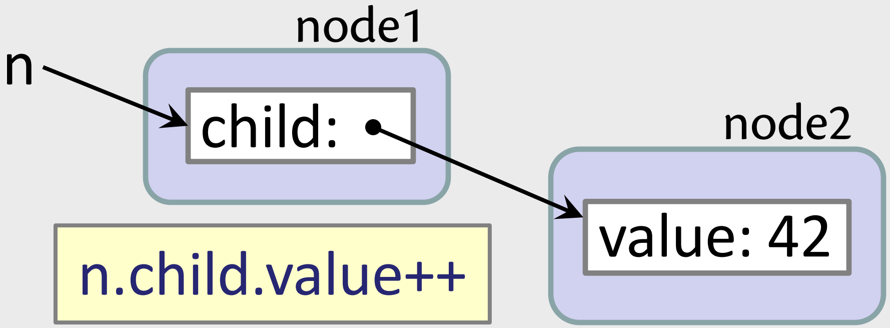
The Web is Not Enough

- The Web: decentralized information-sharing
- Limitations for integrating information
  - Medicine, finance, government, military, …
  - Need **security** and **consistency**

Is there a principled way to build federated applications while guaranteeing security and consistency?

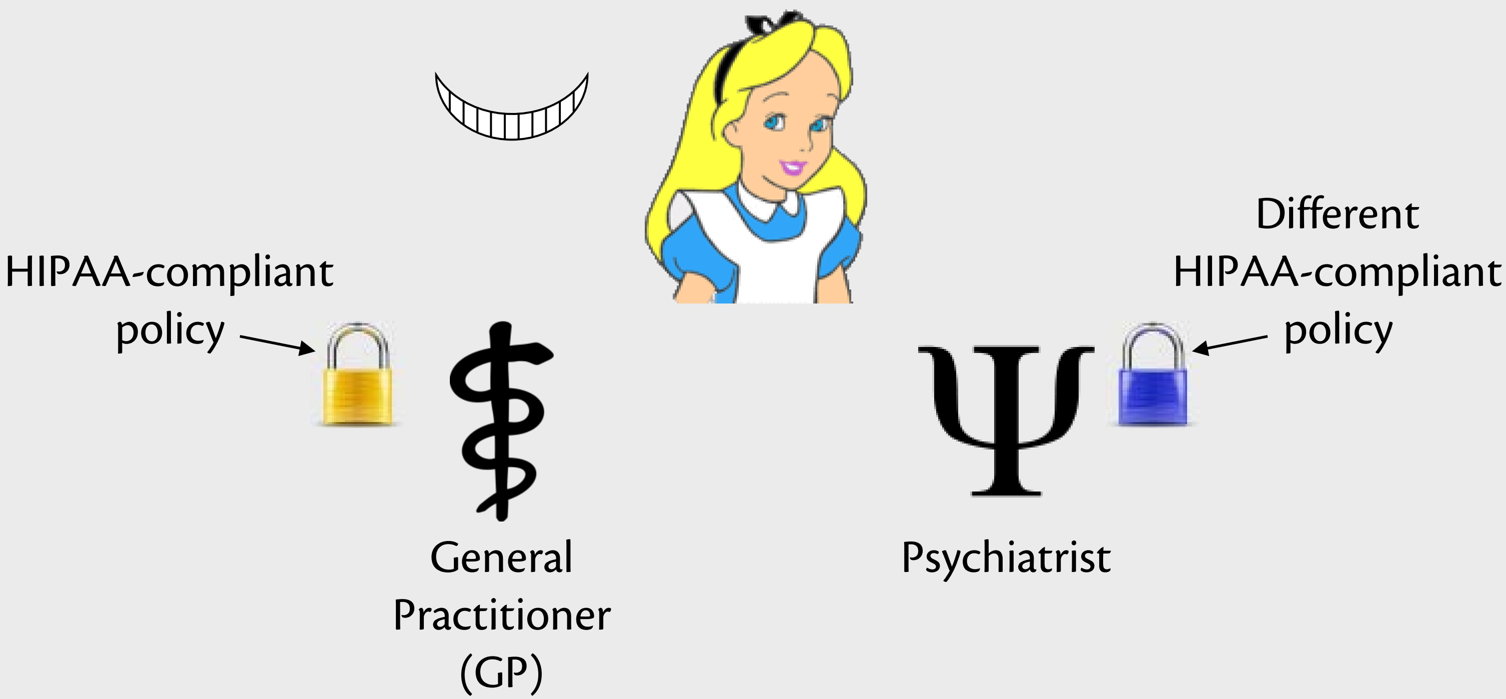
Fabric: A System and a Language

- Decentralized system for securely sharing information and computation
- All information looks like an ordinary program object
- Objects refer to each other with references
  - Any object can be referenced uniformly from anywhere
  - References can cross nodes and trust domains
  - All references look like ordinary object pointers



Compiler and runtime enforce security and consistency despite distrust

Fabric Enables Federated Sharing



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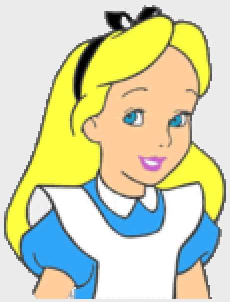
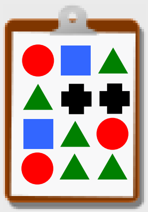
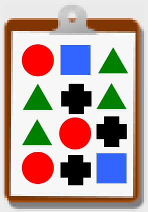


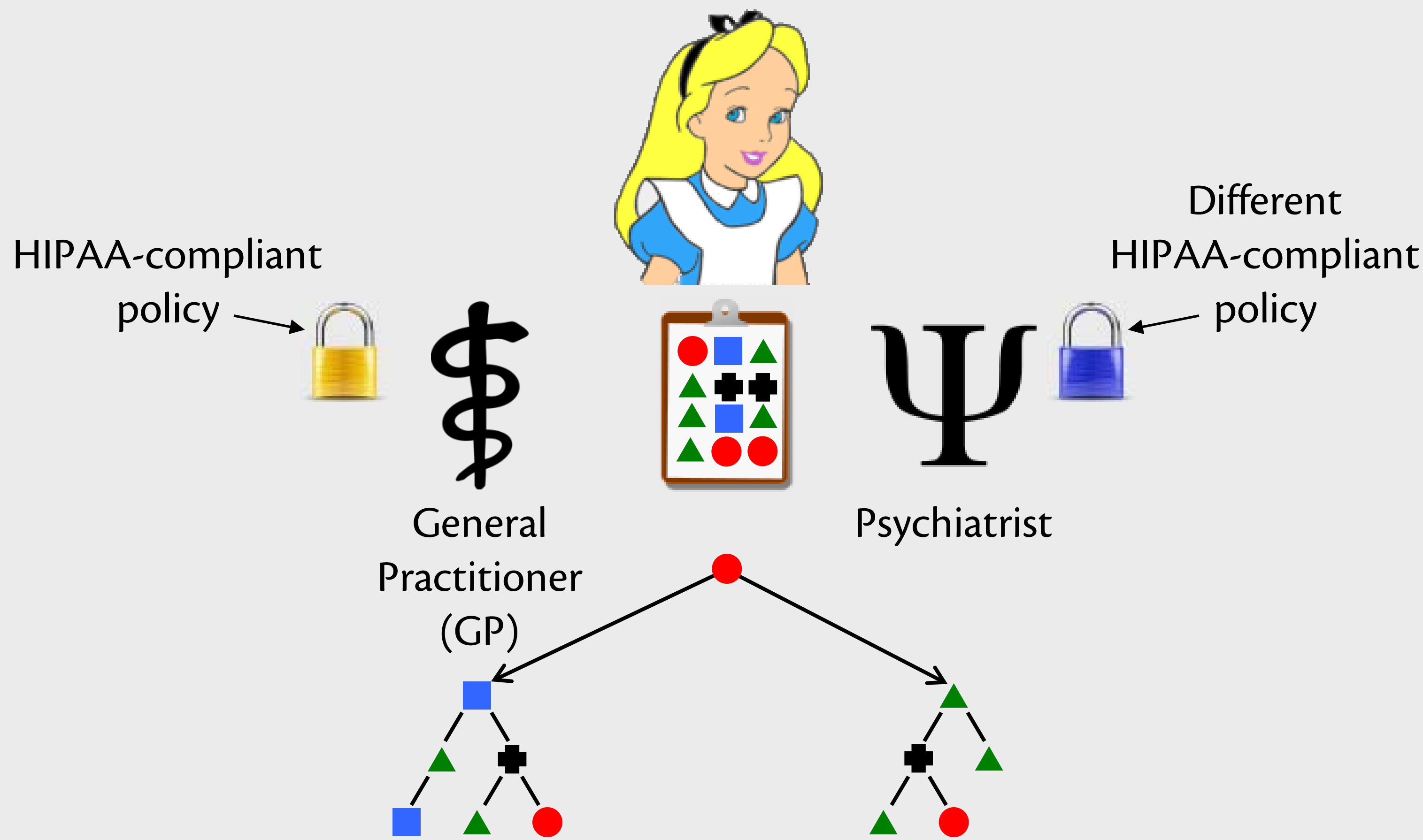


General Practitioner (GP)

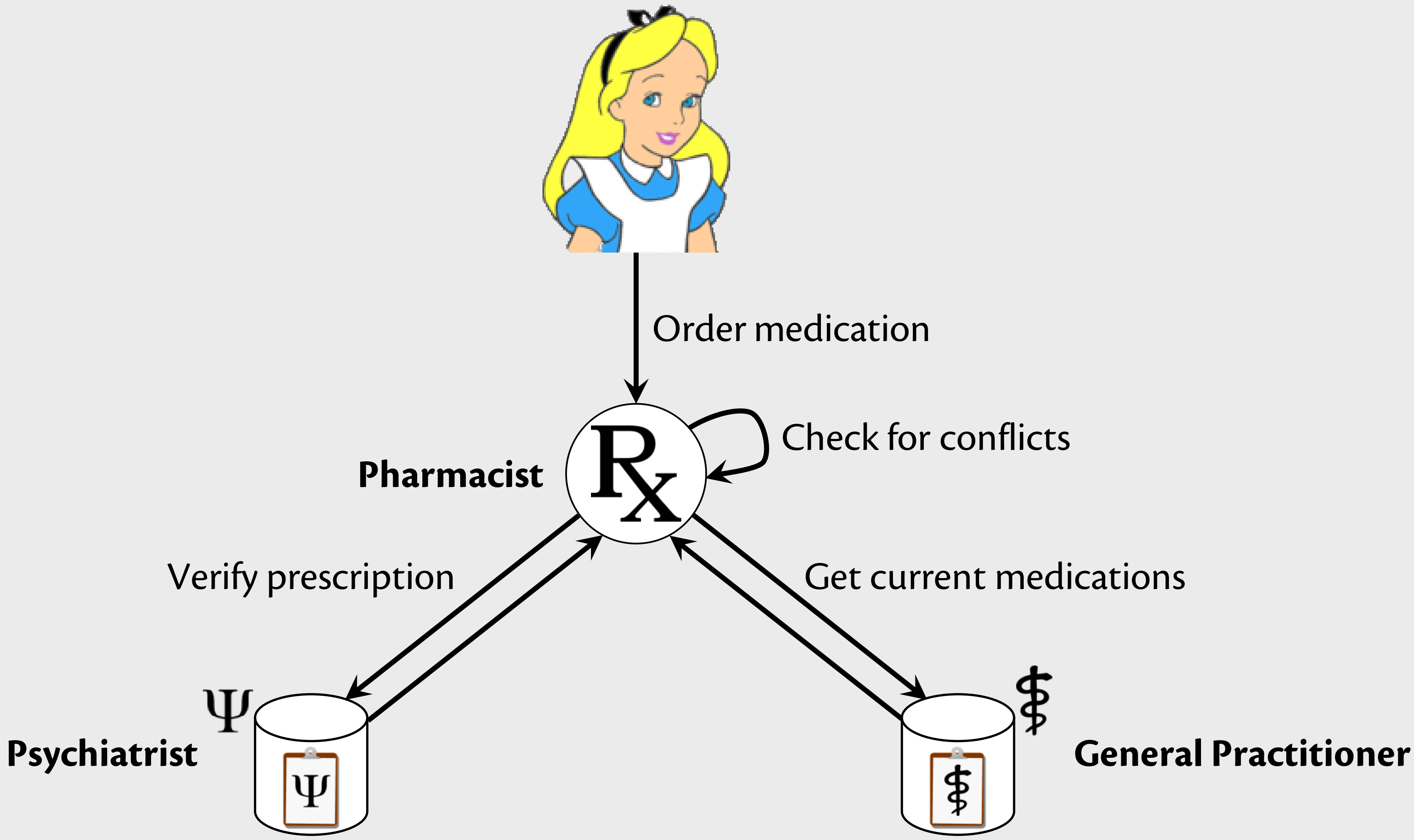


Psychiatrist

Fabric Enables Federated Sharing



Example: Filling a Prescription



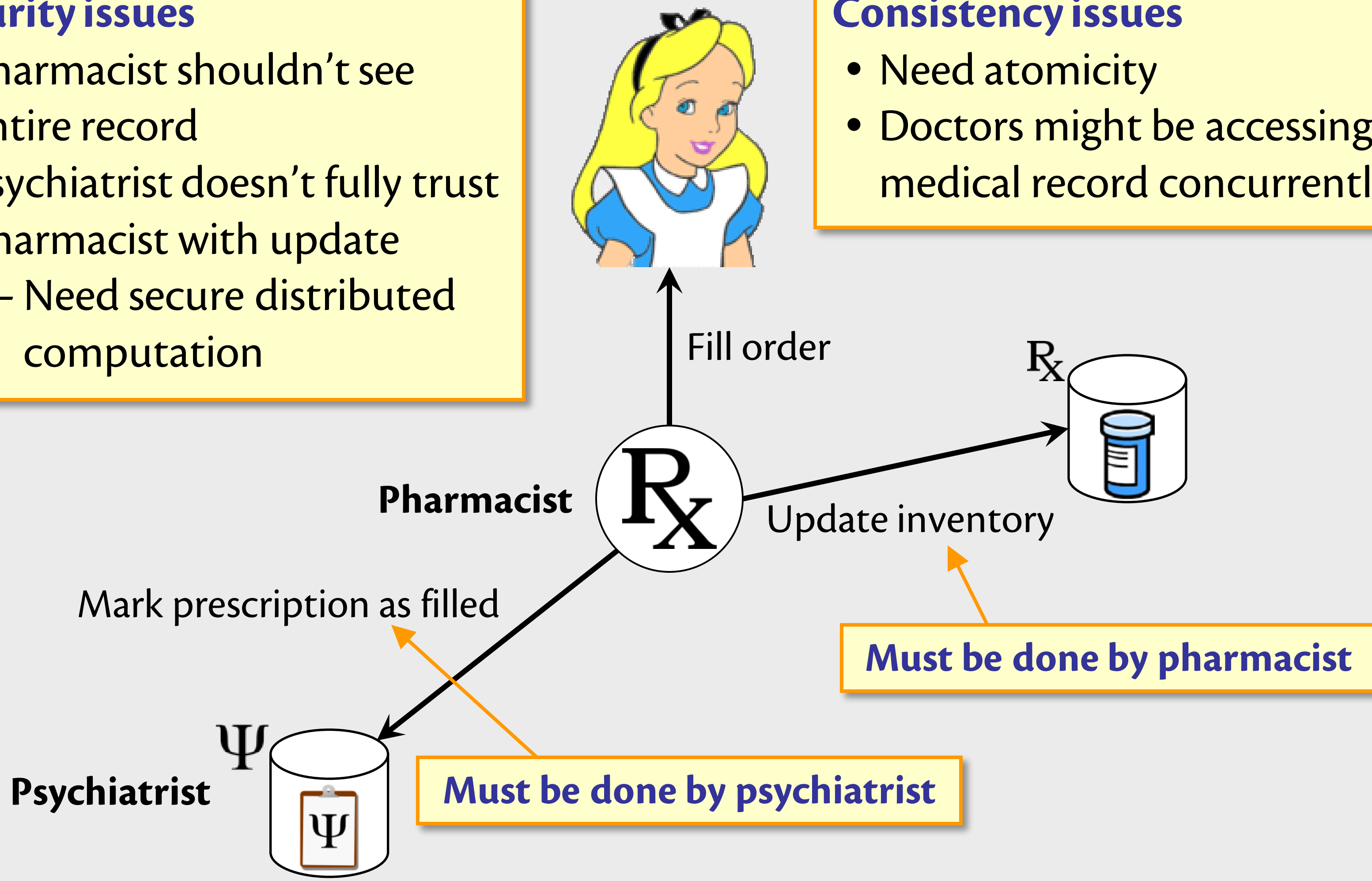
Example: Filling a Prescription

Security issues

- Pharmacist shouldn't see entire record
- Psychiatrist doesn't fully trust pharmacist with update
  - Need secure distributed computation

Consistency issues

- Need atomicity
- Doctors might be accessing medical record concurrently

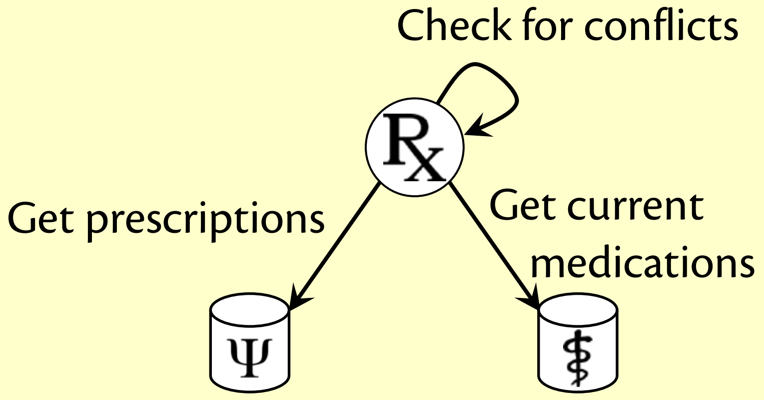


Pharmacy Example in Fabric

```
Order orderMed(PatRec psyRec, PatRec gpRec, Prescription p) {

    if (!psyRec.hasPrescription(p)) return Order.INVALID;
    if (isDangerous(p, gpRec.getMeds())) return Order.DANGER;

}
```



Pharmacy Example in Fabric

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    Worker psy = psyRec.getWorker();
    psyRec.markFilled@psy(p);
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    return Order.fill(p);
  }
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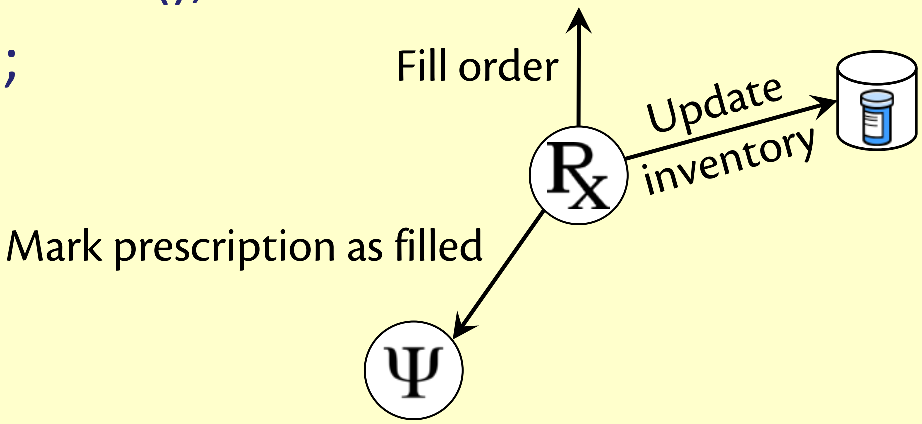
```



A High-Level Language

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Java with:

- Remote calls
- Nested transactions (atomic blocks)
- Label annotations for security (elided)

A High-Level Language

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```

- All objects accessed uniformly regardless of location
- Objects fetched as needed
- Remote calls are explicit

Run-time system requirement:

- **Secure transparent data shipping**

Remote Calls

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Remote call — pharmacist runs method at psychiatrist's node

Run-time system requirements:

- Secure transparent data shipping
- **Secure remote calls**

Federated Transactions

```
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```

Federated transaction — spans multiple nodes & trust domains

Remote call — pharmacist runs method at psychiatrist's node

Run-time system requirements:

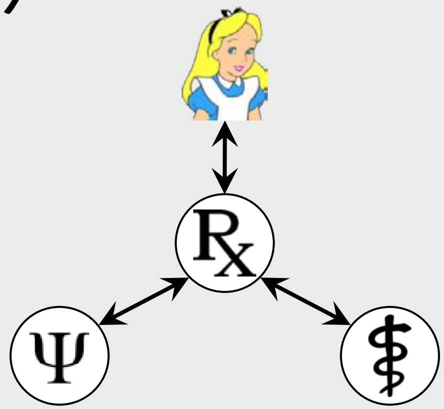
- Secure transparent data shipping
- Secure remote calls
- ***Secure federated transactions***

Fabric Security Model

- Decentralized system – anyone can join
- What security guarantees can we provide?
- **Decentralized security principle:**

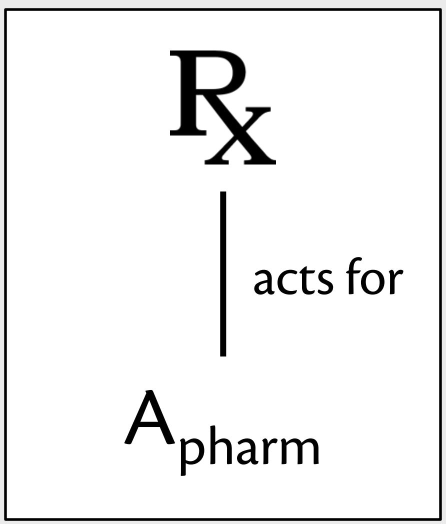
  You can’t be hurt by what you don’t trust

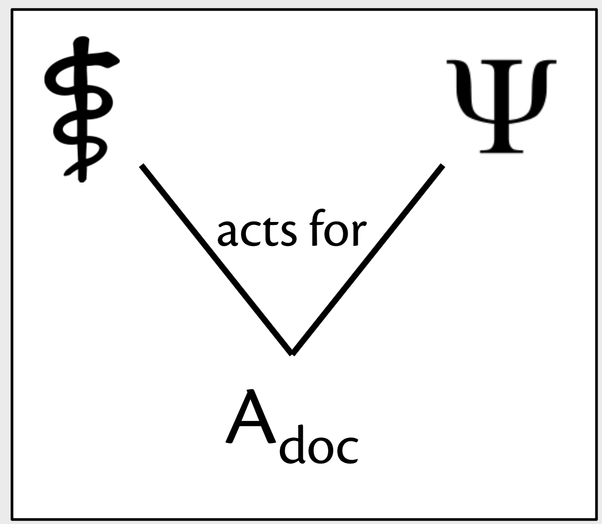
- Need notion of “you” and “trust” in system and language
  - **Principals** and **acts-for**



Principals and Trust in Fabric

- **Principals** represent users, nodes, groups, roles
- Trust delegated via **acts-for**
  - "Alice acts-for Bob" means "Bob trusts Alice"
  - Like "speaks-for" [LABW91]
  - Generates a **principal hierarchy**





Trust Management

- Fabric principals are objects

```
class Principal {
  boolean delegatesTo(principal p);
  void addDelegatesTo(principal p) where caller (this);
  …
}
```

Determines whether *p* acts for this principal

Caller must have authority of this principal

- Explicit trust delegation via method calls

```
// Adds "Alice acts-for Bob" to principal hierarchy
bob.addDelegatesTo(alice)
```

  – Compiler and run-time ensure that caller has proper authority

Security Labels in Fabric

- Based on Jif programming language [M99]
- Decentralized label model [ML98]
  - Labels specify security policies to be enforced

Confidentiality: Alice $\rightarrow$ Bob   Alice permits Bob to read

Integrity: Alice $\leftarrow$ Bob   Alice permits Bob to write

```
class Prescription {
  Drug{Psy→A_pharm; Psy←Psy} drug;
  Dosage{Psy→A_pharm; Psy←Psy} dosage;
  … }
```

- Compiler and run-time system ensure that policies are satisfied

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- Compiler and run-time syst
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Run-time system requirements:

- Secure transparent data shipping
- Secure remote calls
- Secure federated transactions
- **Enforcement of security labels**

Contributions

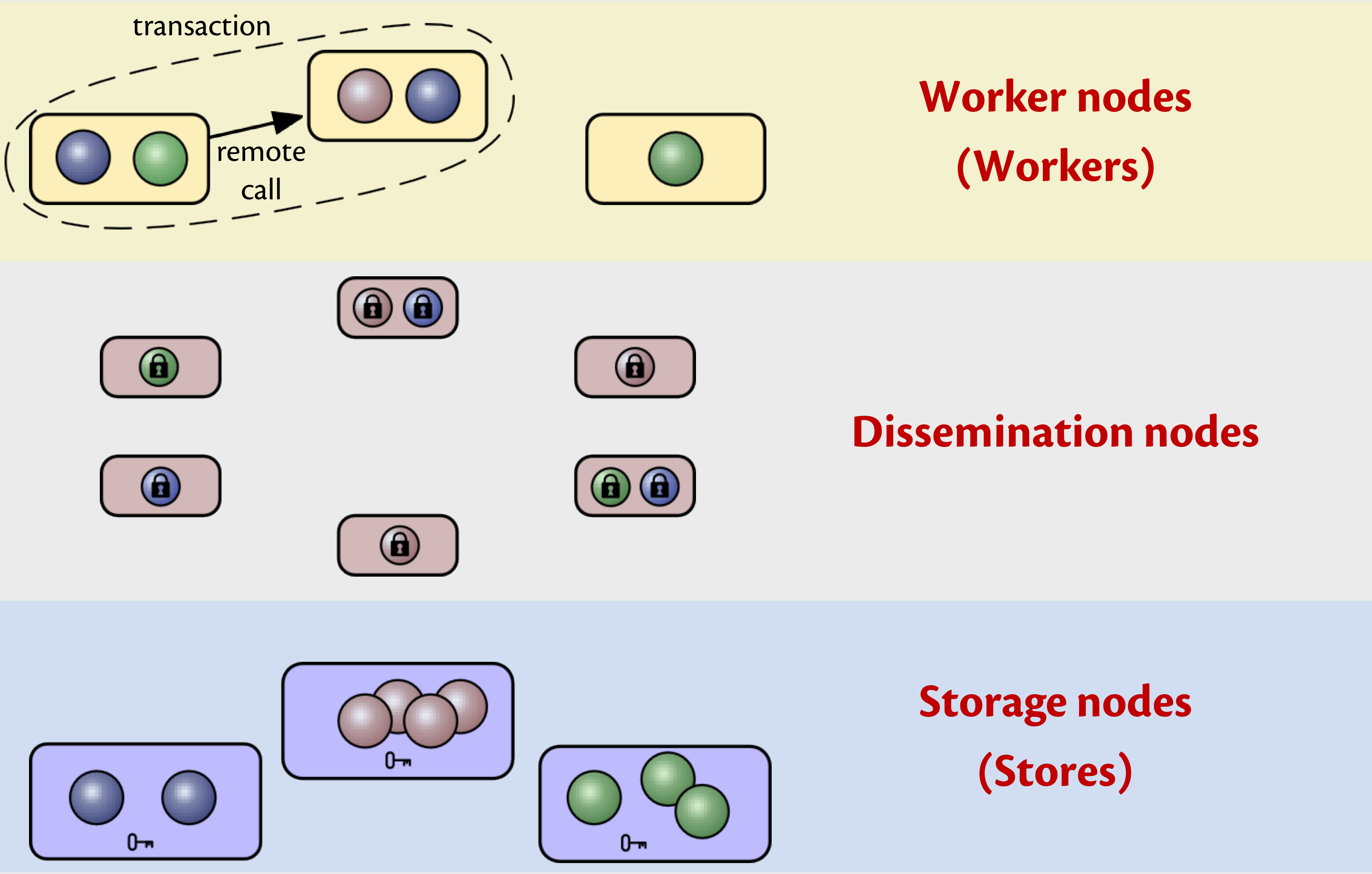
- Language combining:
  - Remote calls
  - Nested transactions
  - Security annotations
- System with:
  - Secure transparent data shipping
  - Secure remote calls
  - Secure federated transactions
  - Enforcement of security labels

Challenge: How to provide all these in the same system?

Fabric Run-Time System

- Decentralized platform for secure, consistent sharing of information and computation
  - Nodes join freely
  - No central control over security
- Nodes are principals
  - Root of trust
  - Authentication: X.509 certificates bind hostnames to principal objects

Fabric Architecture



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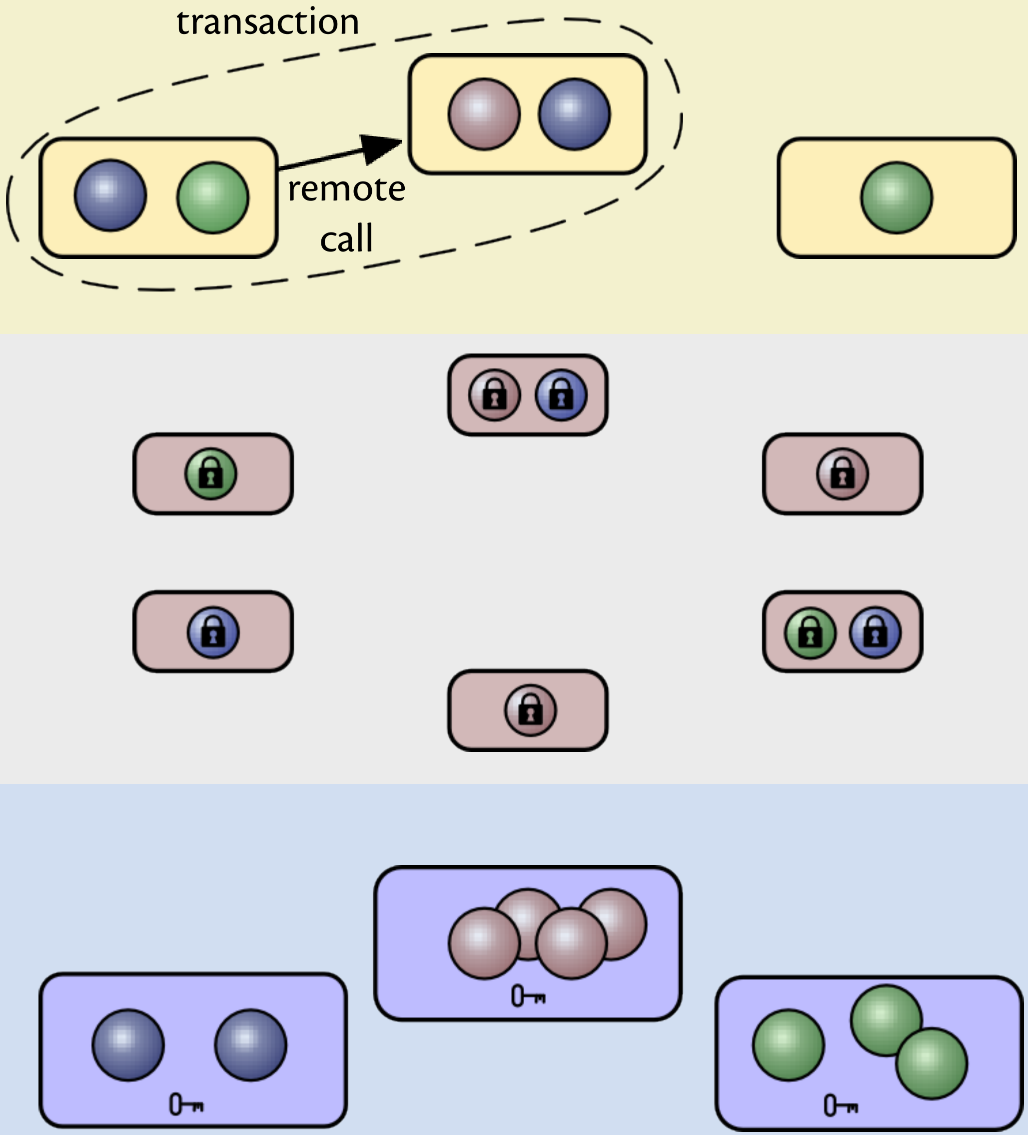
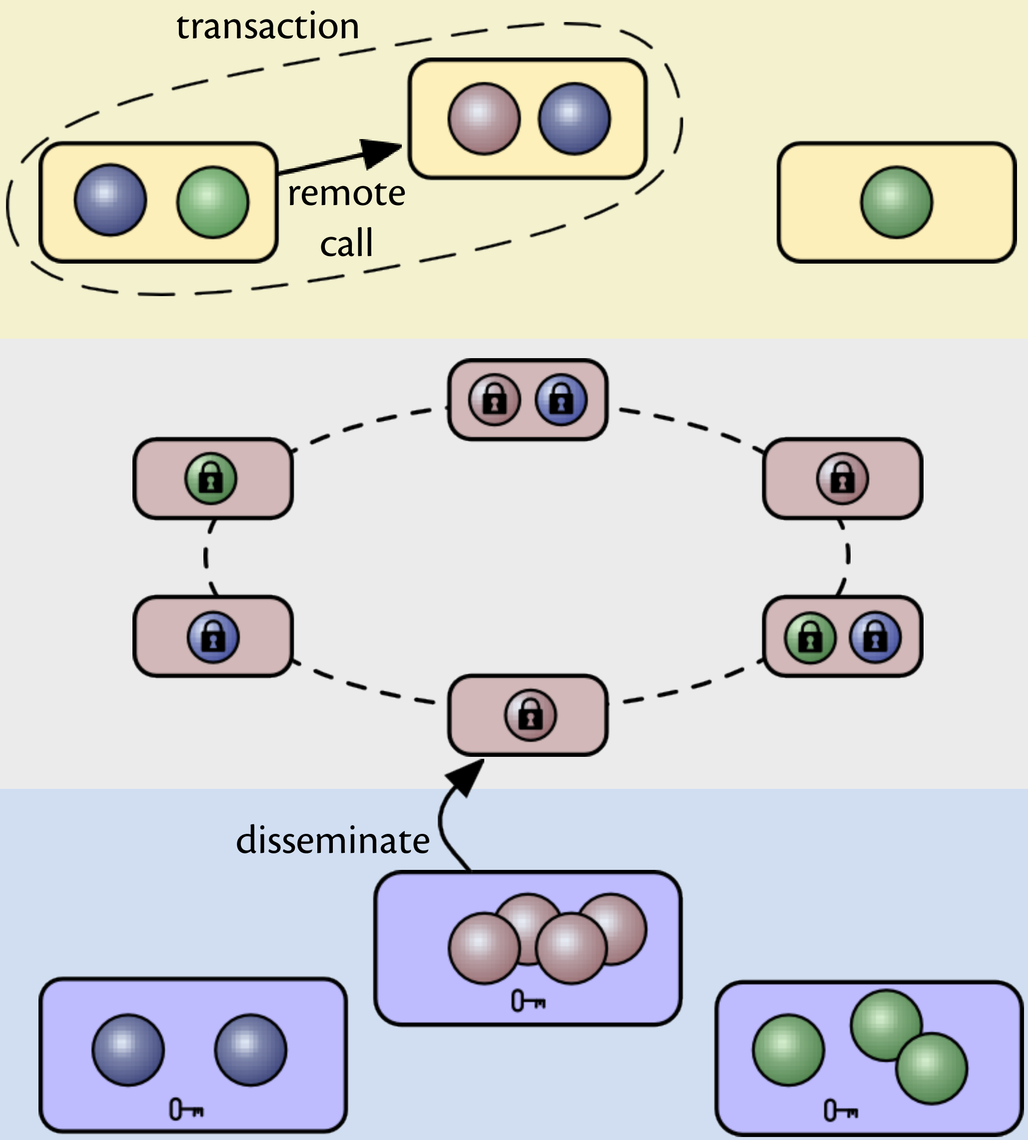


Worker nodes (Workers)

Dissemination nodes

- **Storage nodes** securely store persistent objects
- Each object specifies its own security policy, enforced by store

Fabric Architecture

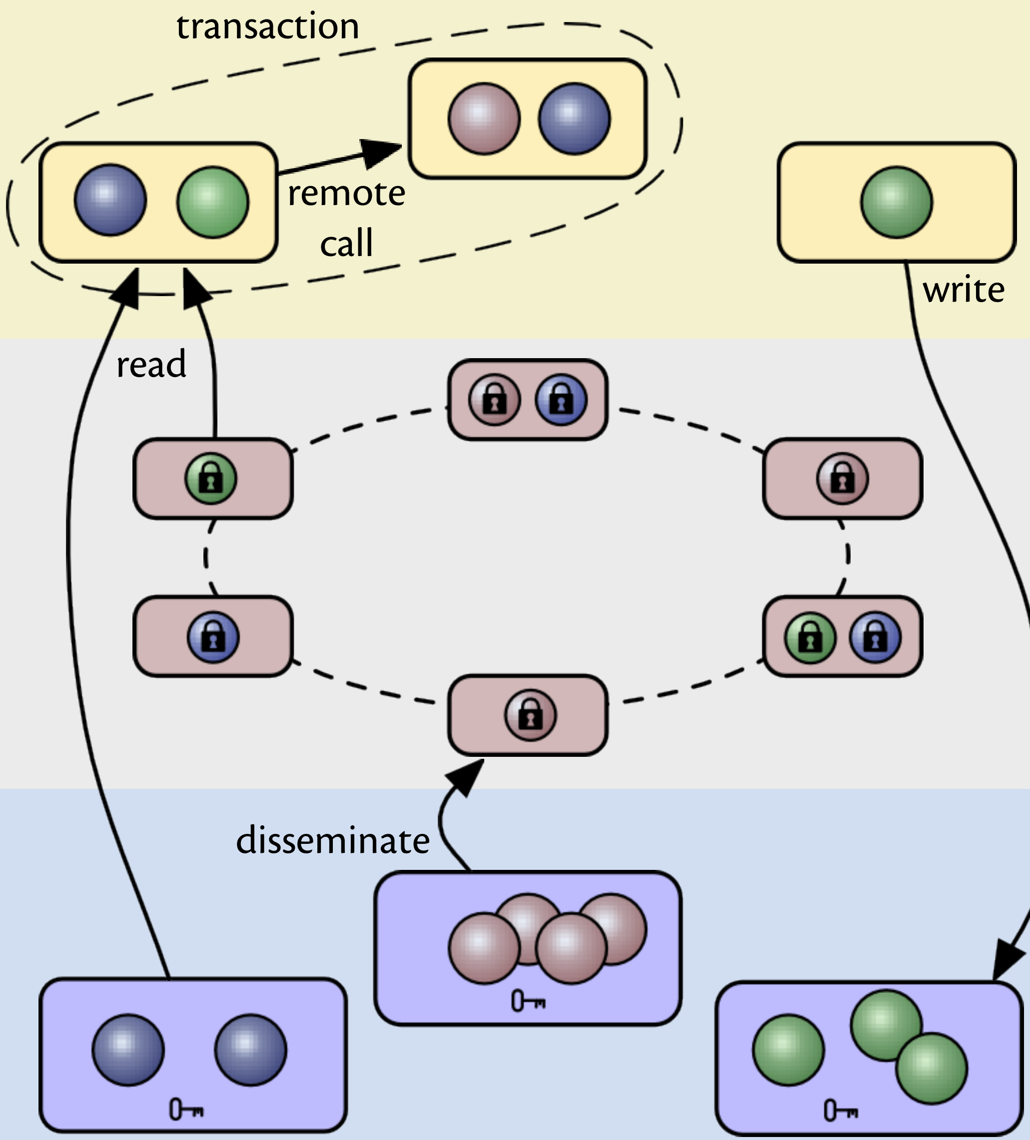


Worker nodes (Workers)

- **Dissemination nodes** cache signed, encrypted objects in peer-to-peer distribution network for high availability

- **Storage nodes** securely store persistent objects
- Each object specifies its own security policy, enforced by store

Fabric Architecture



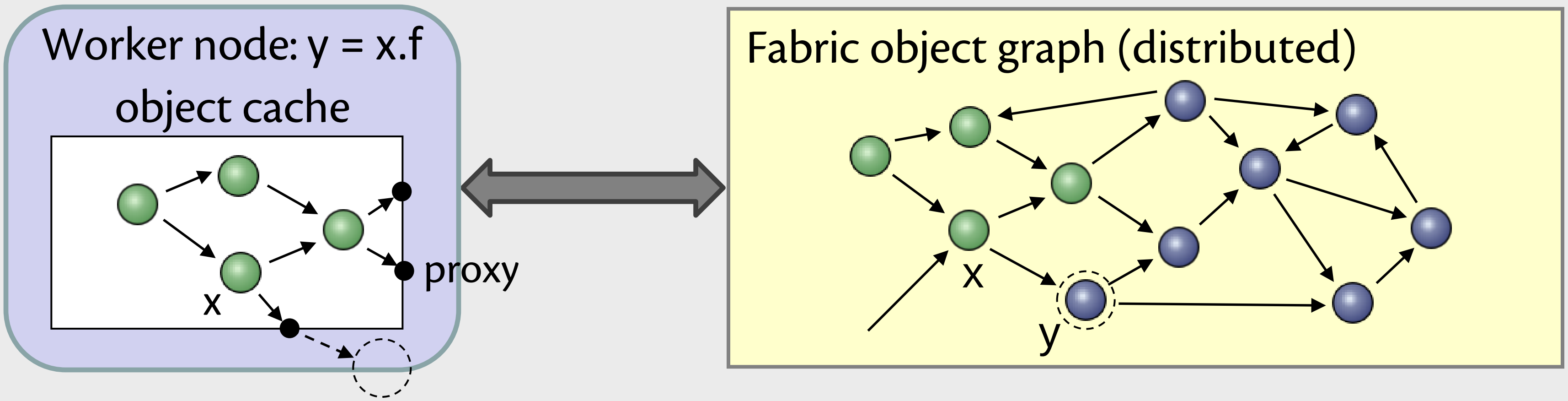
- **Worker nodes** compute on cached objects
- Computation may be distributed across workers in **federated transactions**

- **Dissemination nodes** cache signed, encrypted objects in peer-to-peer distribution network for high availability

- **Storage nodes** securely store persistent objects
- Each object specifies its own security policy, enforced by store

Secure Transparent Data Shipping

- Illusion of access to arbitrarily large object graph
  - Workers cache objects
  - Objects fetched as pointers are followed out of cache



- Stores enforce security policies on objects
  - Worker can read (write) object only if it's trusted to enforce confidentiality (integrity)

Secure Transparent Data Shipping

- Illusion of access to arbitrarily large object graph
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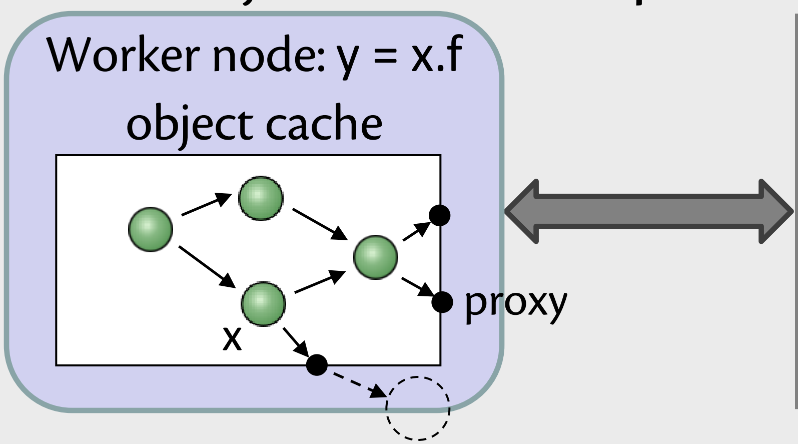
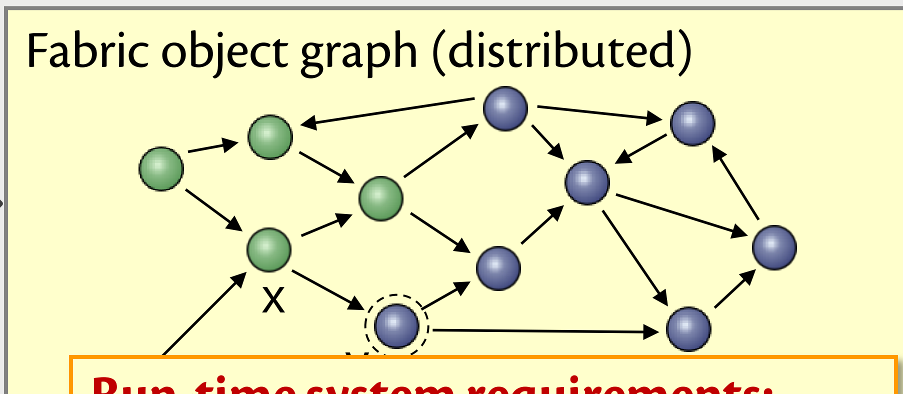




- Stores enforce security poli
  - Worker can read (write) obj
    confidentiality (integrity)

Run-time system requirements:

- ✓ Secure transparent data shipping
- Secure remote calls
- Secure federated transactions
- ✓ Enforcement of security labels

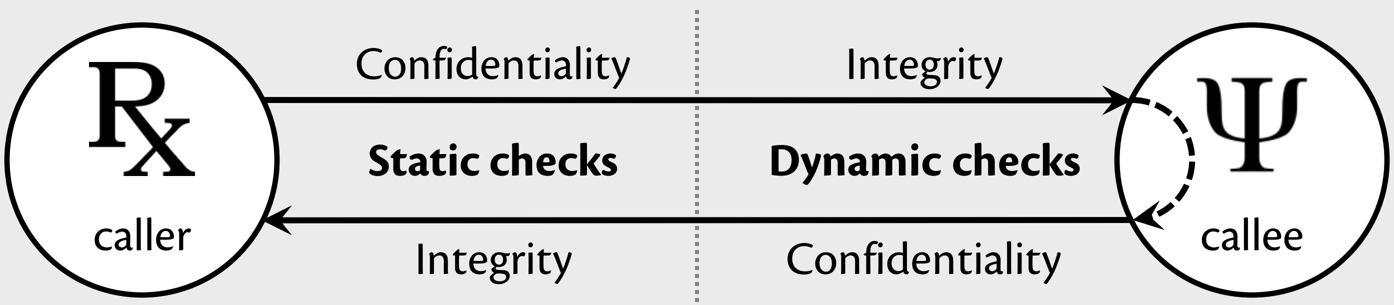
Secure Remote Calls

Is callee trusted to see call?

- Call itself might reveal private information
- Method arguments might be private

Is caller trusted to make call?

- Caller might not have sufficient authority to make call
- Method arguments might have been tampered with by caller



Is callee trusted to execute call?

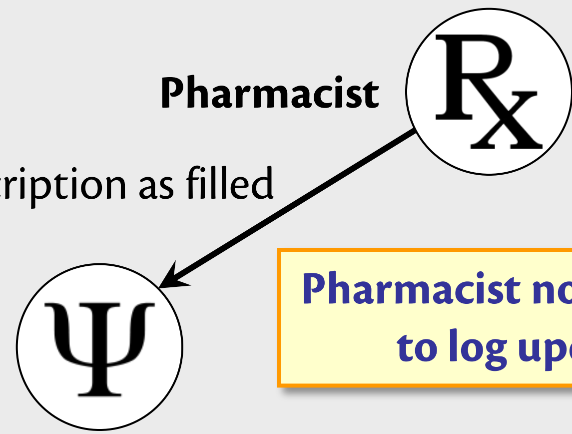
- Call result might have been tampered with by callee

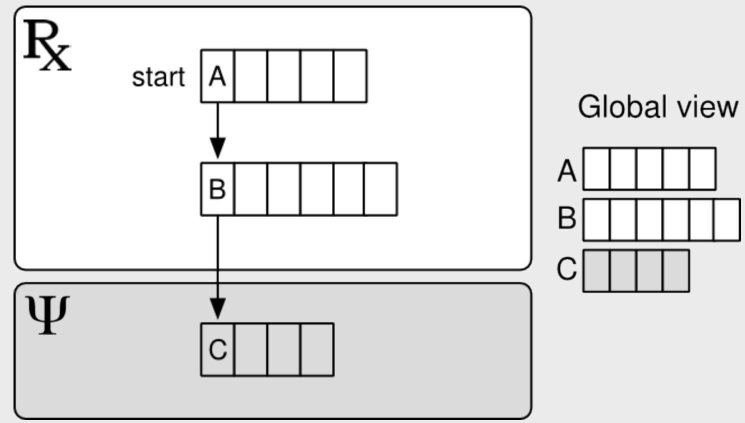
Is caller trusted to see result?

- Call result might reveal private information

Secure Federated Transactions

- Transactions can span multiple workers, cross trust domains
  - No single node trusted for entire log: distributed log structure





Pharmacist not trusted to log update

- Object updates propagated transparently and securely in multi-worker transactions

Also in the Paper…

- Dissemination of encrypted object groups
  - Key management to support this
- Writer maps for secure propagation of updates
- Hierarchical two-phase commit for federated transactions
- Interactions of transaction abort and information flow control
- Automatic ‘push’ of updated objects to dissemination layer
- In-memory caching of object groups at store
- Caching acts-for relationships at workers

Implementation

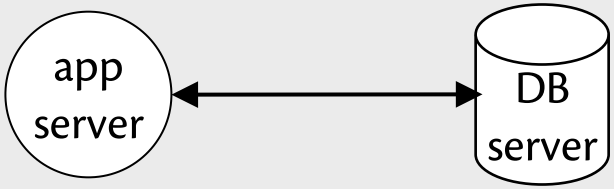
- Fabric prototype implemented in Java and Fabric
  - Total: 35 kLOC
  - Compiler translates Fabric into Java
    - 15 k-line extension to Jif compiler
    - Polyglot [NCM03] compiler extension
  - Dissemination layer: 1.5k-line extension to FreePastry
    - Popularity-based replication (à la Beehive [RS04])
  - Store uses BDB as backing store

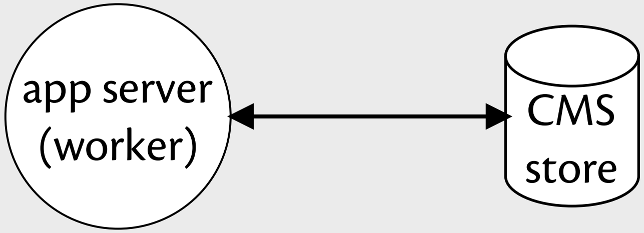
Overheads in Fabric

- Extra overhead on object accesses at worker
  - Run-time label checking
  - Logging reads and writes
  - Cache management (introduces indirection)
  - Transaction commit
- Overhead at store for reads and commits
- Ported non-trivial web app to evaluate performance

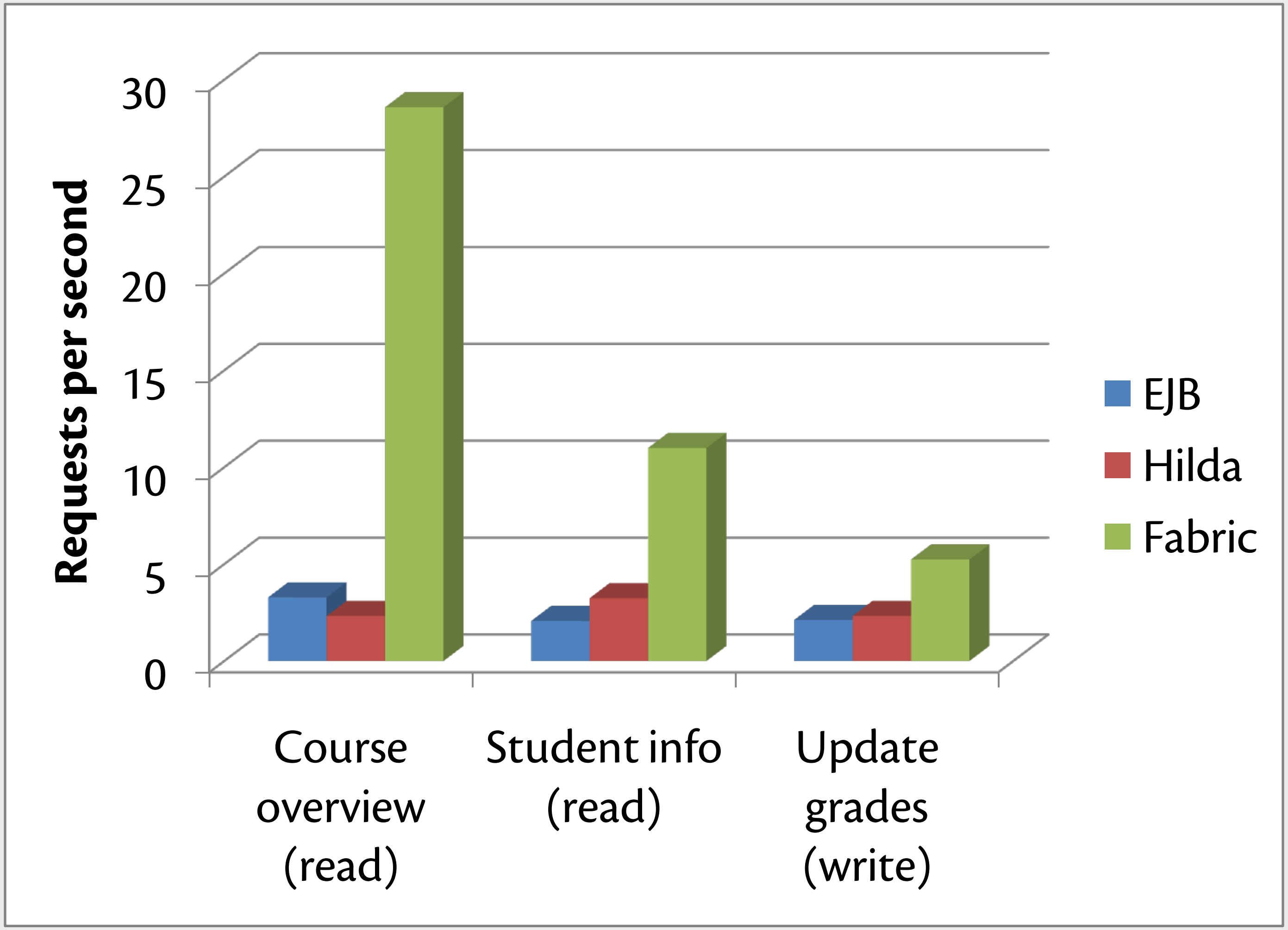
Cornell CMS Experiment

- Used at Cornell since 2004
  - Over 2000 students in over 40 courses
- Two prior implementations:
  - J2EE/EJB2.0
    - 54k-line web app with hand-written SQL
    - Oracle database
  - Hilda [YGG+07]
    - High-level language for data-driven web apps
- Fabric implementation



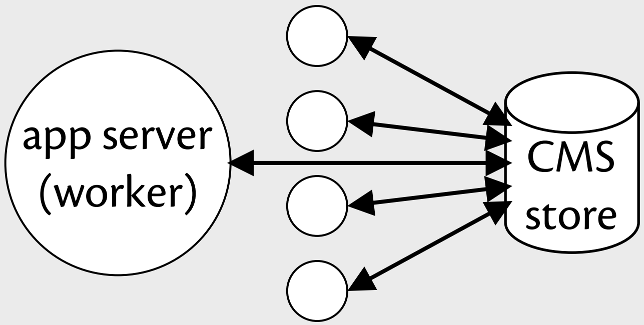


Performance Results



Scalability Results

- Language integration: easy to replicate app servers



- Reasonable speed-up with strong consistency
  - Work offloaded from store onto workers

	3 workers	5 workers
Course overview	2.18 x	2.49 x
Student info	2.45 x	2.94 x

Related Work

Category	Examples	What Fabric Adds
Federated object store	OceanStore/Pond	• Transactions • Security policies
Secure distributed storage systems	Boxwood, CFS, Past	• Fine-grained security • High-level programming
Distributed object systems	Gemstone, Mneme, ObjectStore, Sinfonia, Thor	• Security enforcement • Multi-worker transactions with distrust
Distributed computation/RPC	Argus, Avalon, CORBA, Emerald, Live Objects, Network Objects	• Single-system view of persistent data • Strong security enforcement
Distributed information flow systems	DStar, Jif/Split, Swift	• Transactions on persistent data

Fabric is the first to combine information-flow security, remote calls, and transactions in a decentralized system.

Summary

- Fabric is a platform for secure and consistent federated sharing
- Prototype implementation
- Contributions:
  - High-level language integrating information flow, transactions, distributed computation
  - Transparent data shipping and remote calls while enforcing secure information flow
  - New techniques for secure federated transactions: hierarchical commits, writer maps

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