Disciplined Inconsistency

with *Consistency Types*

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UNIVERSITY of WASHINGTON

UCSC – CMPS290S – 2018

Building **scalable** & **reliable** applications is **difficult**.

Constantly changing network conditions, traffic spikes…

NEWSFEED VIRAL

The Dress That Broke the Internet, and the Woman Who Started It All

Rishi Iyengar @Iyengarish | Feb. 27, 2015

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MOVIES | STAR WARS GALAXY

Star Wars: The Force Awakens presale crashes ticketing websites

BY OLIVER GETTELL · @OGETTELL

Share | 14064 Tweet | 0 | 15 | 0

(Lucasfilm)

Top Stories

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'Ghostbusters' cast shows off new gadgets

Emma Watson's Tina Turner ringtone interrupts interview

What to Watch Wednesday: 'Barely Famous' is fully funny

'Night Of': Riz Ahmed held 'onto trauma for 6 months' during filming

Building **scalable** & **reliable** applications is **difficult**.

Programming languages can **help**:

- Prevent common mistakes *statically*
- Communicate application requirements

TicketSleuth

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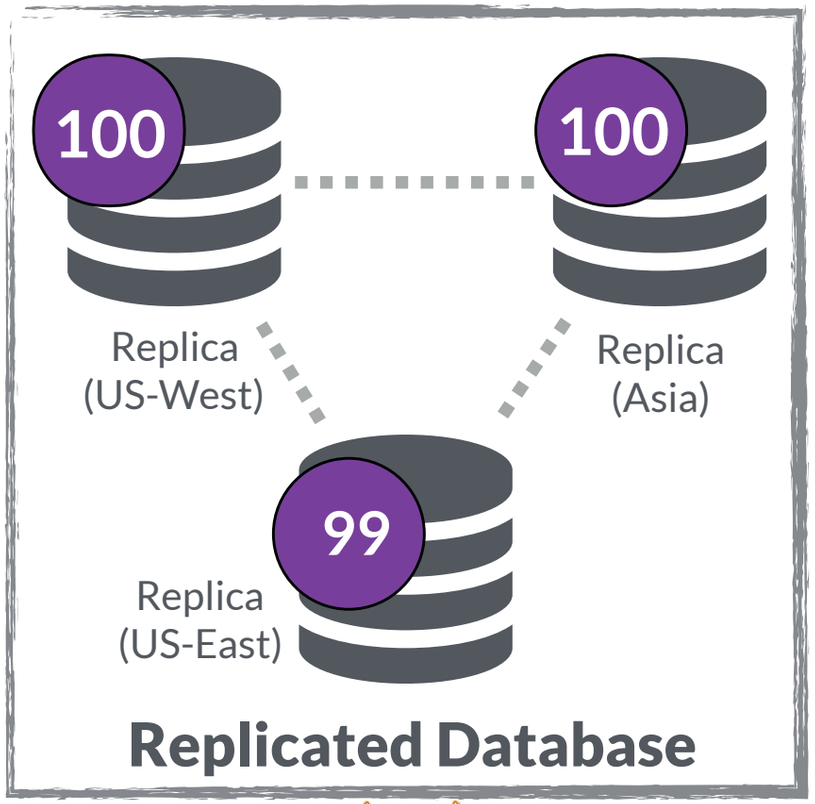
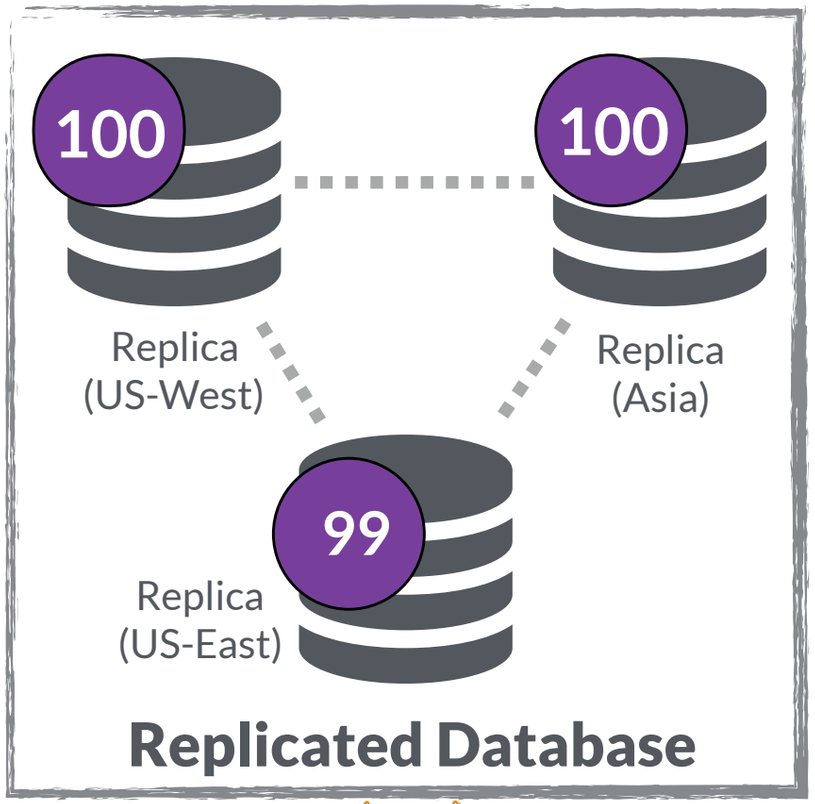


Strong consistency

Performance constraint:
< 50 ms latency

Hard constraint:
do not over-sell tickets

Error tolerance:
count does not need to be exact…



Performance constraint:
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Hard constraint:
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Weak?

Strong consistency

Error tolerance:
count does not need to be exact…

Trading off consistency

Strong Consistency

Linearizable

Serializable

Causal

Read-your-writes

Local quorum

Eventual

Weak Consistency

easier to use,
slower

faster,
more **error-prone**

Inconsistent
Performance-bound
Approximate

} **Programming Model**

Trading off consistency

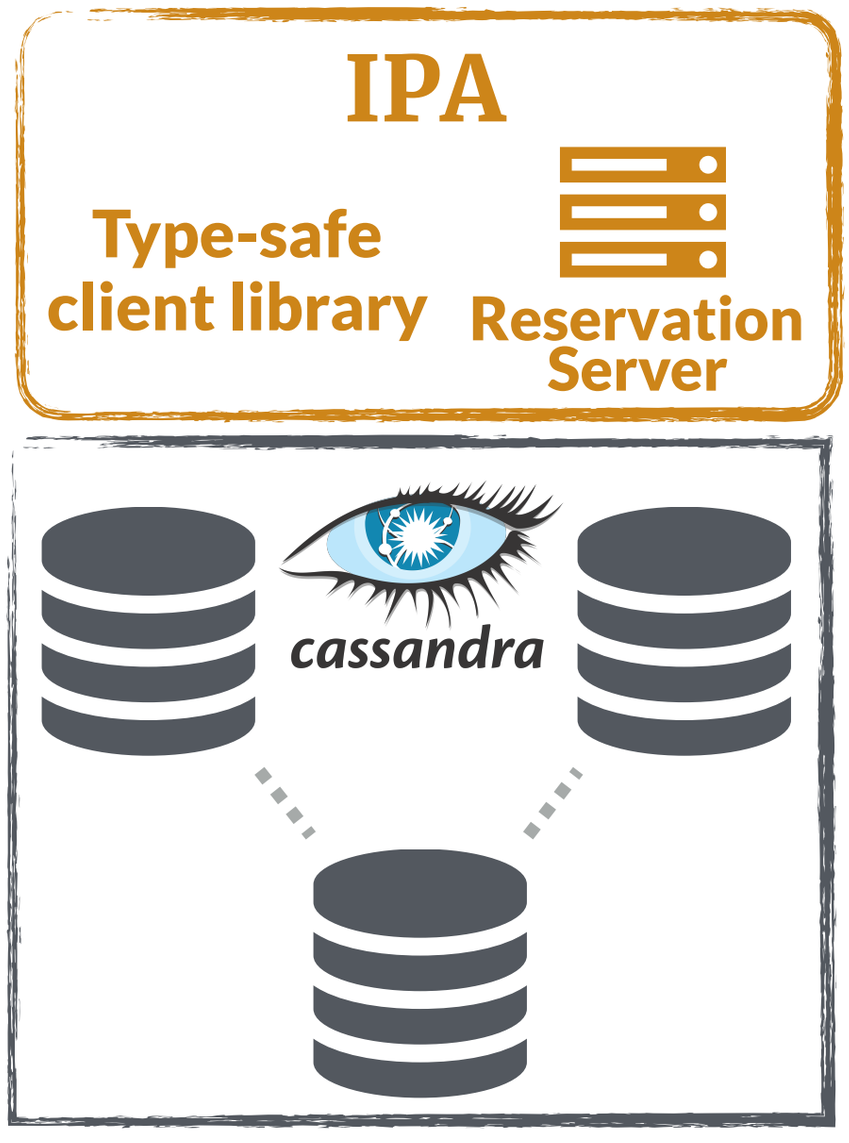
Consistency types

- Statically prevent consistency bugs

Performance & accuracy constraints

- Dynamically adjust consistency

Case study



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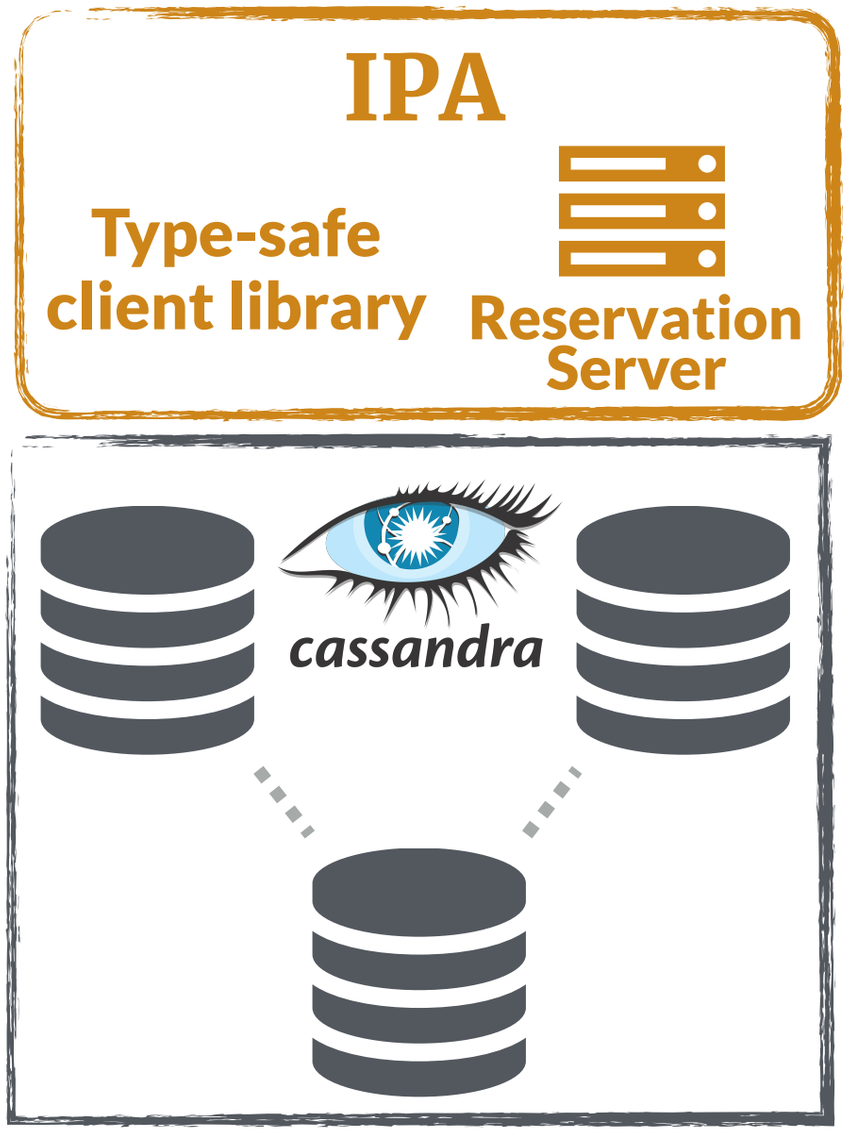
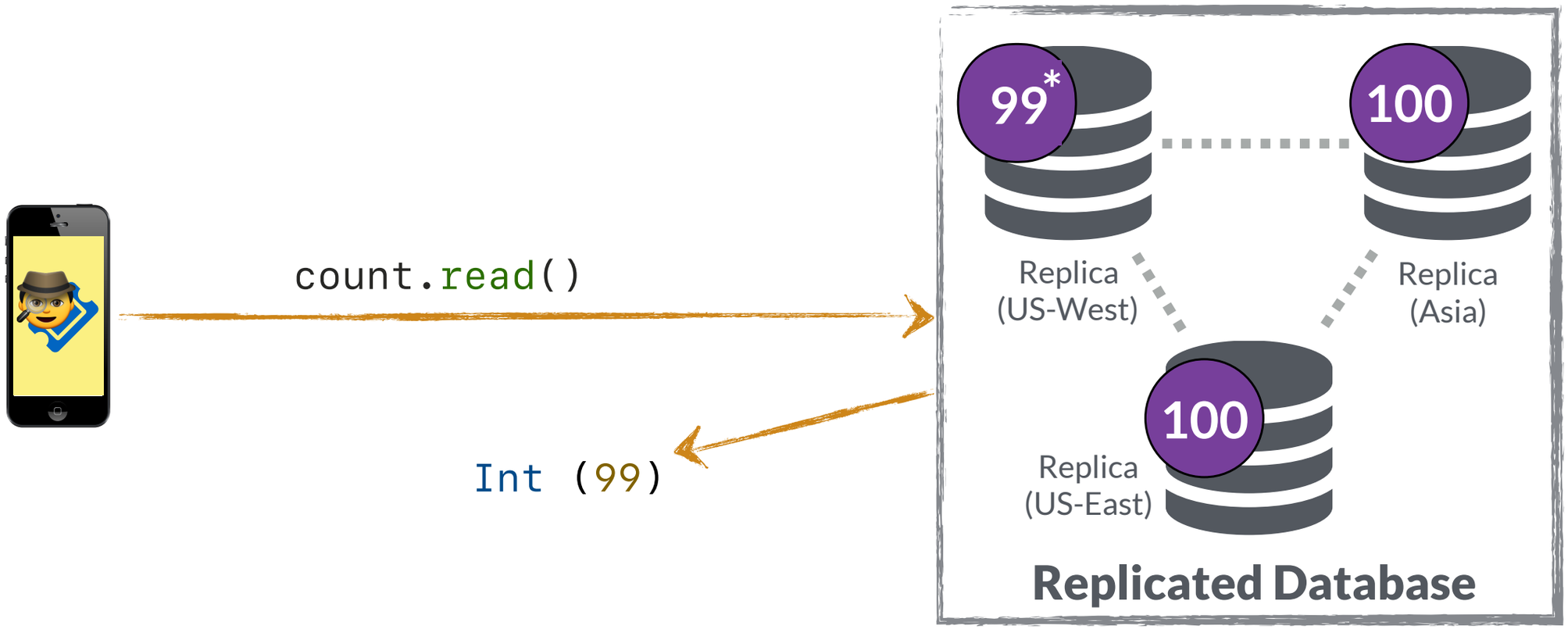


Consistency Types

Every value returned from the datastore has a *consistency type*.



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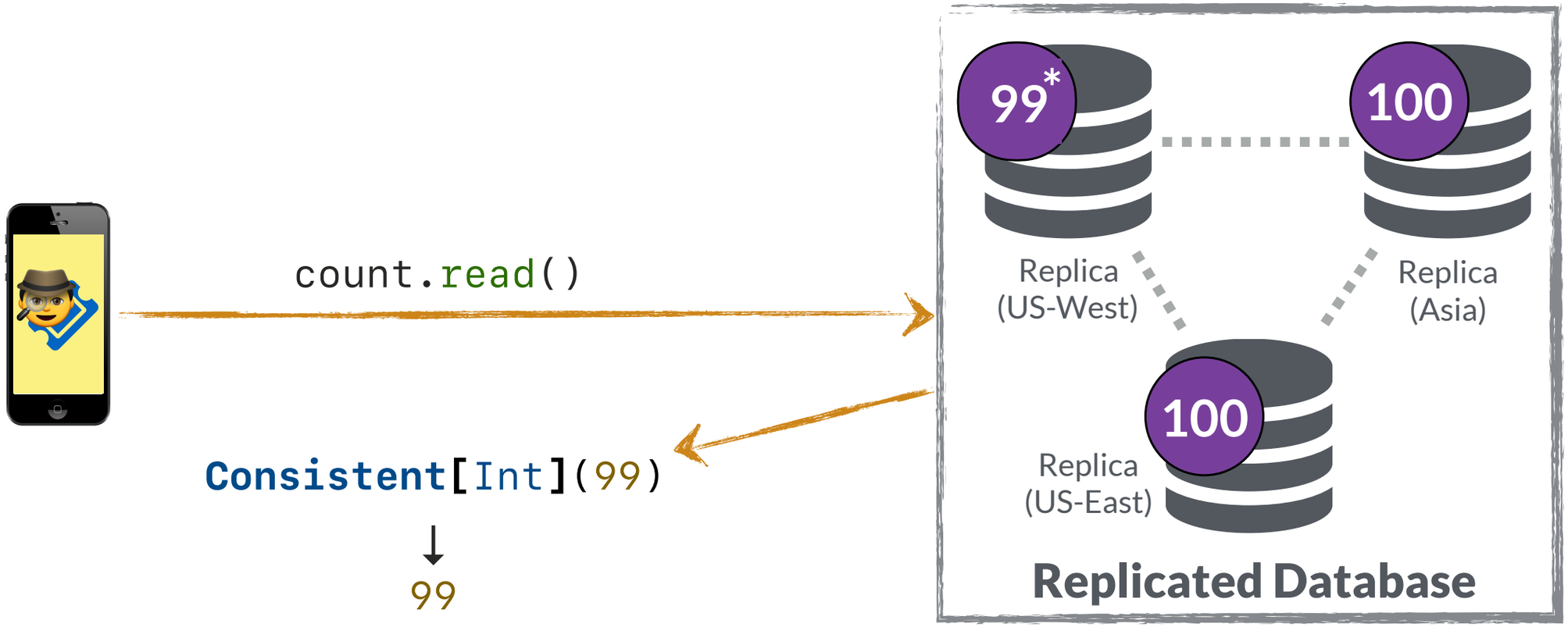
<u>Strong</u> reads return `Consistent[T]`

- Can be implicitly converted to `T` (treated as a normal value)



Consistency Types

Every value returned from the datastore has a *consistency type*.

Strong reads return `Consistent[T]`

- Can be implicitly converted to `T` (treated as a normal value)

Weak reads return `Inconsistent[T]`

- Explicitly *endorse* to get the value:

```
endorse(Inconsistent(99)) → 99
```

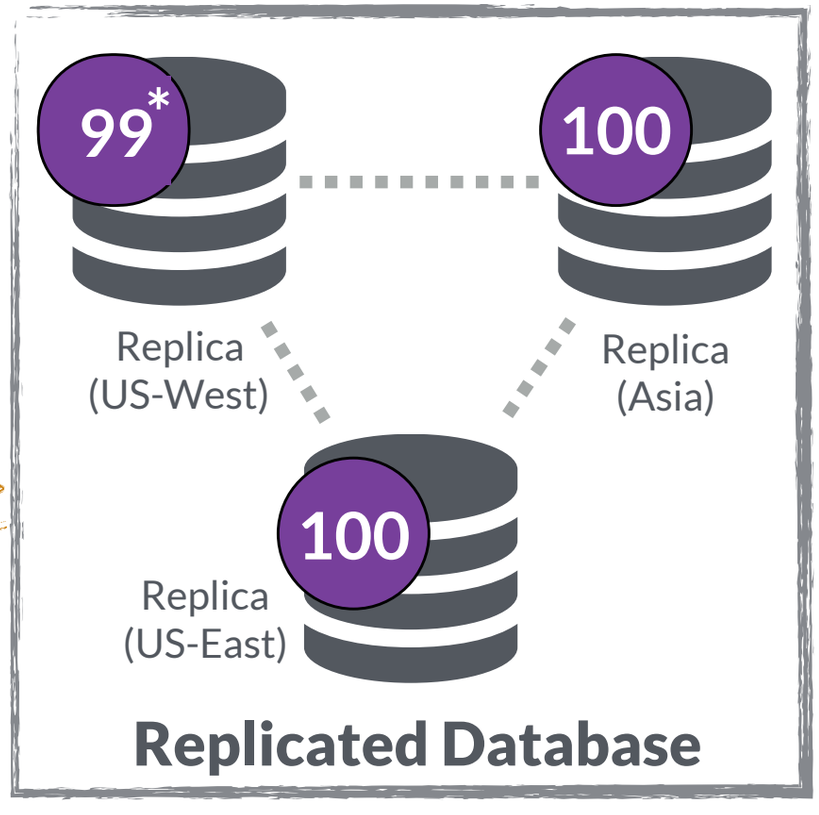
or with a case match:

```
case Inconsistent(x) ⇒ x:Int
```

`count.read_weak()`

`Inconsistent[Int](99)`

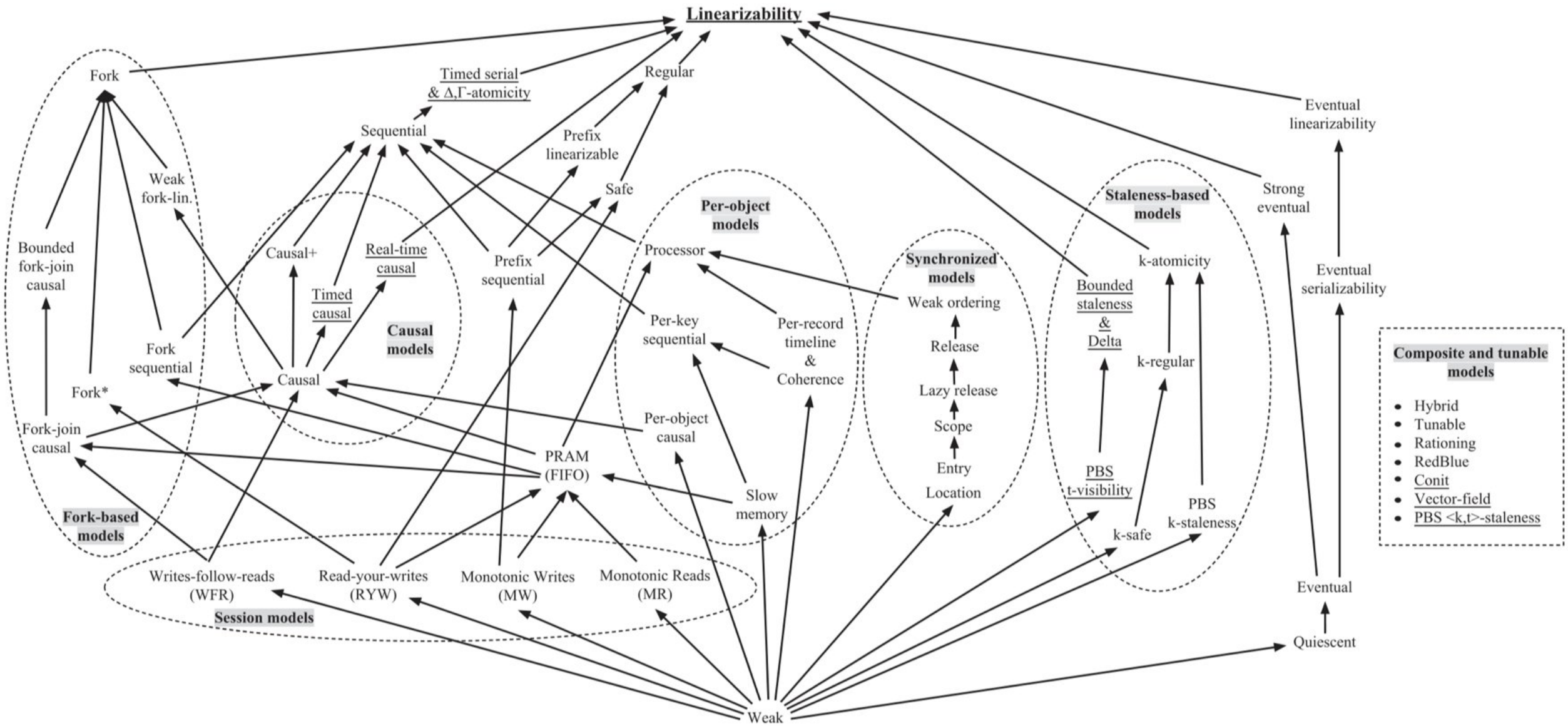
or… **`Inconsistent[Int](100)`**



Consistency Types

***Partially ordered*, forming a *lattice*:**

$$\top := \texttt{Consistent[T]} \Rightarrow \texttt{T}$$



$$\bot := \texttt{Inconsistent[T]}$$

Consistency Types

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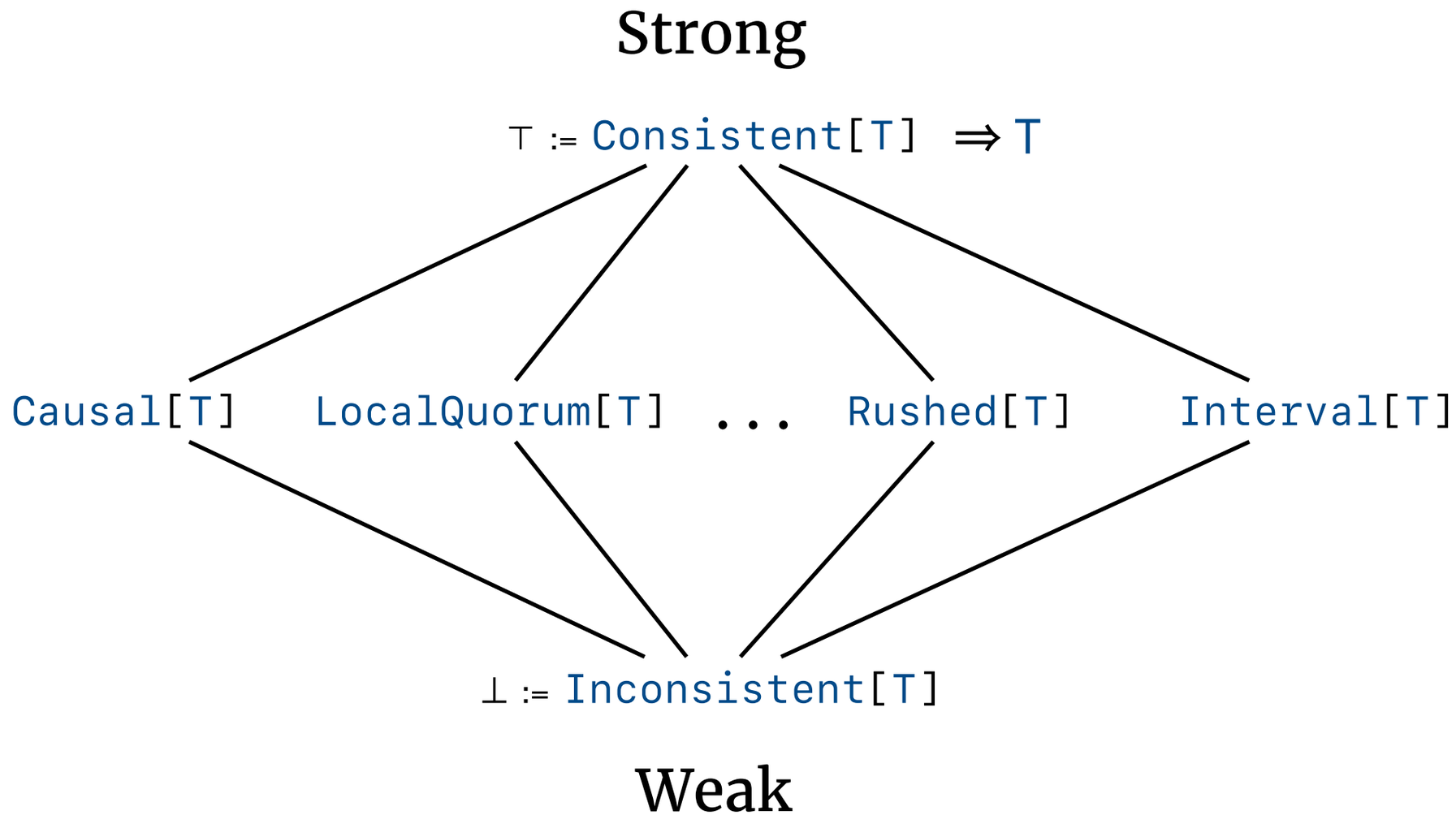

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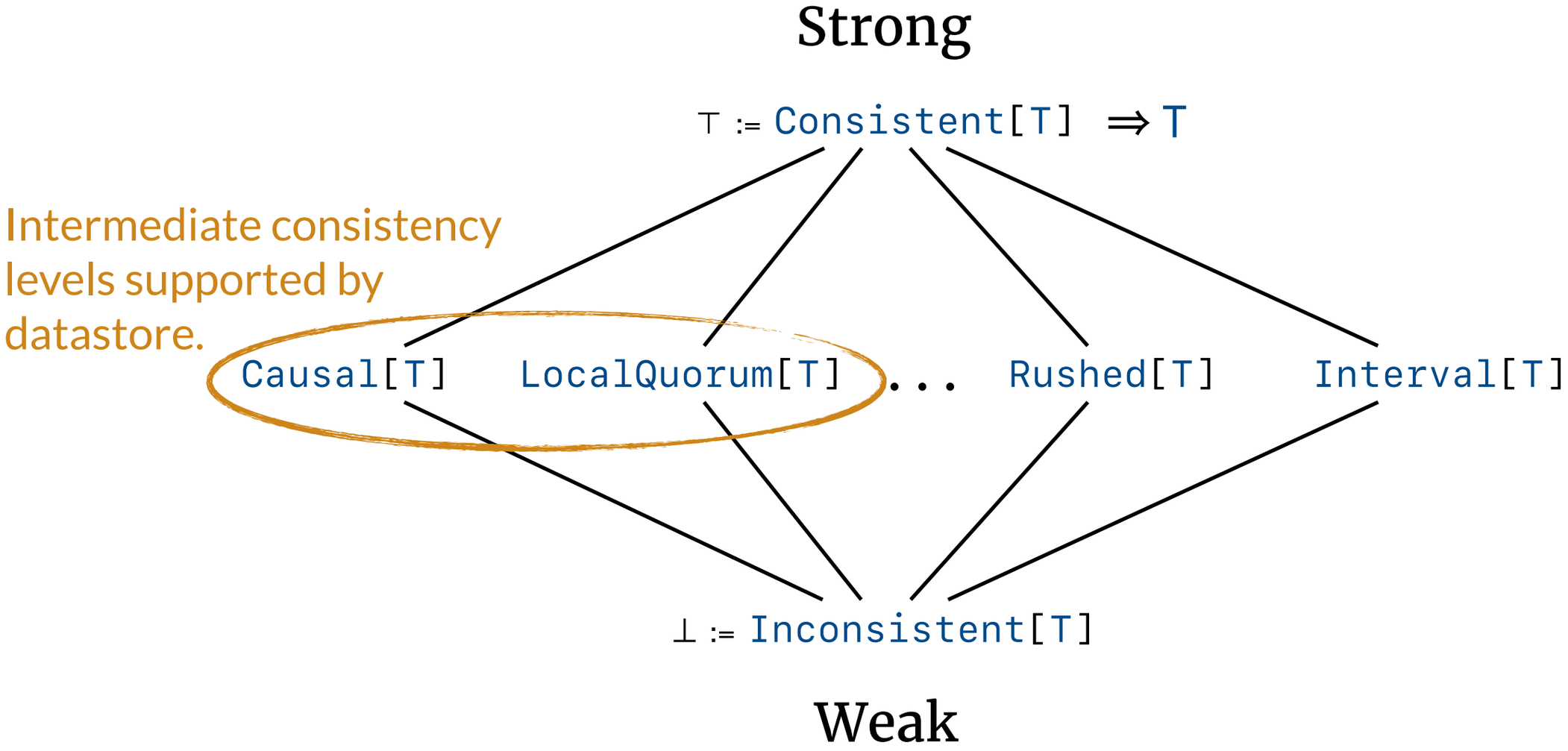

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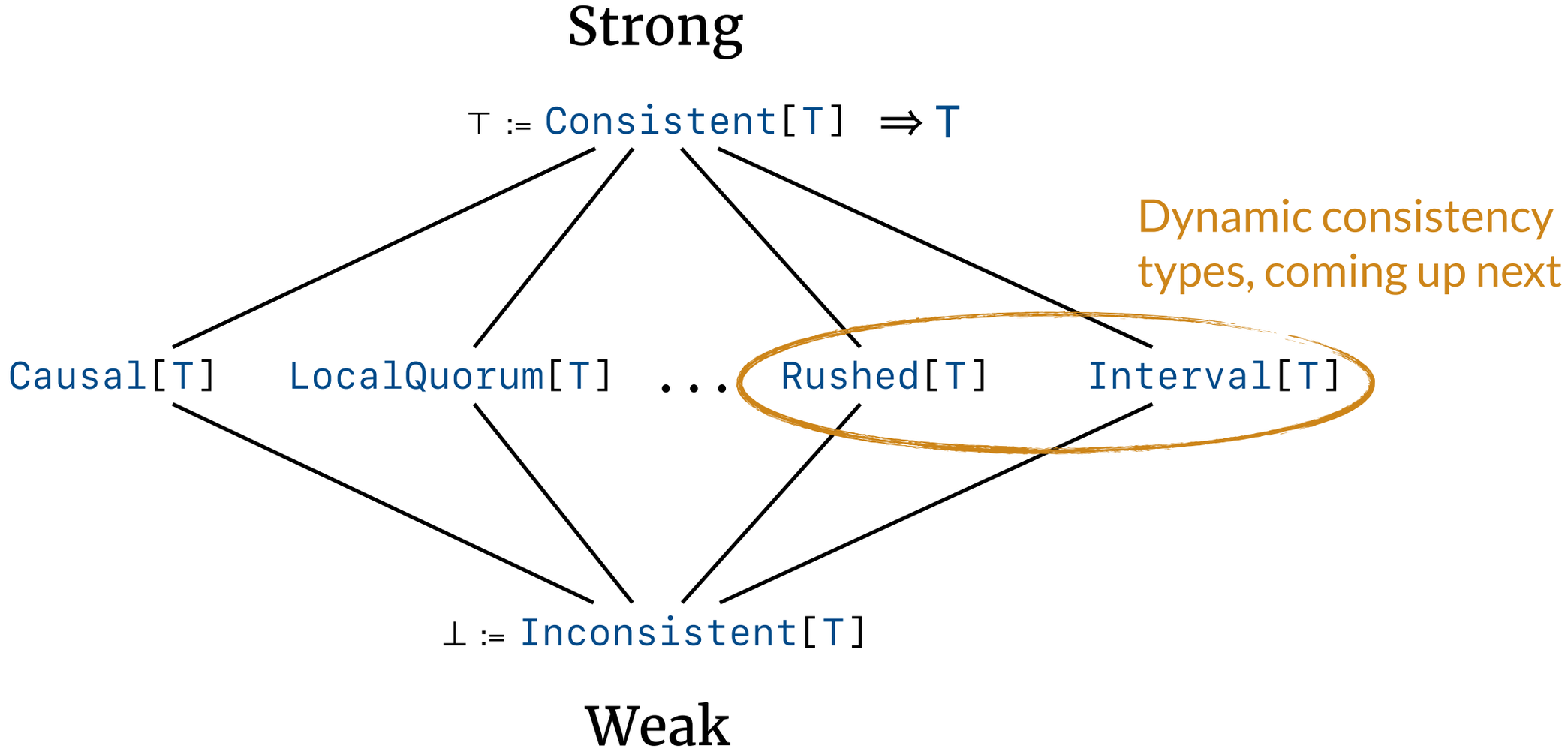
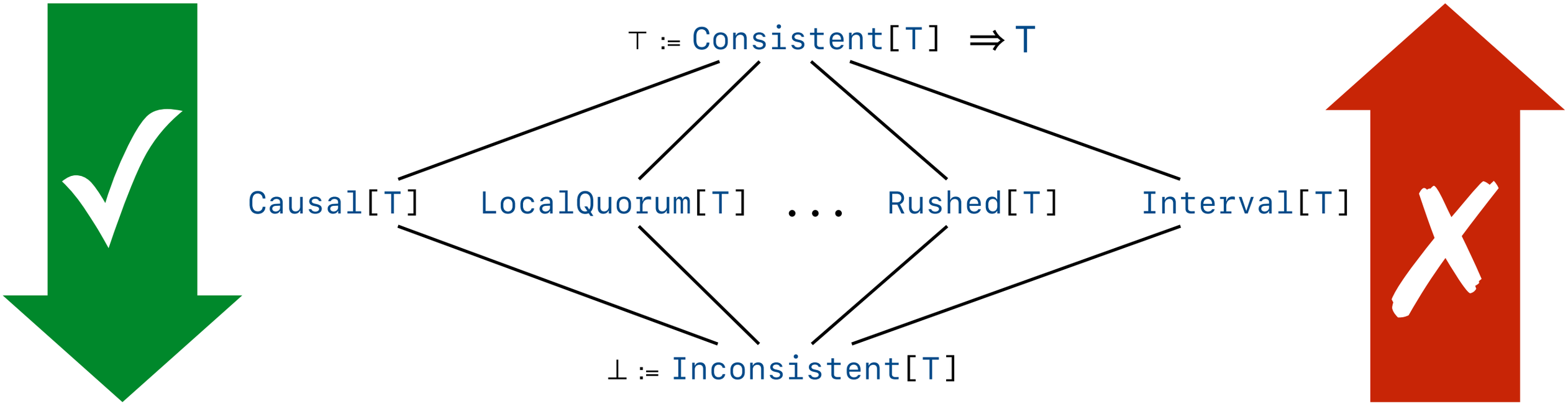


Consistency Types

IPA type system enforces *consistency safety*.



***Consistency safety*:**
Weaker values cannot flow into stronger computations.

```
val n: Inconsistent[Int] = count.read()

if n < 100:
    print("Value is less than 100.")
```

Constraints

Every item in the datastore has a datatype with methods.

```
Counter:
   .increment(): Unit
   .decrement(): Unit
   .read():      Int
```

Constraints

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Datatypes can be annotated with *consistency constraints*.

- Constraints determine the consistency type of results.

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Static constraints:

```
Counter with Consistency(Strong):
  .increment(): Unit
  .decrement(): Unit
  .read():      Consistent[Int]

Counter with Consistency(Weak):
  .increment(): Unit
  .decrement(): Unit
  .read():      Inconsistent[Int]
```

Constraints

Every item in the datastore has a datatype with methods.

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- Constraints determine the consistency type of results.

Static constraints

- Enforced by the underlying datastore

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Consistency(Strong) → Consistent[T]
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Constraints

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- Constraints determine the consistency type of results.

Static constraints

- Enforced by the underlying datastore

```
Consistency(Strong) → Consistent[T]
Consistency(Weak) → Inconsistent[T]
```

Dynamic constraints

- Performance targets:

```
LatencyBound(50 ms) → Rushed[T]
```

- Approximation opportunity:

```
ErrorTolerance(10%) → Interval[T]
```

Constraints: Latency bounds

Need result in a fixed amount of time.

- Dynamically adjust consistency to meet the target latency.

```
Counter with LatencyBound(50 ms):
  .increment(): Unit
  .read():      Rushed[Int]
```

? `Consistent[Int]` `LocalQuorum[Int]` `Inconsistent[Int]`

Return value represents achieved consistency

- **Rushed** is a ***union*** of other consistency types

```
count.read() match {
  case Consistent(x)   => print("consistent")
  case LocalQuorum(x)  => print("locally consistent")
  case Inconsistent(x) => print("???")
}
```

Constraints: Latency bounds

Implementation:

- Send requests to # replicas needed for strong consistency

```
Counter with LatencyBound(50 ms):
  .increment(): Unit
  .read():      Rushed[Int]
```

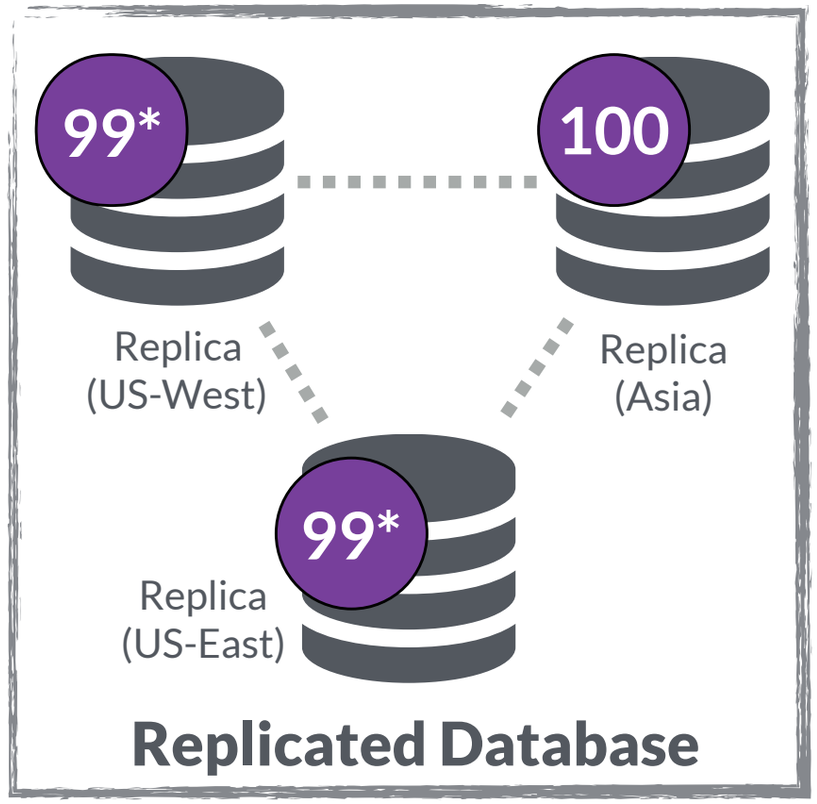
Calculating consistency

Strong consistency is achieved if:

$$W + R > N$$

(W = # replicas written to,
R = # replicas read from,
N = total # replicas)

cassandra



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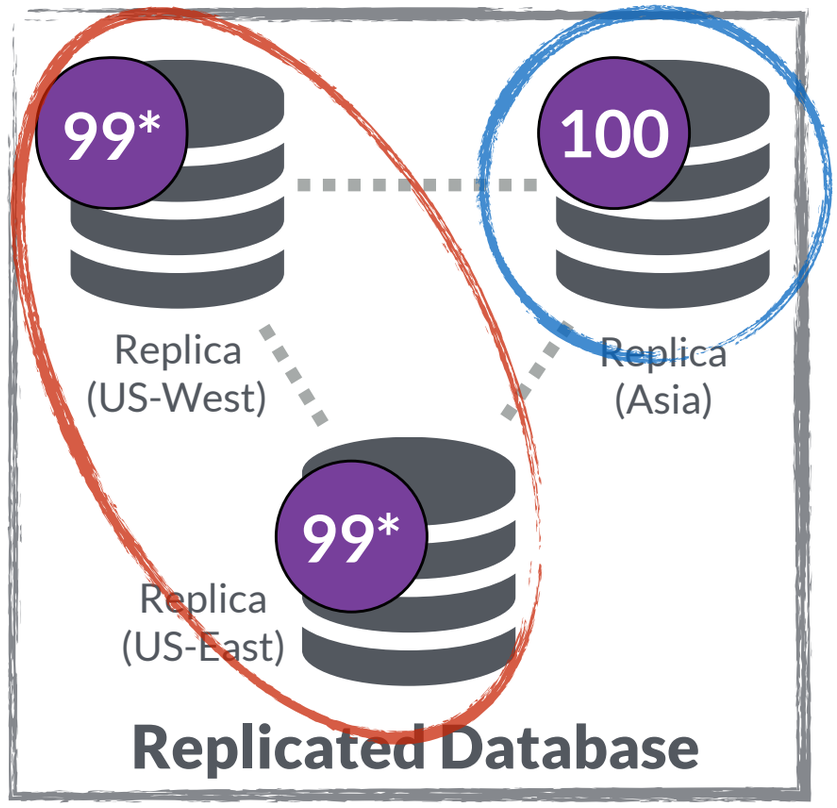

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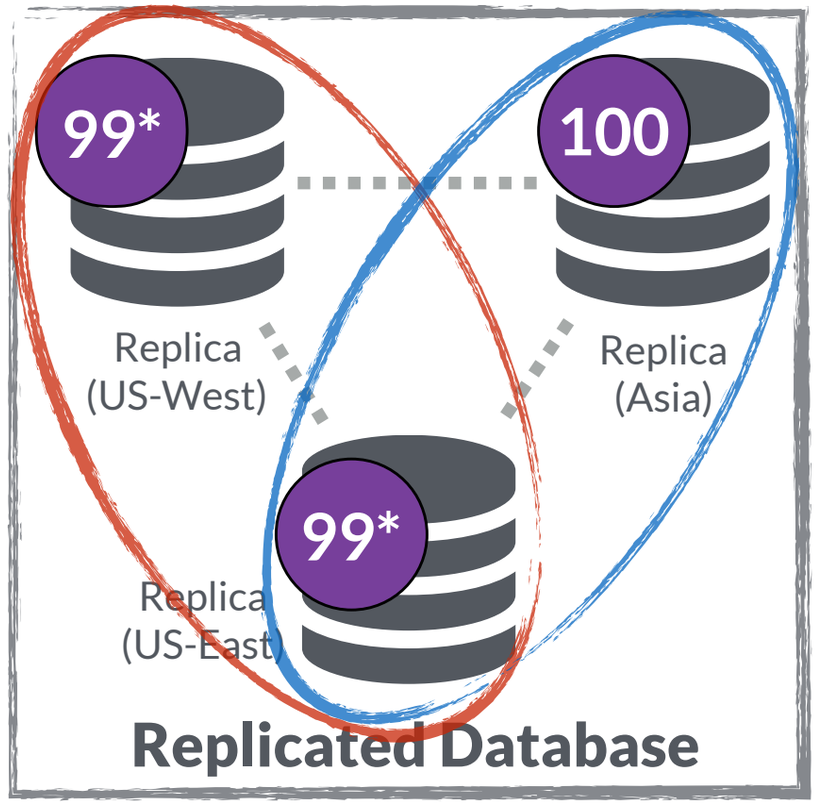

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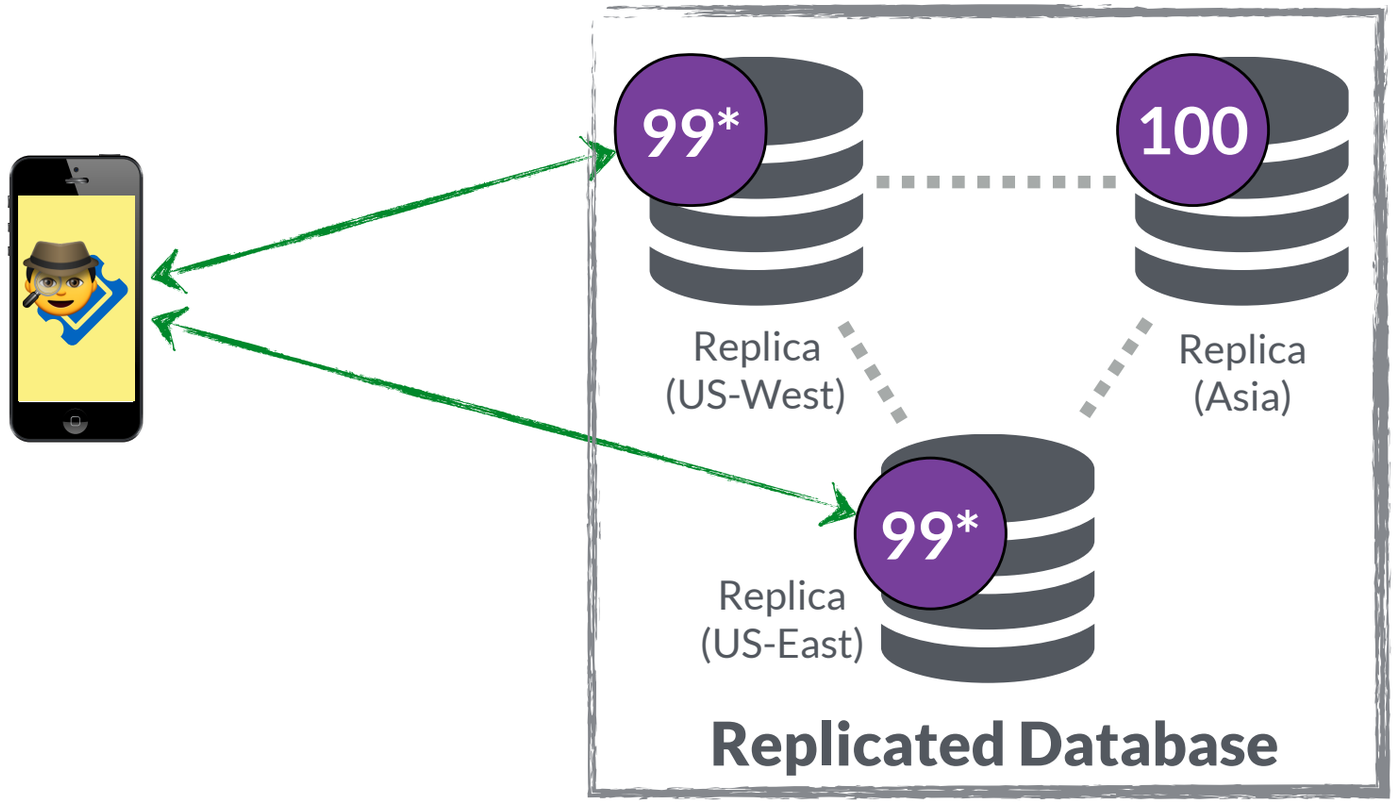

Constraints: Latency bounds

Implementation:

- Send requests to # replicas needed for strong consistency
- Wait for time limit

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Counter with LatencyBound(50 ms):
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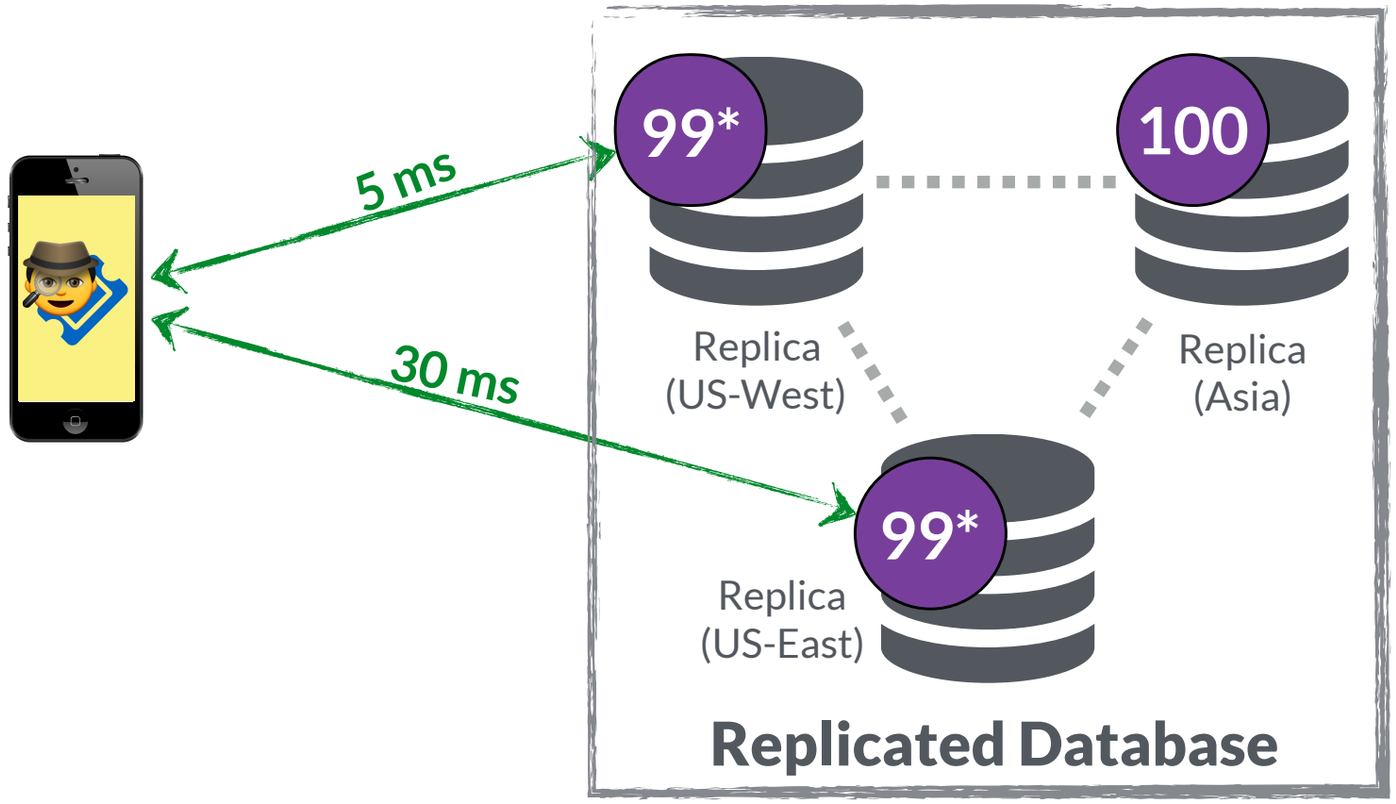

Constraints: Latency bounds

Implementation:

- Send requests to # replicas needed for strong consistency
- Wait for time limit
- Resulting consistency determined by number of on-time responses

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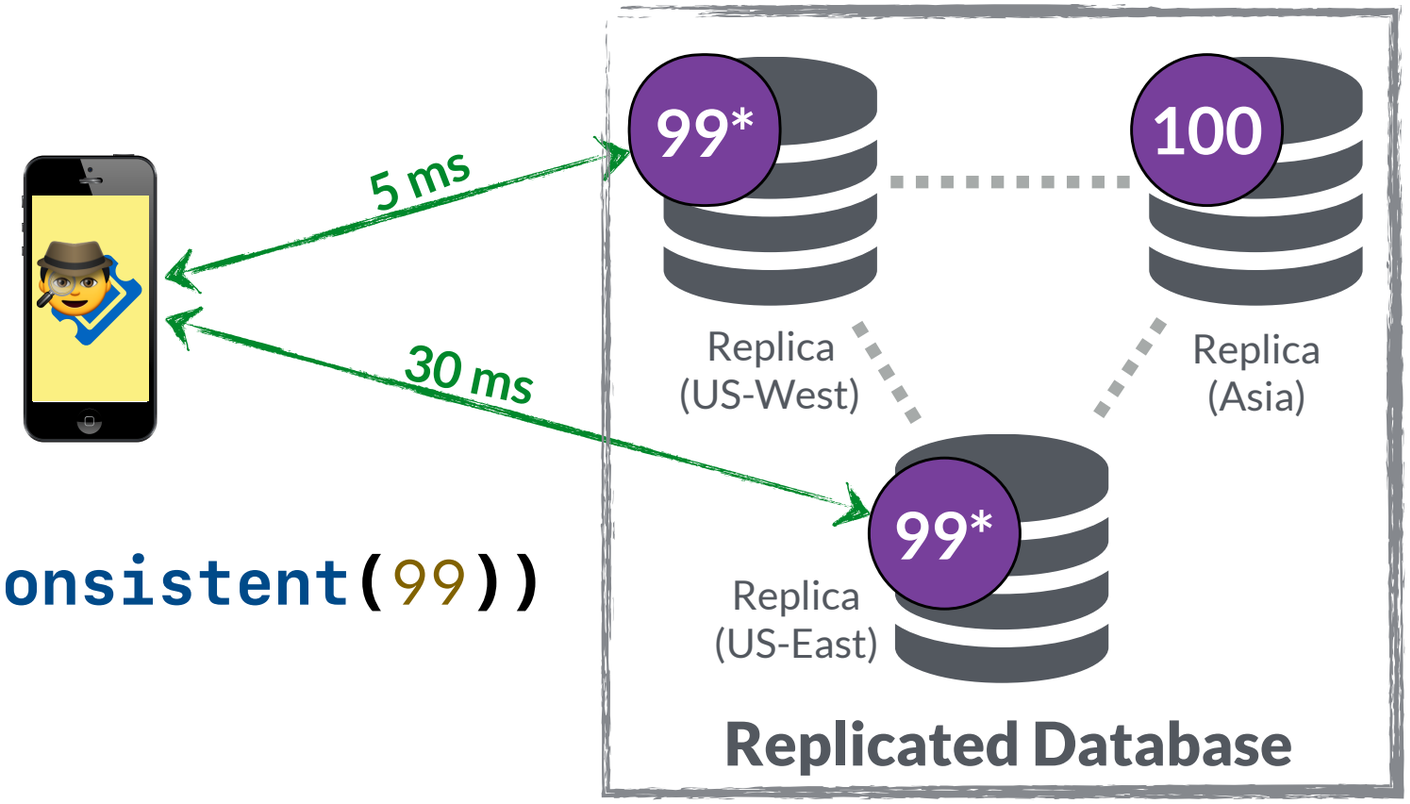


```
Rushed[Int](Consistent(99))
```

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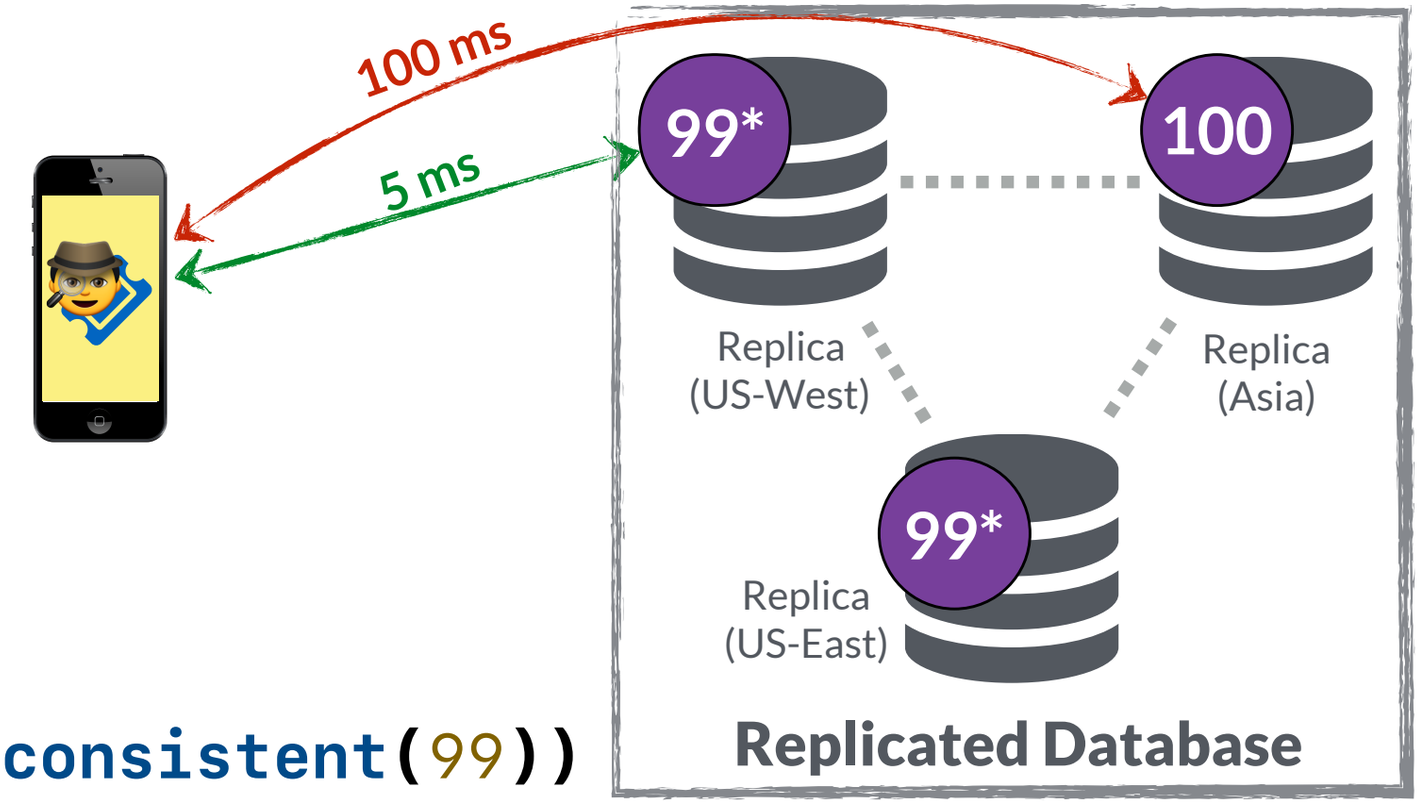


```
Rushed[Int](Inconsistent(99))
```

Constraints: Error bounds

Tolerate a fixed amount of *inaccuracy* in value.

```
Counter with ErrorTolerance(10%):
  .decrement(): Unit
  .read(): Interval[Int]
```

Return value represents a range of possible consistent values

- Programmer must decide what to do with the `Interval` value

```
val remaining = ticketCount.read()
if (remaining.min > 100) {
  display("At least 100 tickets left.")
}
```

Works by limiting outstanding writes

- Requires knowing the semantics of each operation

`decrement() × (0..10)` ⇒ `read() = Interval[Int](90,100)`

Constraints: Error bounds

Implementation:

- **Reservations:** pre-allocate permission to do updates, distribute among replicas.

```
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```
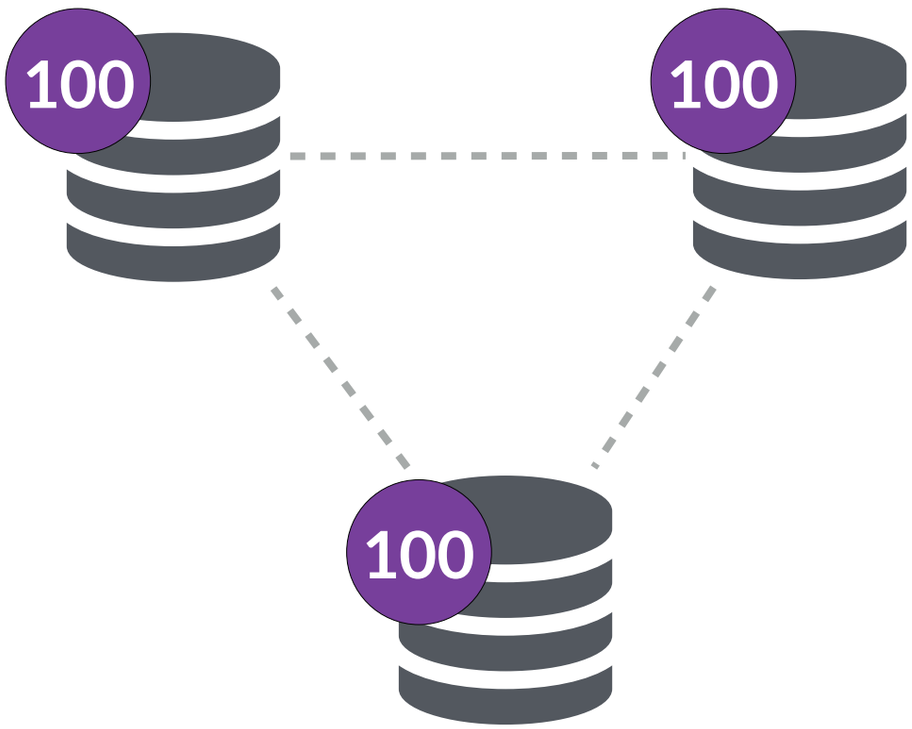

10 × `decr()`



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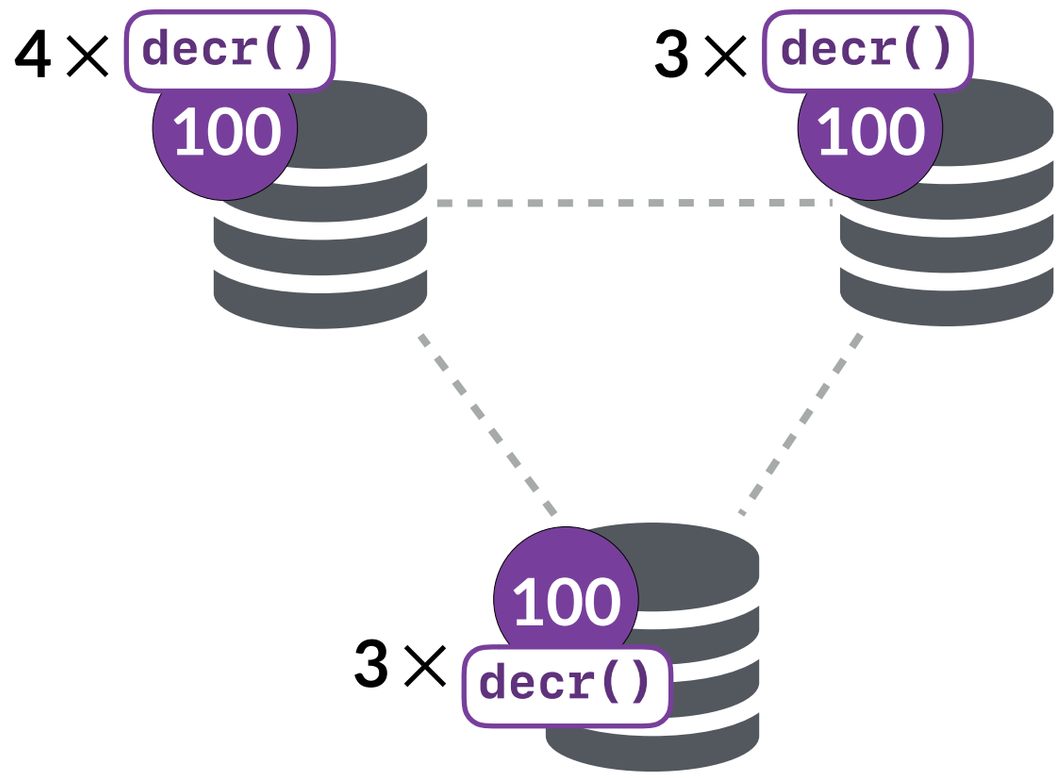

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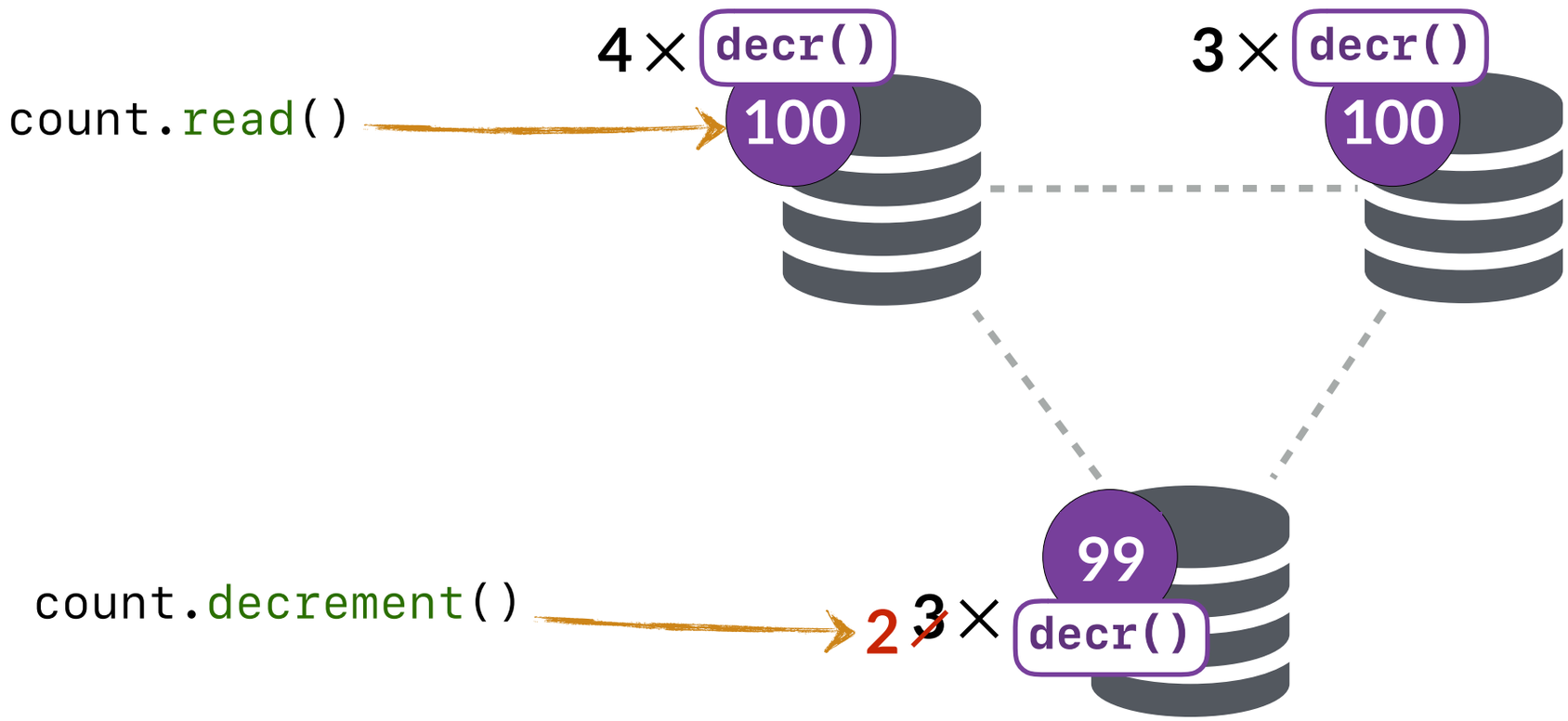

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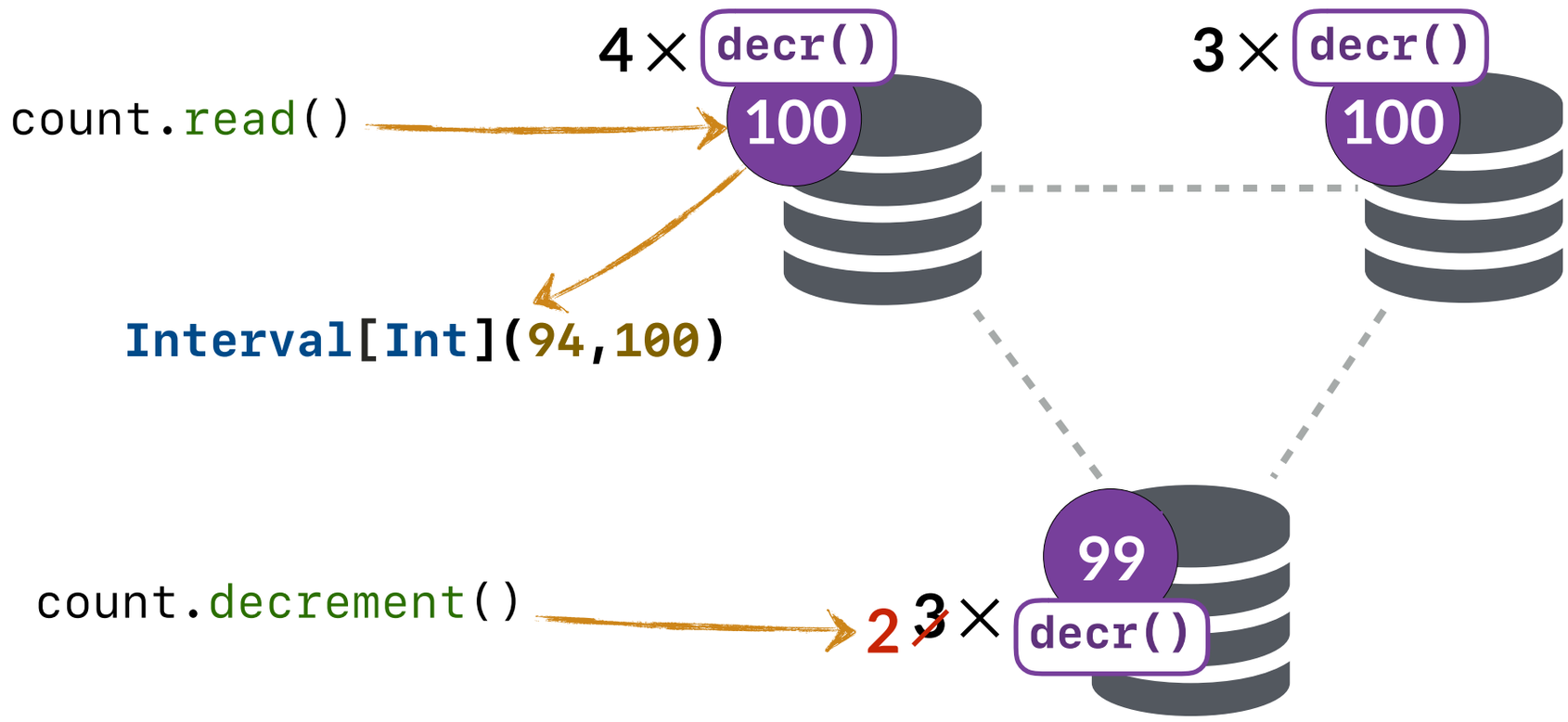

Constraints: Error bounds

Implementation:

- **Reservations:** pre-allocate permission to do updates, distribute among replicas.
- Refresh permissions on sync.

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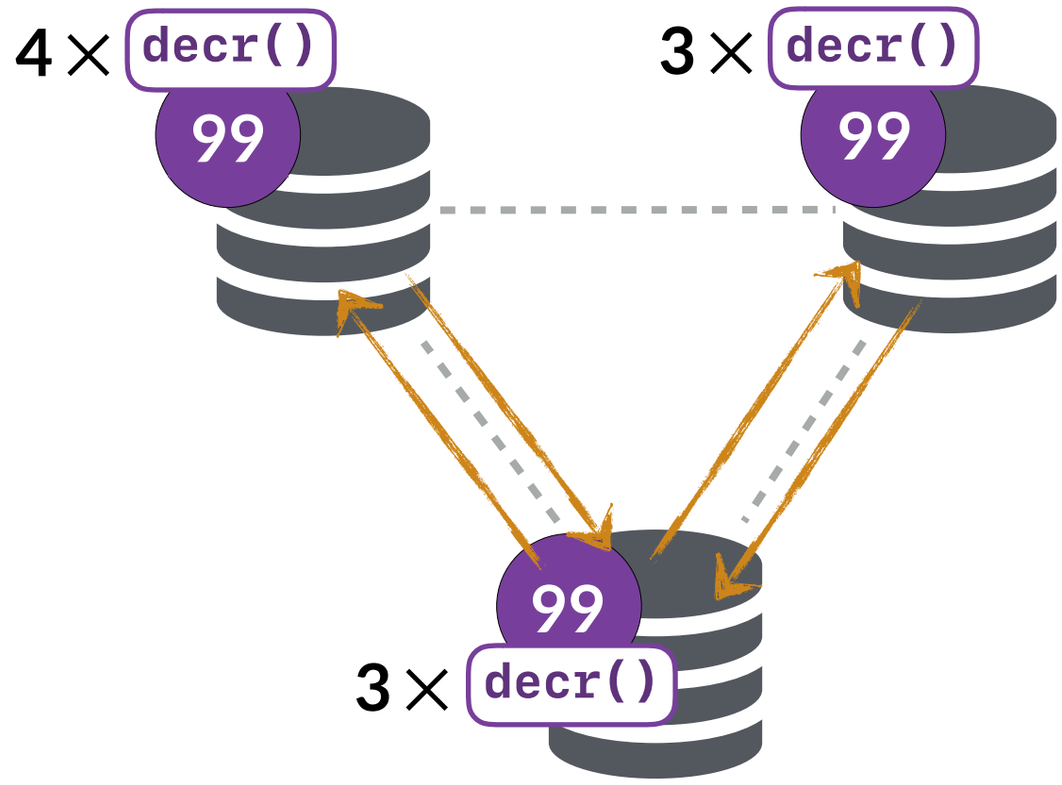

Constraints: Error bounds

Implementation:

- **Reservations:** pre-allocate permission to do updates, distribute among replicas.
- Refresh permissions on sync.
- **Reservation servers** mediate requests.

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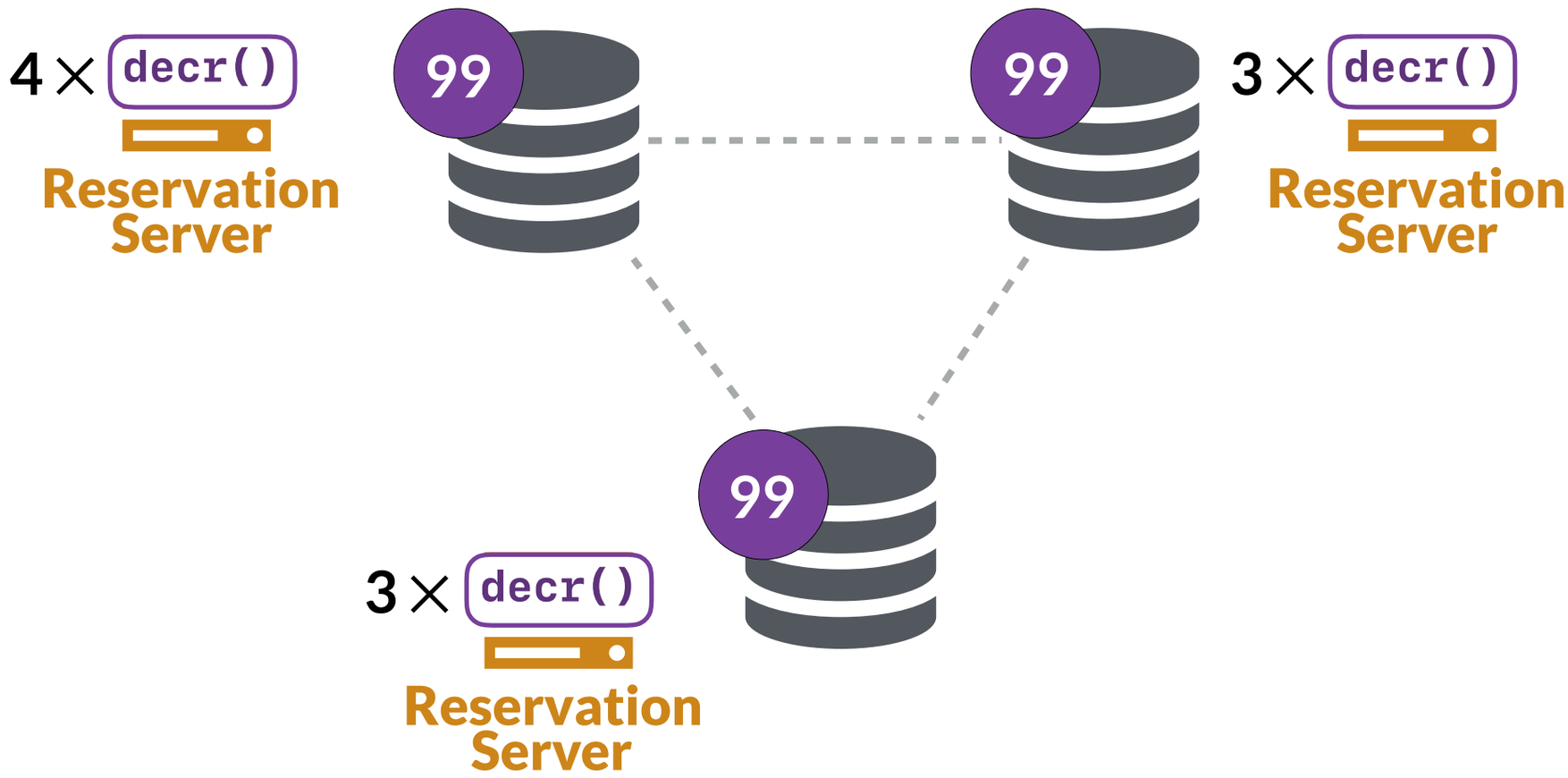

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Approximate

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Consistency types

- Statically prevent consistency bugs

Performance & accuracy constraints

- Dynamically adjust consistency

Case study

Case Study: TicketSleuth

Performance constraint:
< 50 ms latency

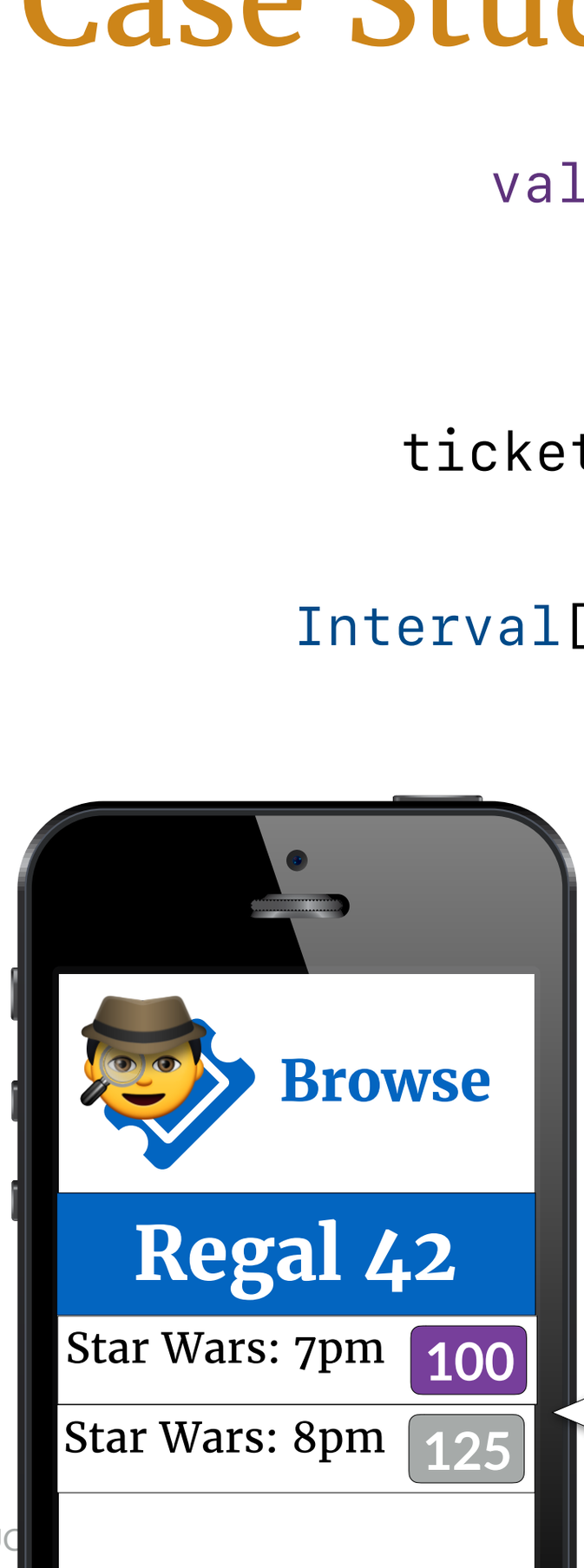

```
val events = List[EventID]()
                    with LatencyBound(50 ms)

events("Regal42:StarWars").range(0,2)

Rushed(Inconsistent(List("7pm","8pm")))

endorse
```

Case Study: TicketSleuth

```
val tickets = UUIDPool()
                with ErrorTolerance(count,5%)
```

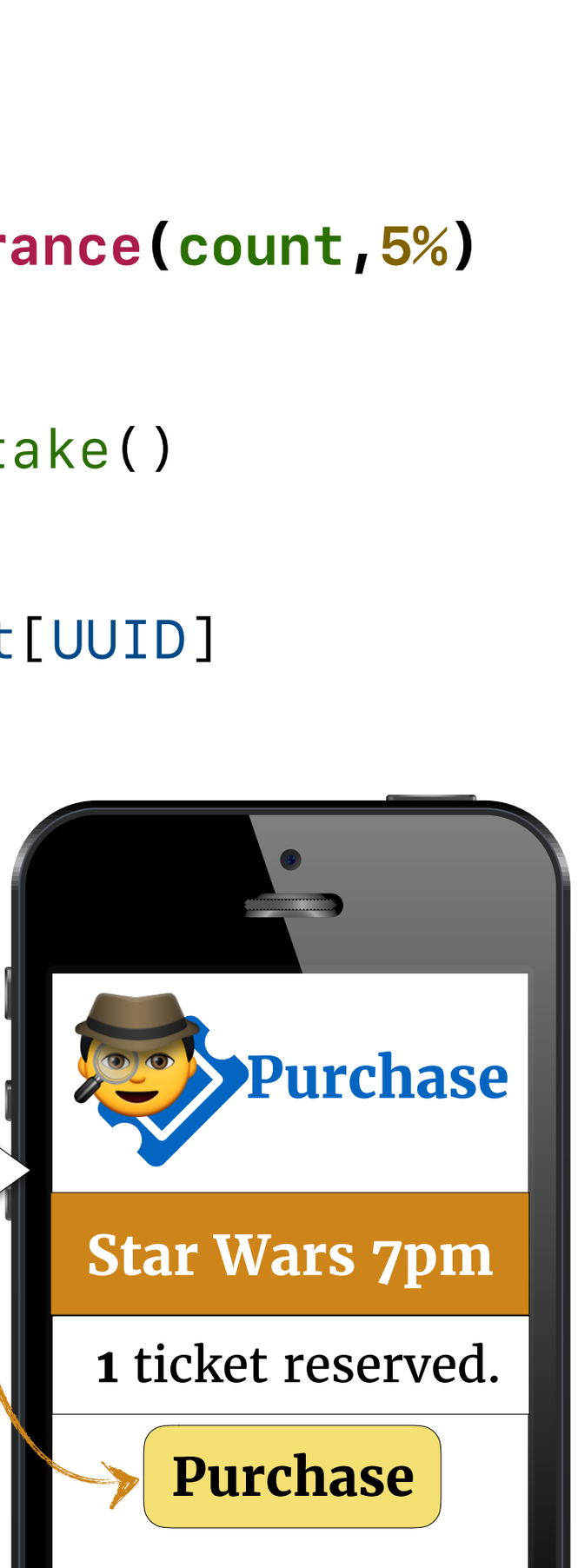
`tickets.count()` → `Interval[Int](96,100)` → `.max`

`tickets.take()` → `Consistent[UUID]`



Error tolerance:
count does not need to be exact…

Hard constraint:
do not over-sell tickets



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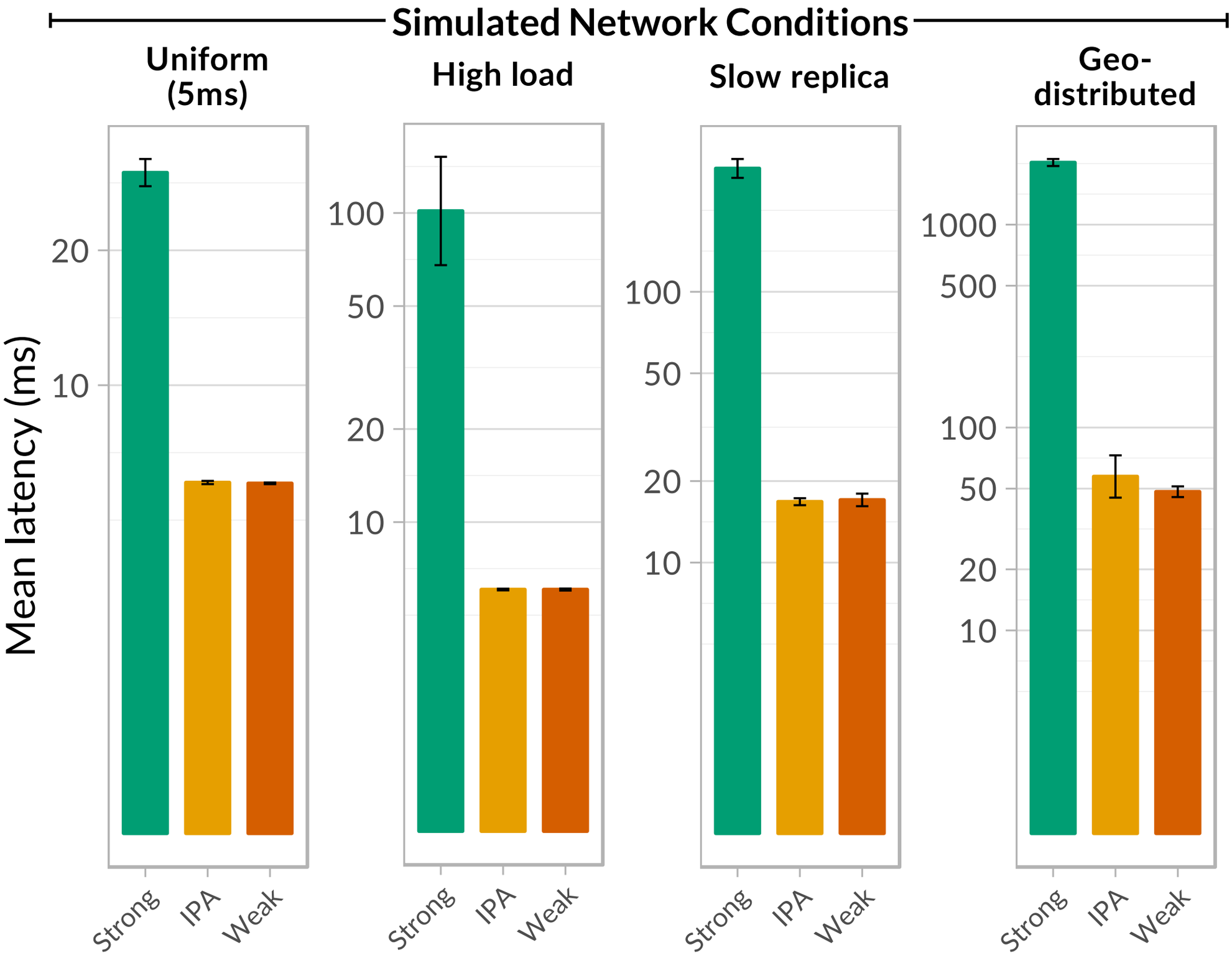


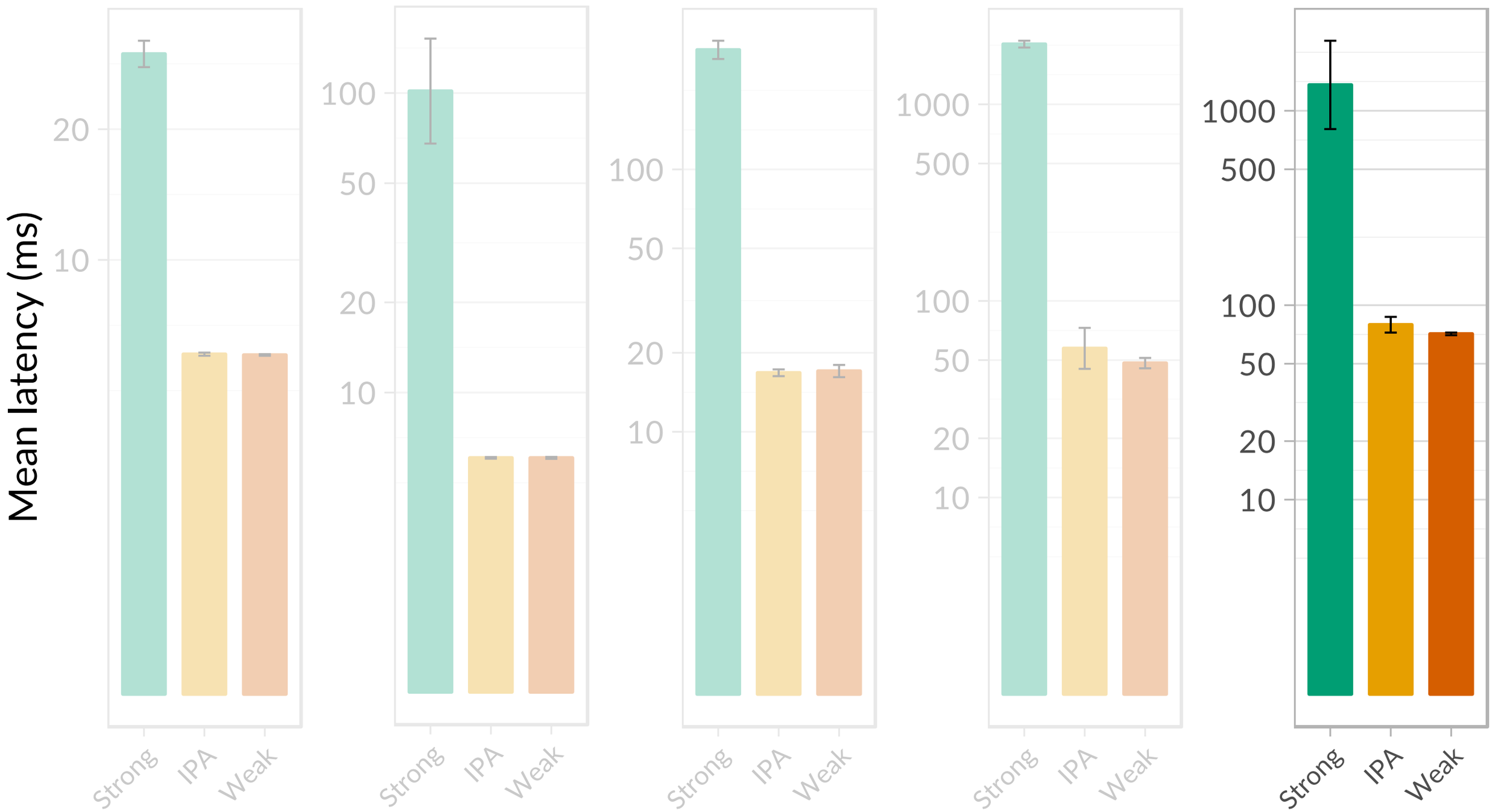
Case Study: TicketSleuth

VMs in US, Europe, and Asia

Simulated Network Conditions

Uniform (5ms) | High load | Slow replica | Geo-distributed | Google Compute Engine

Mean latency (ms)



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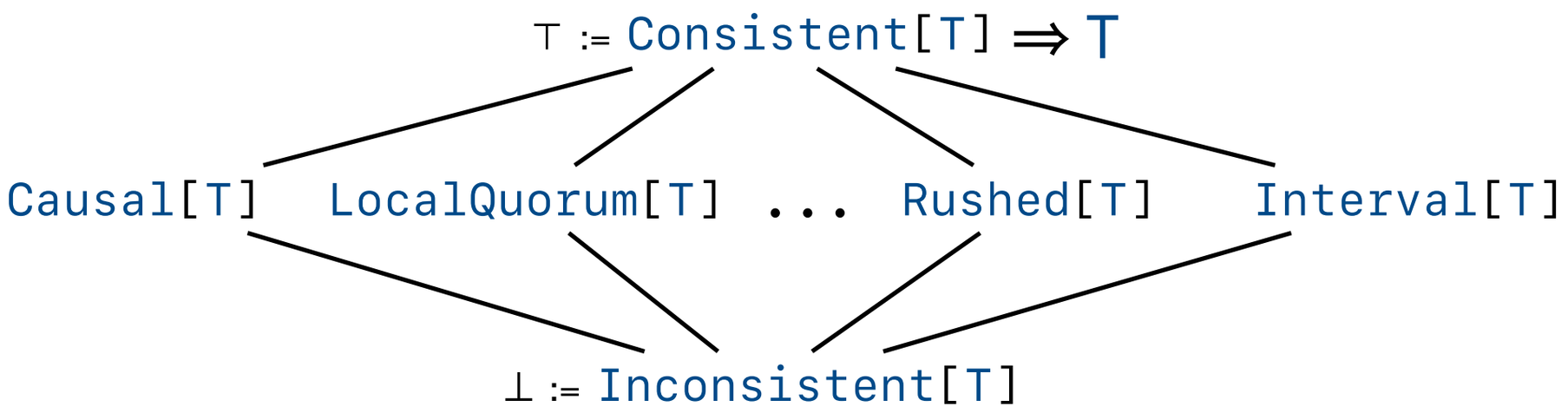
Approximate

} **Programming Model**



Discussion

Mixed consistency systems

- Geo-distributed databases
- Multiple layers of caches and downstream services
- Example: Facebook's TAO graph store

Data-type- vs operation-centric consistency

- Why do we usually annotate individual operations with consistency rather than annotating data types?
- How does this relate to CRDTs?

Other uses for reservations

Verifying or synthesizing ADT/constraint implementations

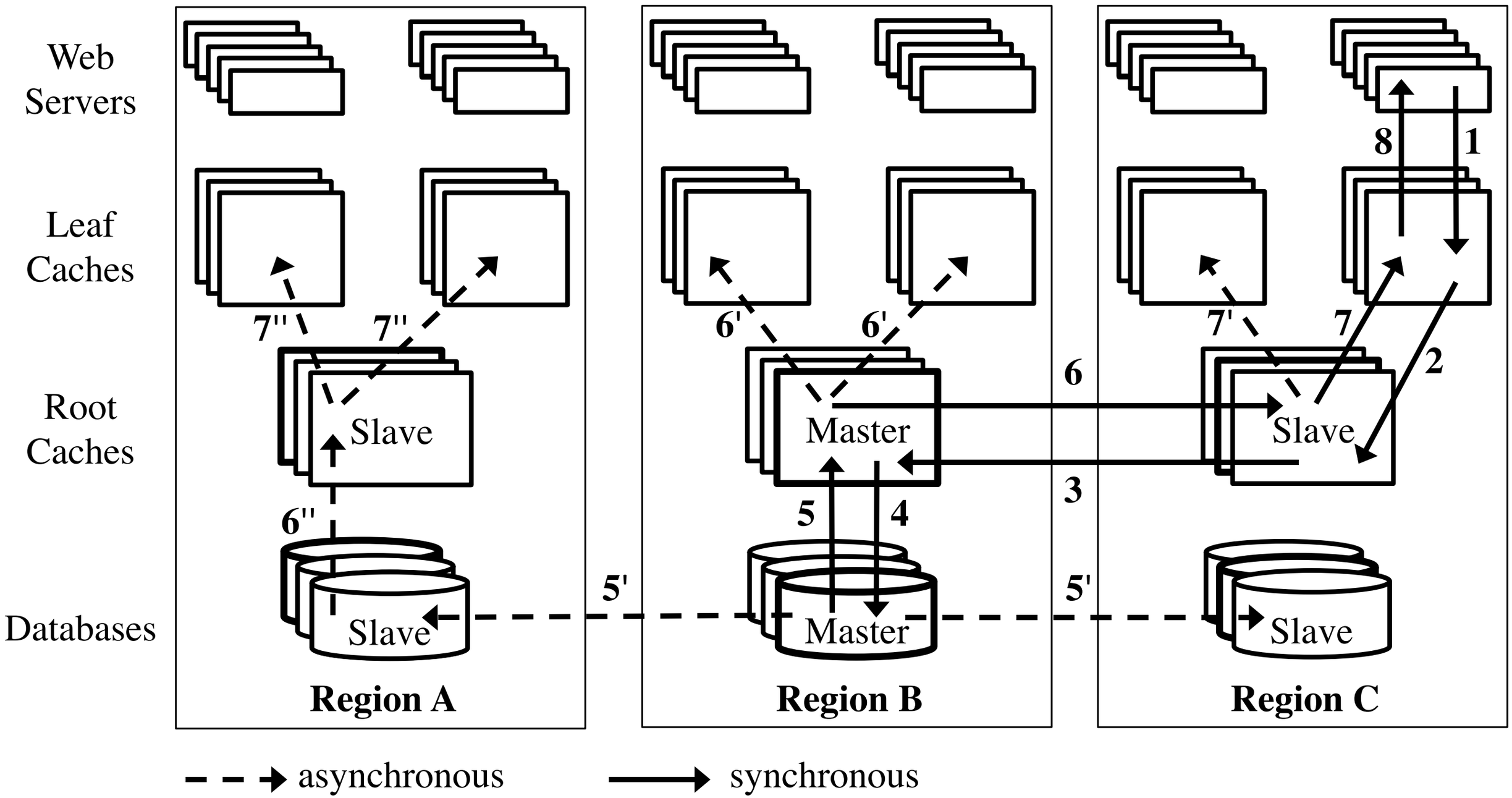
Composition of multiple operations or datatypes

Facebook TAO

Haonan Lu*†, Kaushik Veeraraghavan†, Philippe Ajoux†, Jim Hunt†,
Yee Jiun Song†, Wendy Tobagus†, Sanjeev Kumar†, Wyatt Lloyd*†

*University of Southern California, †Facebook, Inc.

(SOSP'15)



System architecture of TAO graph store.

Facebook TAO

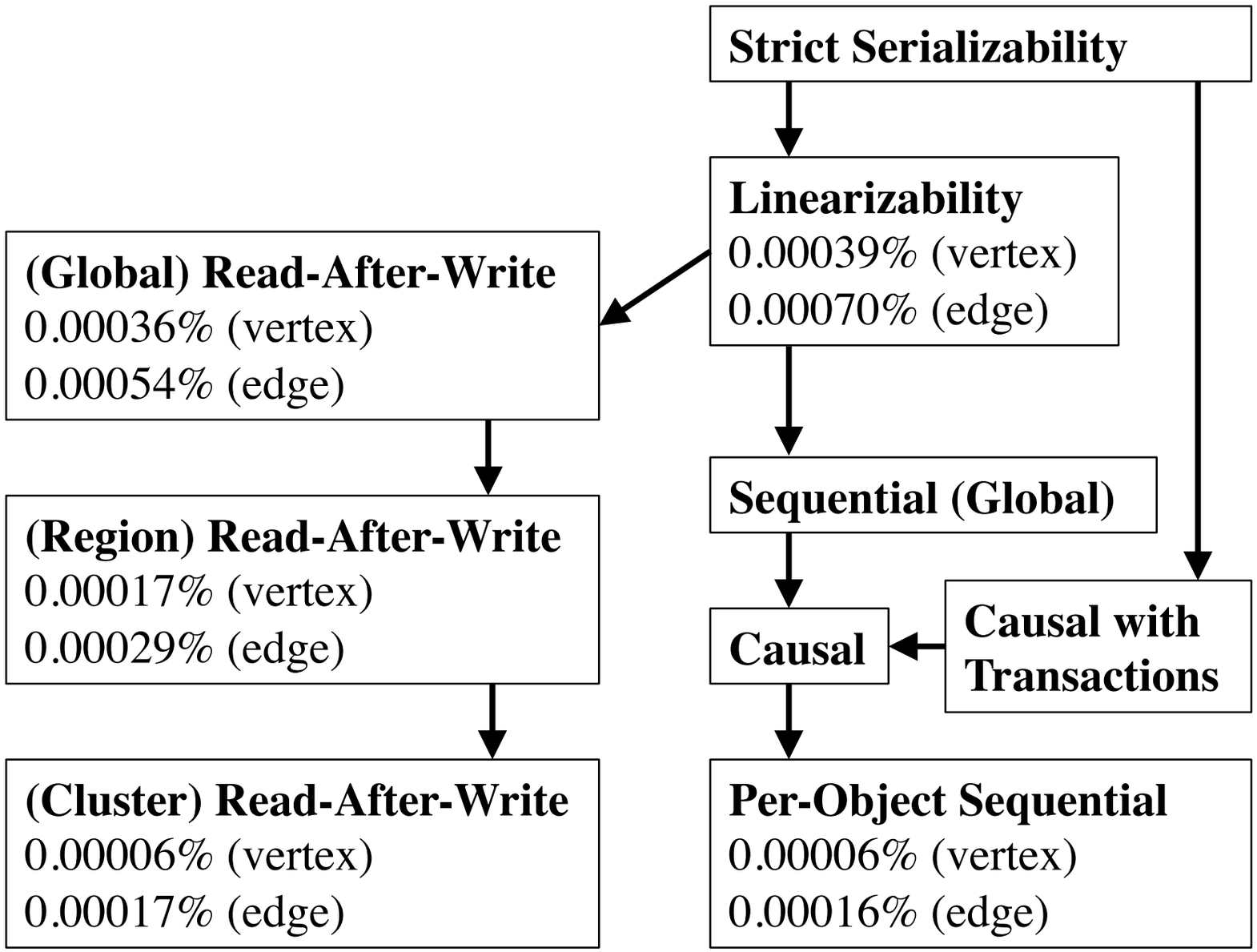


Figure 8: Spectrum of consistency models with arrows from stronger to weaker models. Measured anomaly rates are shown. Bounds on the anomaly rate in unmeasureable non-local consistency models can be inferred.

Case Study: Twitter clone

```
class Tweet(
  id: TweetID,
  user: UserID,
  body: String,
  retweets: Set[UserID] with ErrorTolerance(size,5%)
)
```

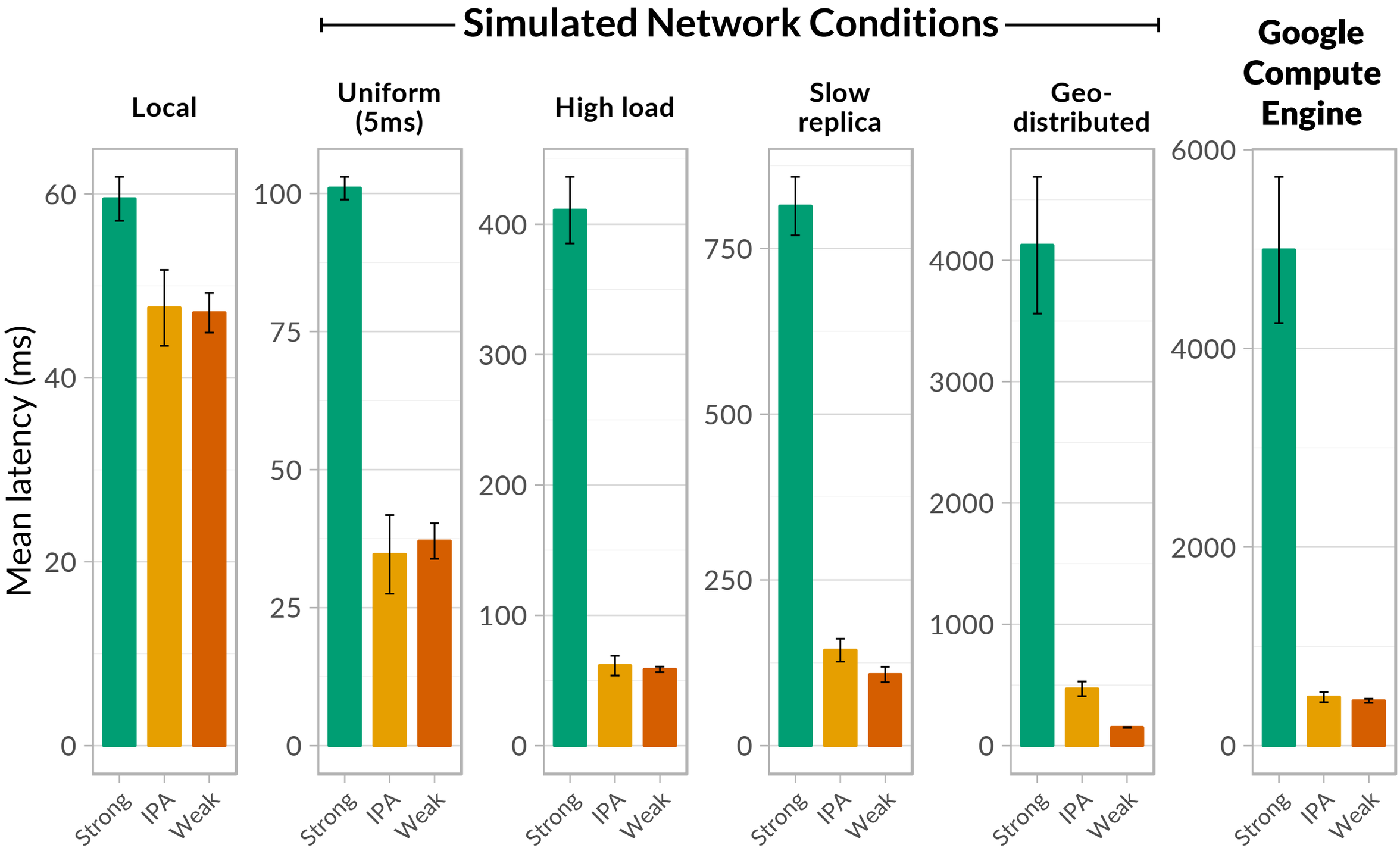
Exact count for average tweets.

Approximate count for popular tweets

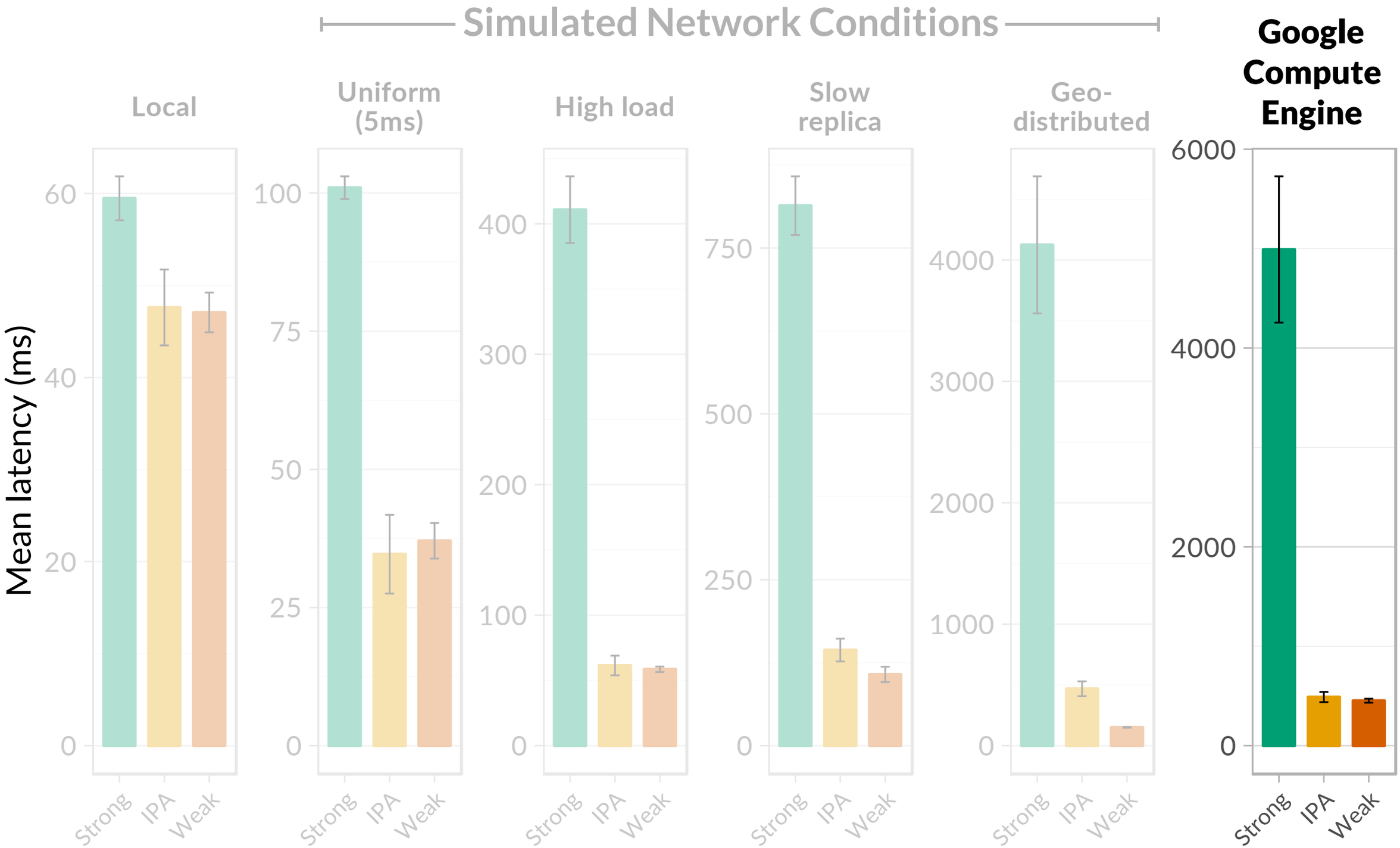
Case Study: Twitter clone

```
class User(
  id: UserID,
  name: String,
  followers: Set[UserID] with LatencyBound(20 ms),
  timeline: List[TweetID] with LatencyBound(20 ms)
)
```

Case Study: Twitter clone



Case Study: Twitter clone



Consistency-based SLAs

(SOSP'13)

Douglas B. Terry, Vijayan Prabhakaran, Ramakrishna Kotla, Mahesh Balakrishnan, Marcos K. Aguilera, Hussam Abu-Libdeh

- SLAs specify consistency and target latency.
- Operations specify a set of SLAs with utility values.
- System monitors and predicts which SLA can be met, tries to maximize utility.
- Speculative execution

Consistency Levels
Strong
Eventual
Read-My-Writes
Monotonic
Bounded
Causal

```
CreateTable (name);
DeleteTable (name);
tbl = OpenTable (name);

s = BeginSession(tbl, sla);
EndSession(s);

Put (s, key, value);
value, cc = Get (s, key, sla);
```

Figure 2. The Pileus API

Consistency	Latency	Utility
Strong	300 ms	1.0
Eventual	300 ms	0.5

Example: Shopping Cart

A Romp Through the Consistency Zoo

by Brandon Holt


The **Strongest**
The **Safest**
The (least) Freedom
Strong Serializable

~~Linearizable~~

Lionizable

~~Linearizable~~

Lionizable

~~Seri~~alizable

Siri

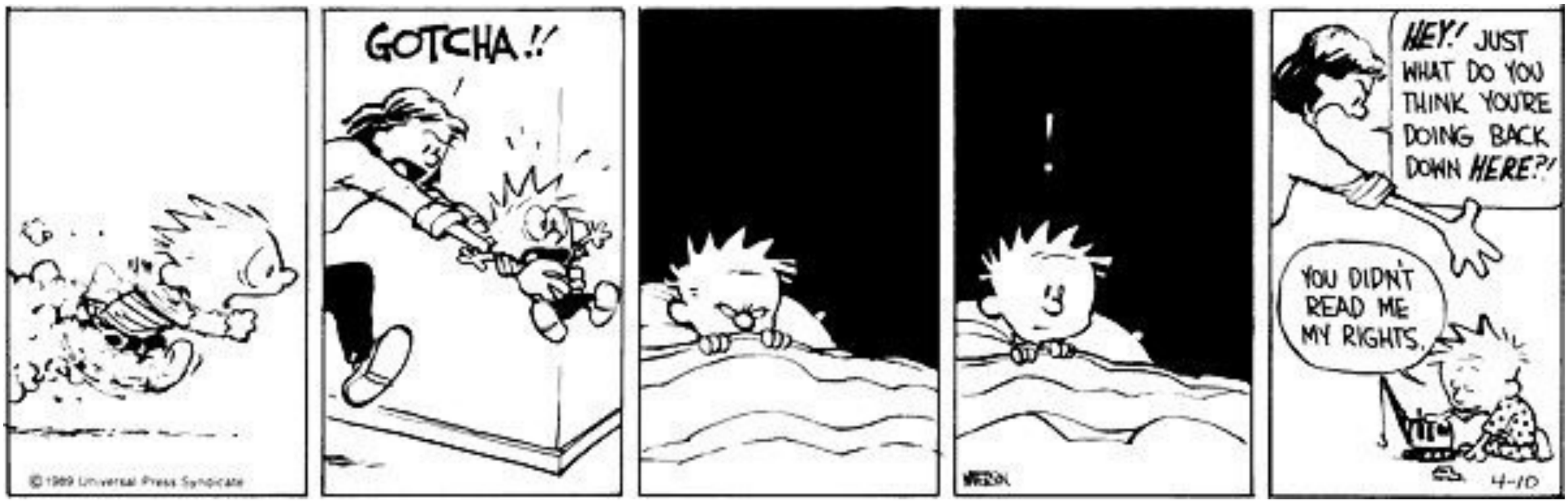
~~Serializable~~

Siri

Bet you thought I was gonna say:

Cerealizable

Read-Your-~~Writes~~
^ Rights



Monotonic consistency

PRAM

~~Causal~~ Consistency

Casual

Causal Consistency