Incremental Consistency Guarantees

For Replicated Objects

Rachid Guerraoui, Matej Pavlovic, Dragos-Adrian Seredinschi

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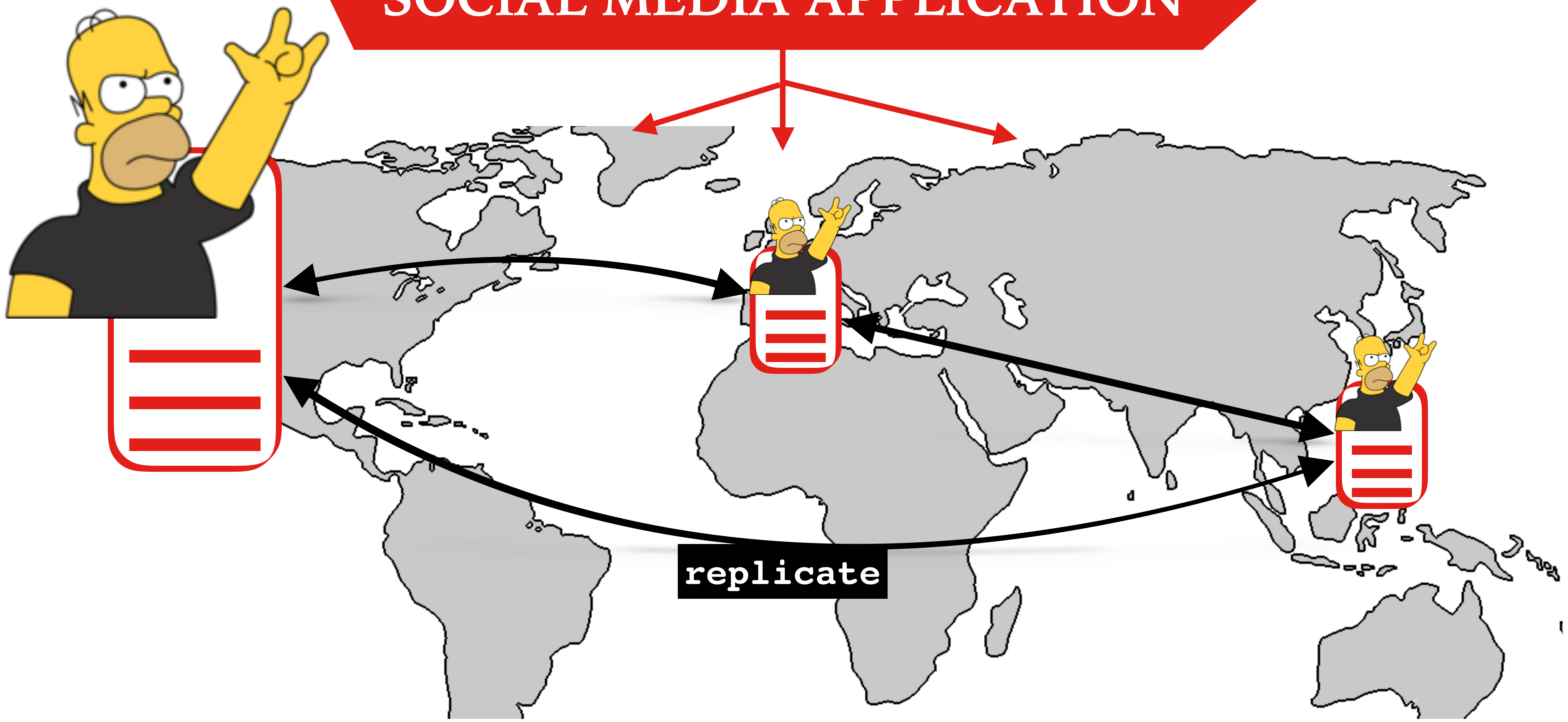
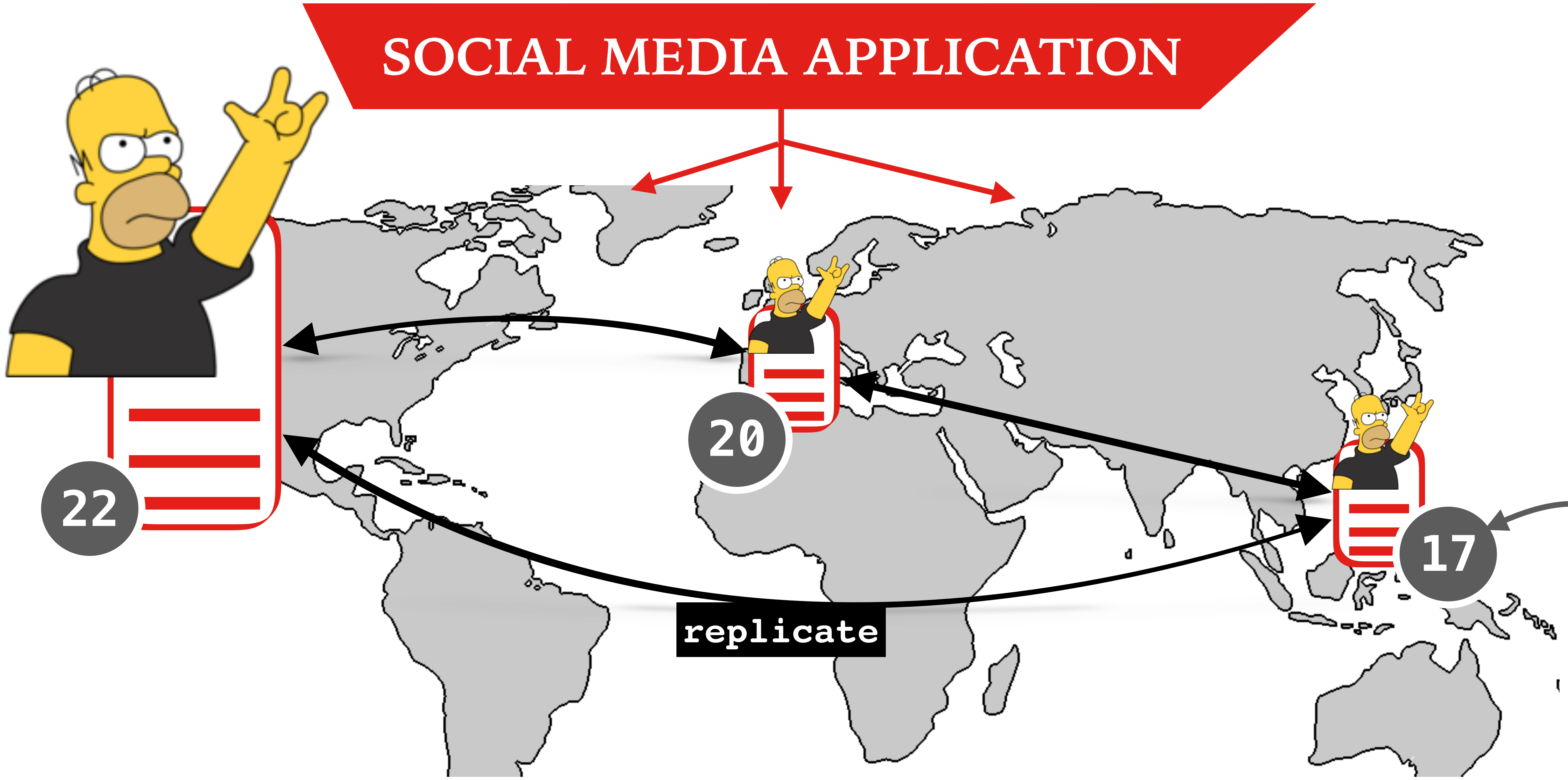
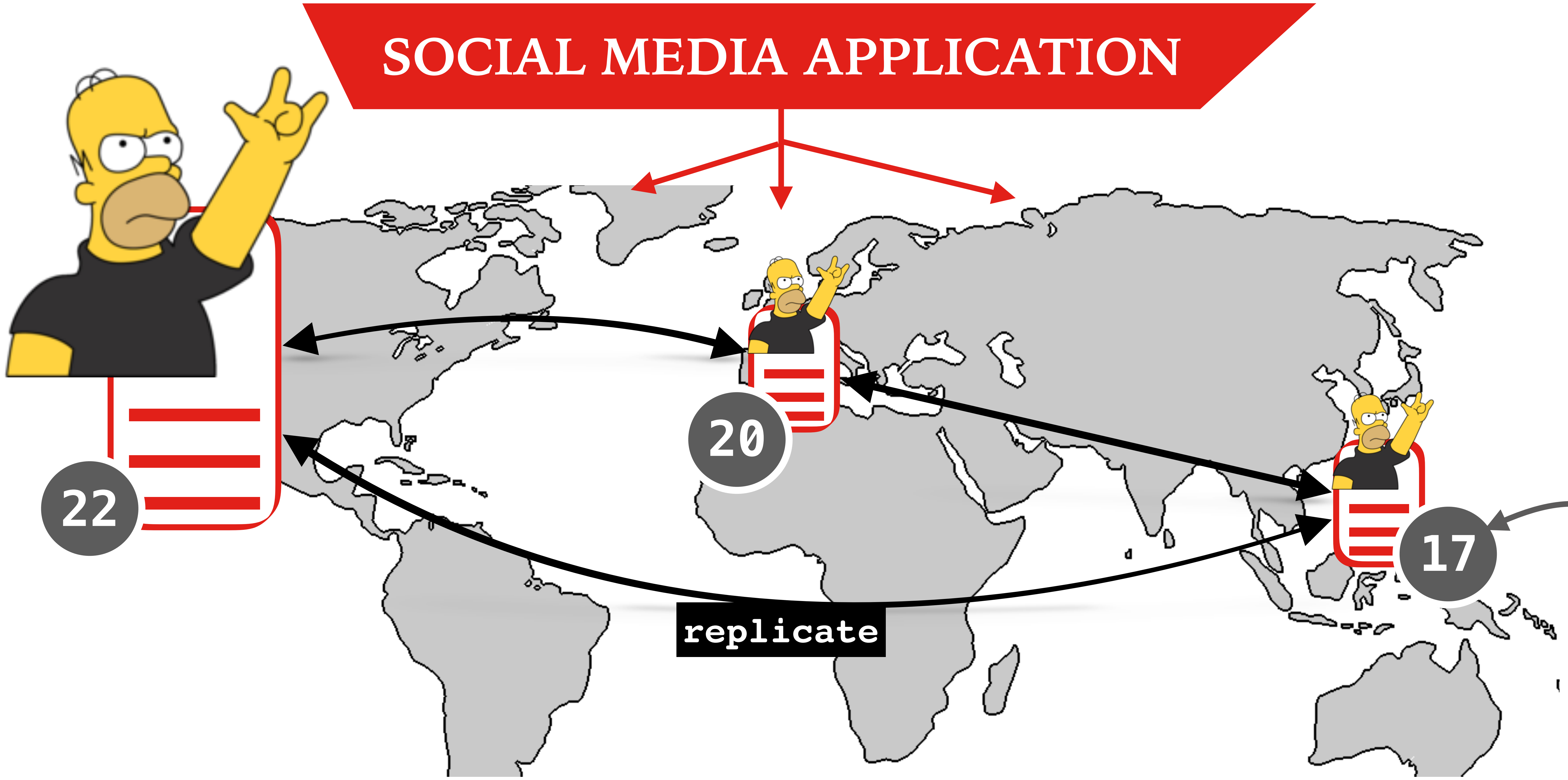
SOCIAL MEDIA APPLICATION



SOCIAL MEDIA APPLICATION



Number of **recent events** on the user’s timeline



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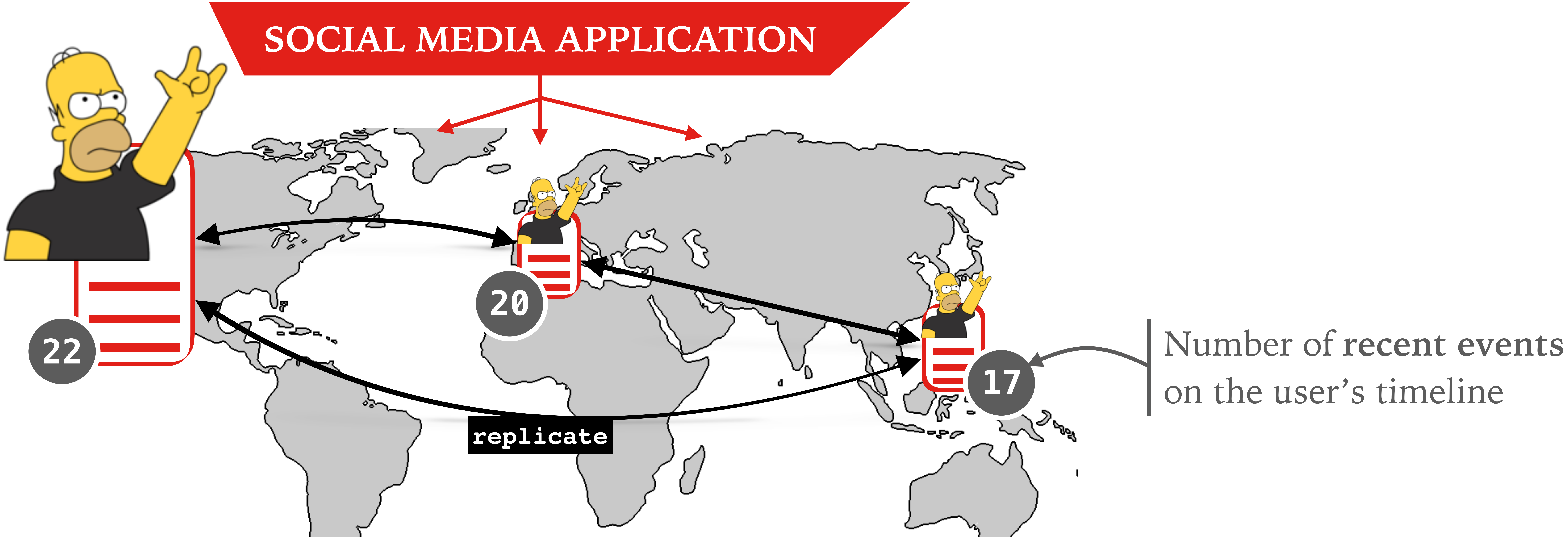
Number of **recent events** on the user's timeline

Strong Consistency

- Returns the **correct** data 22
- Latency: ~**200 ms**
- Can become **unavailable**

  [CAP], [PACELC]



Strong Consistency

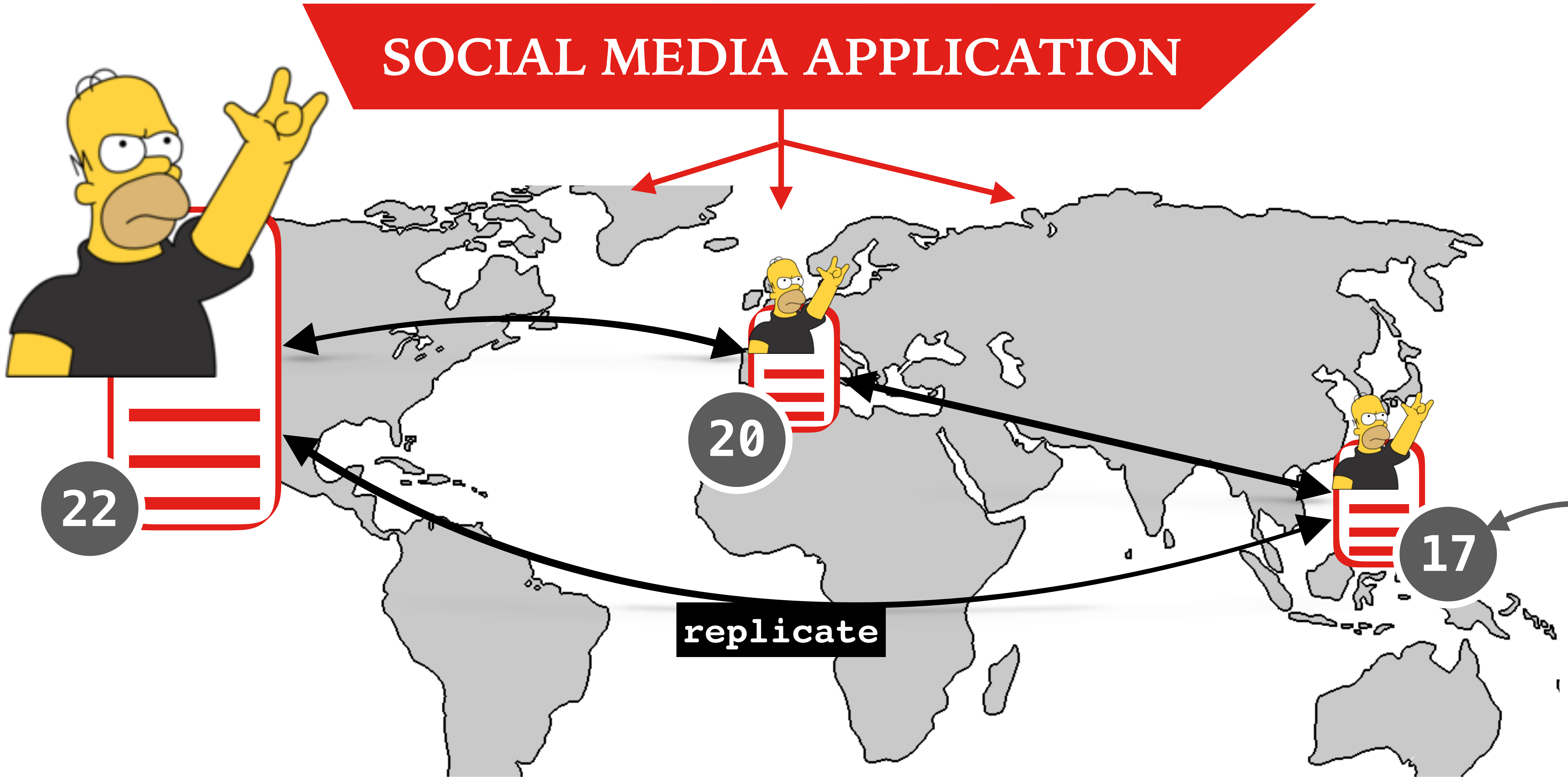
- Returns the **correct** data 22
- Latency: ~**200 ms**
- Can become **unavailable**

[CAP], [PACELC]

Weak Consistency

- Latency: ~**100 ms**
- **High availability**
- Allows inconsistencies: can return

22 *or* 20 *or* 17

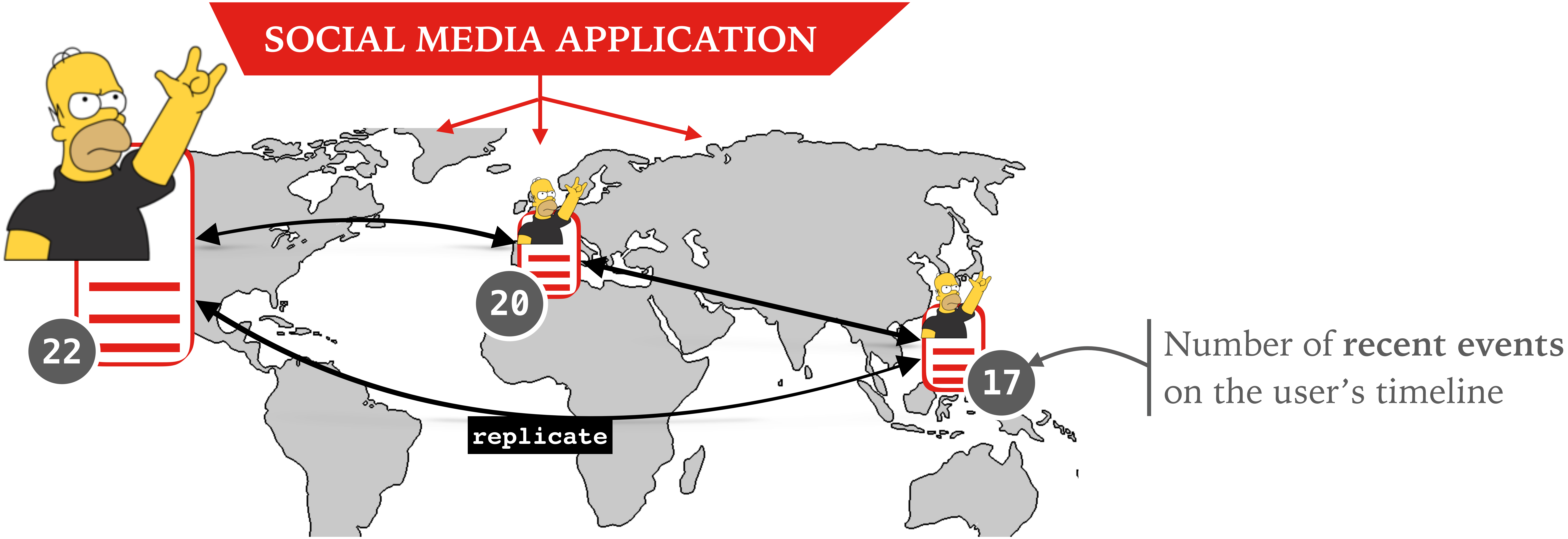


Number of **recent events** on the user's timeline

Strong Consistency

Weak Consistency

Neither model is ideal!



Strong Consistency

Weak Consistency

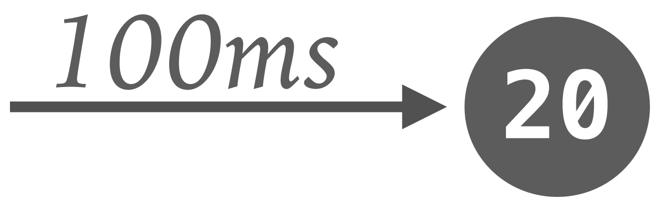
Neither model is ideal!

↓

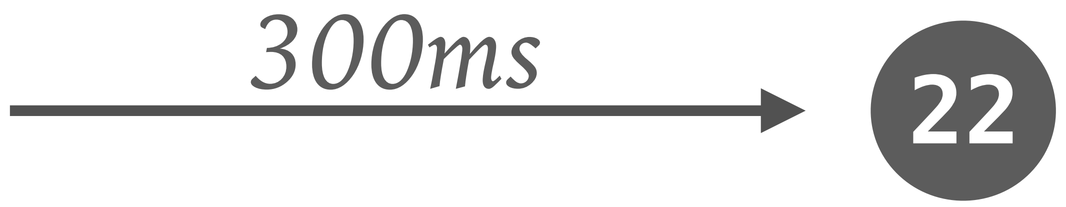
We use both models.

Multiple models

1. **Weak consistency**



2. **Strong consistency**



Multiple models

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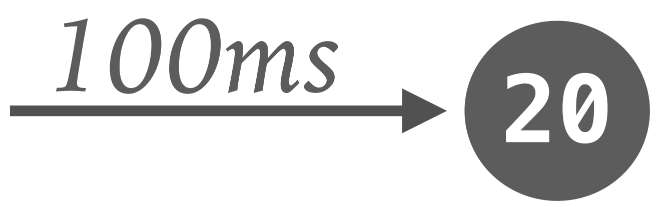


2. **Strong consistency**

Increasingly many systems expose multiple consistency models:

App Engine

cassandra

Dynamo [SOSP'07]

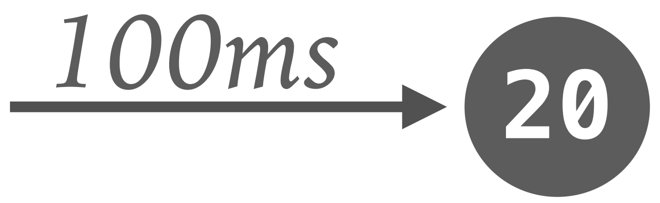
SimpleDB

riakKV

Pileus [SOSP'13]

Multiple models

1. **Weak consistency**



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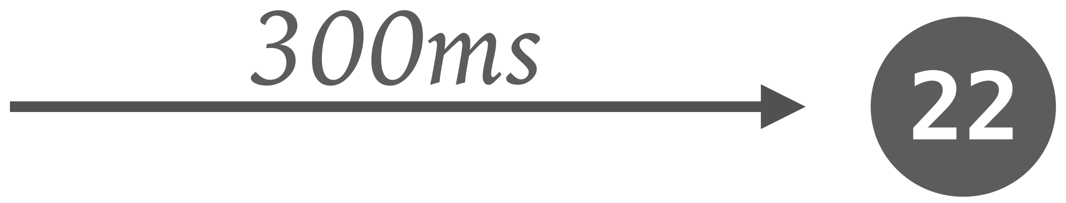

Increasingly many systems expose multiple consistency models:

App Engine

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Issues

1. *Send multiple requests?*
2. *How to leverage individual responses?*
3. *Semantics?*
4. *…*

Multiple models

1. **Weak consistency**

   100ms → 20

2. **Strong consistency**

   300ms → 22

Increasingly many systems expose multiple consistency models:

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Issues

1. *Send multiple requests?*
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Problem

How do you program with

★ inconsistencies?

★ multiple values?

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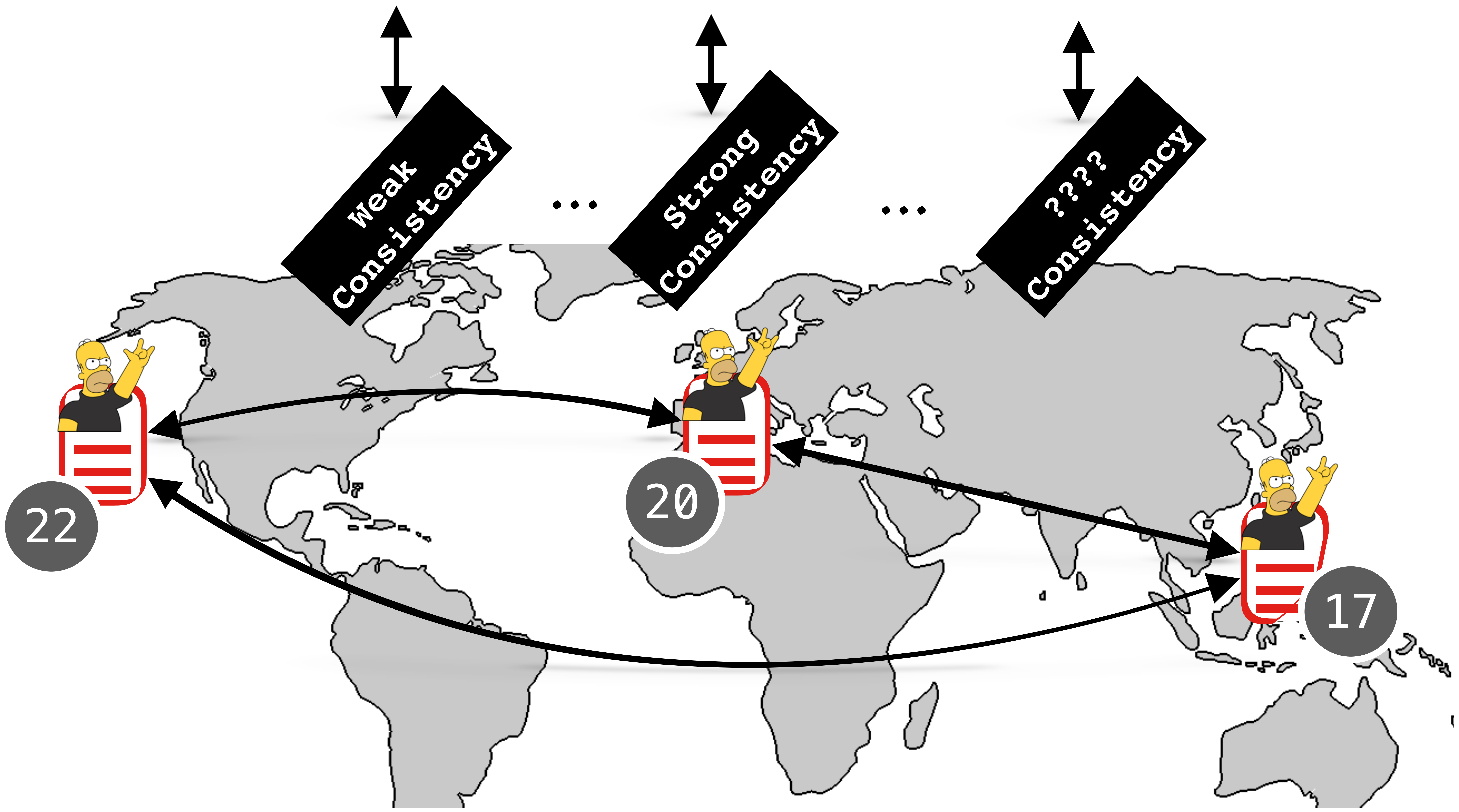
ABSTRACTION
FOR REPLICATED OBJECTS



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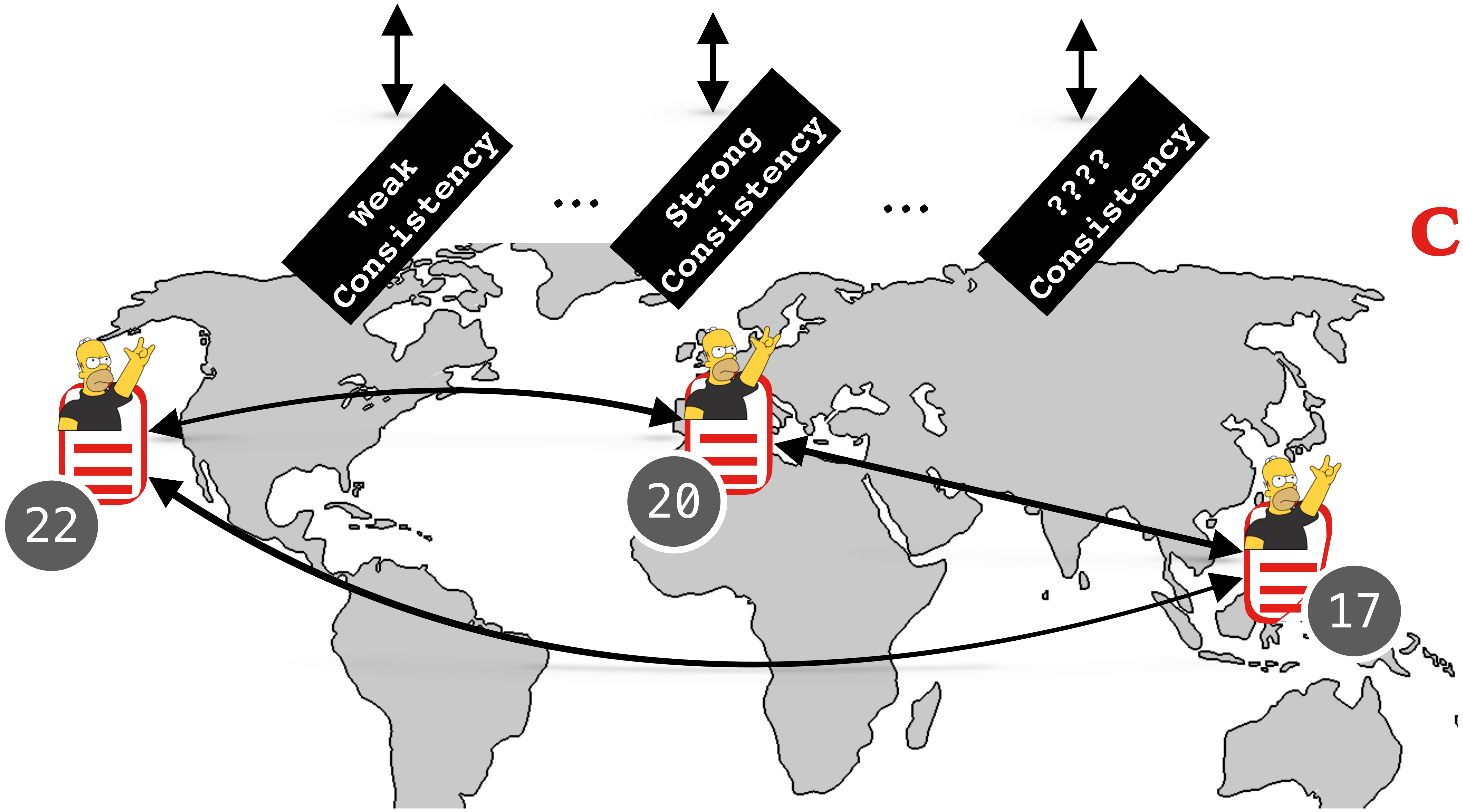
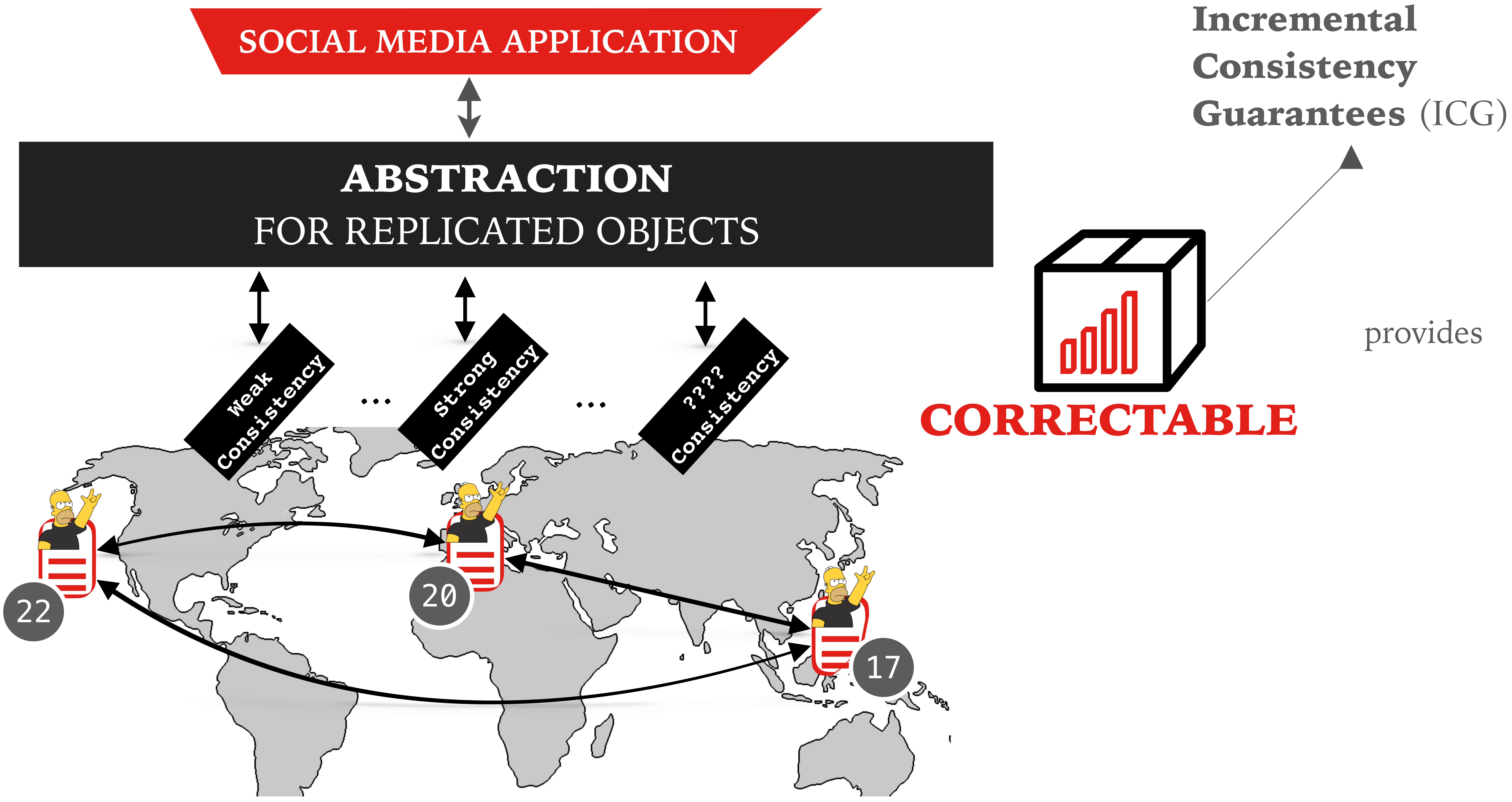


CORRECTABLE



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ABSTRACTION
FOR REPLICATED OBJECTS

Incremental Consistency Guarantees (ICG)

provides

CORRECTABLE

Correctables / **Design**

- ➤ Starting point: **Promises**
  - ➤ Placeholders for values
  - ➤ Becoming mainstream

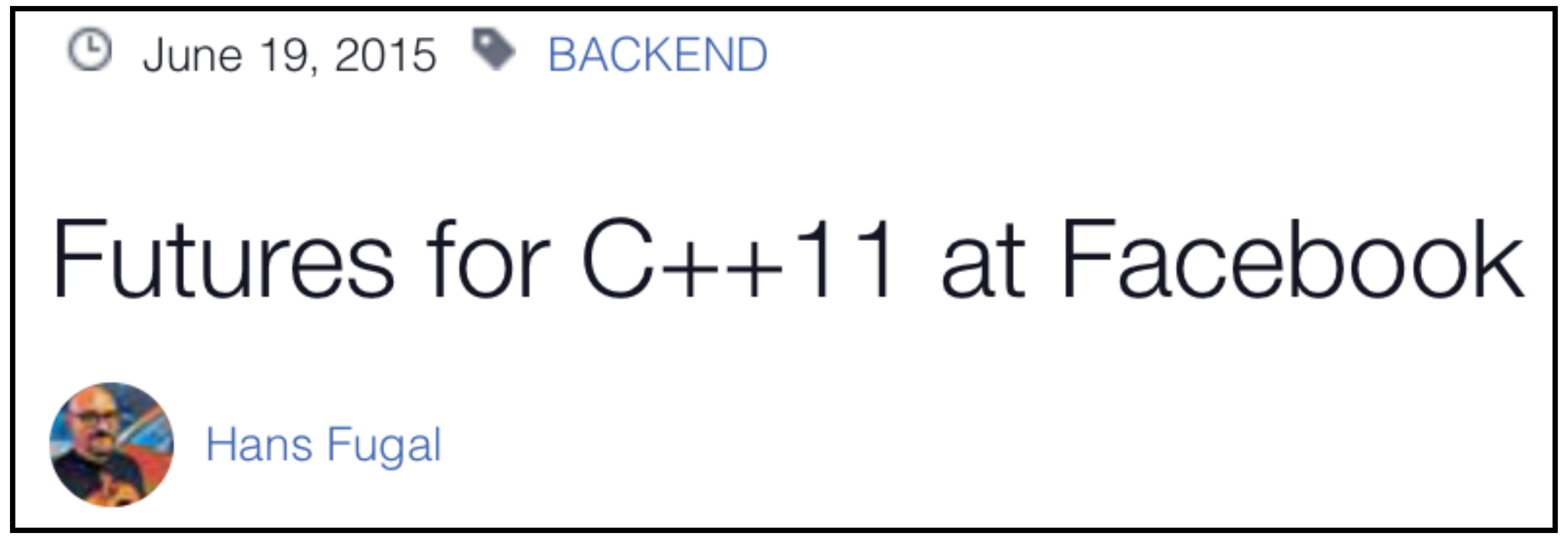
Futures and Promises

Scala

finagle

JS

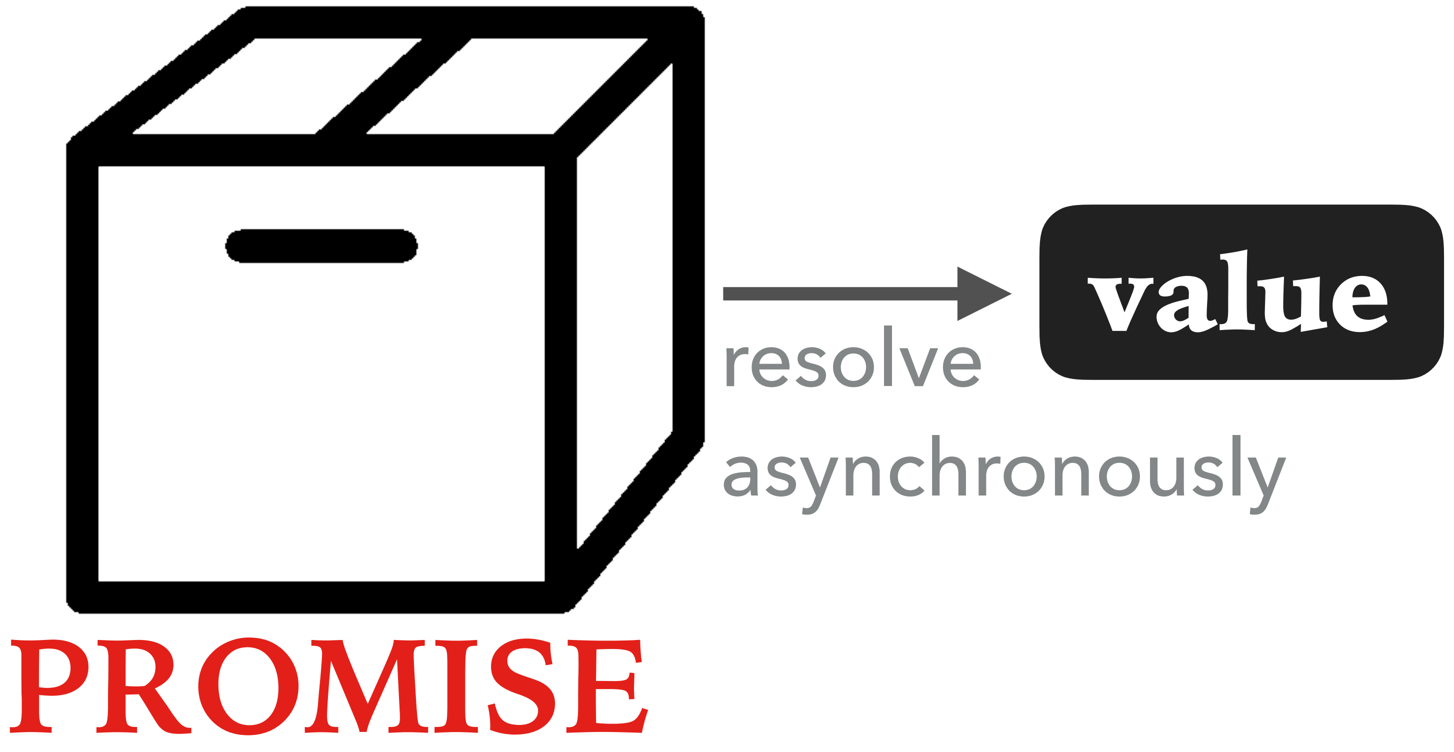
then Promises/A+


June 19, 2015 BACKEND

Futures for C++11 at Facebook

Hans Fugal

Google Guava
Core libraries for Java & Android


PROMISE

resolve asynchronously

value

Correctables / **Design**

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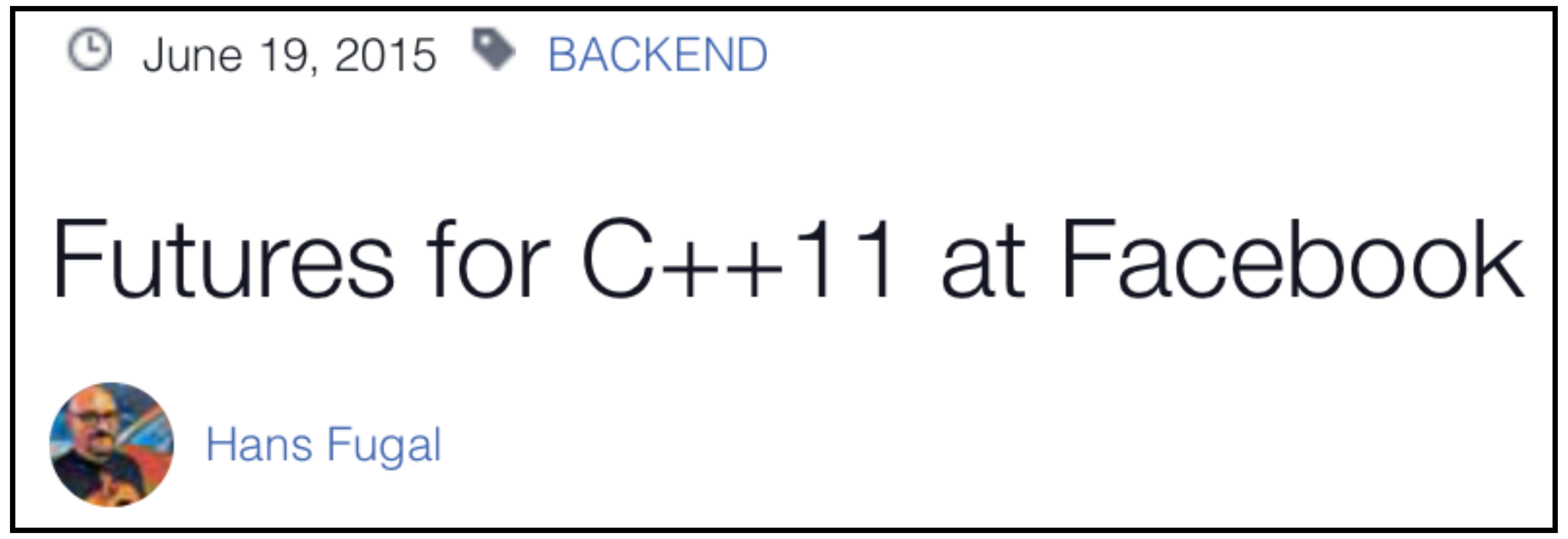

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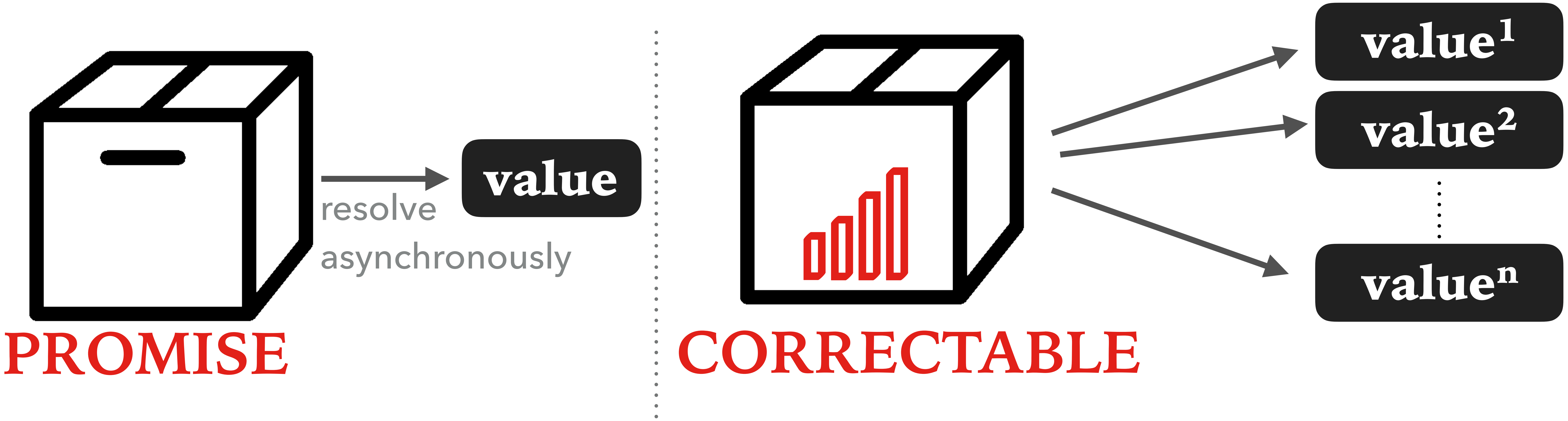

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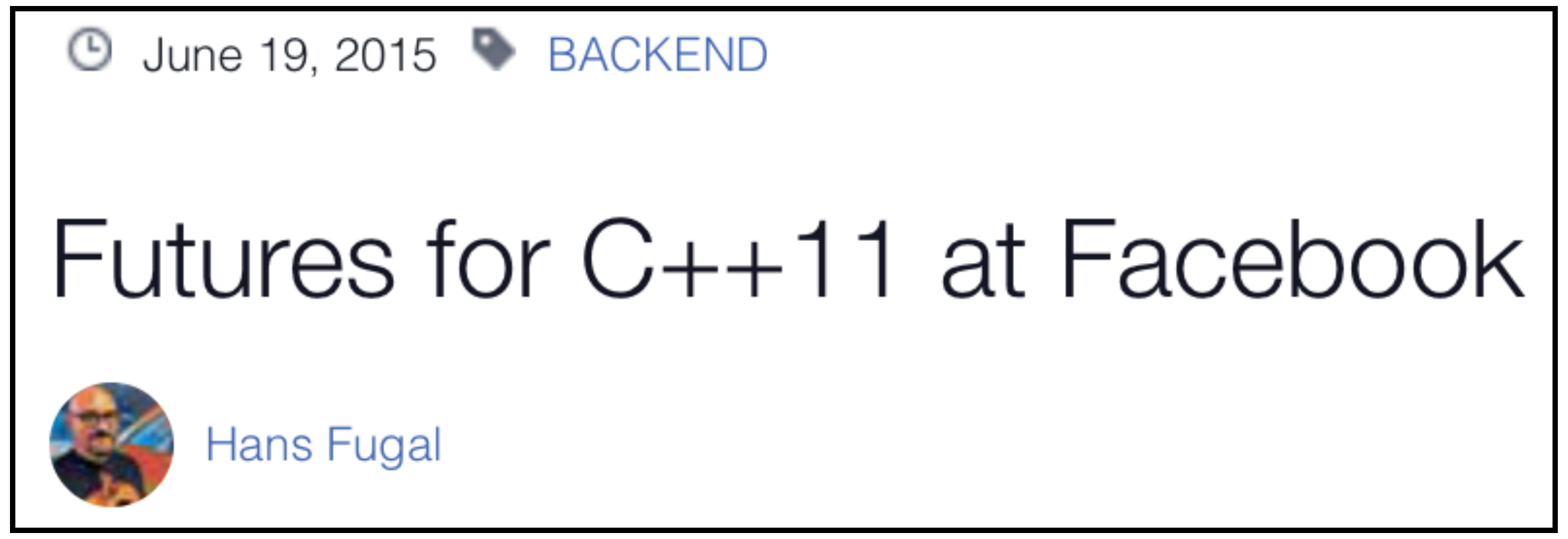

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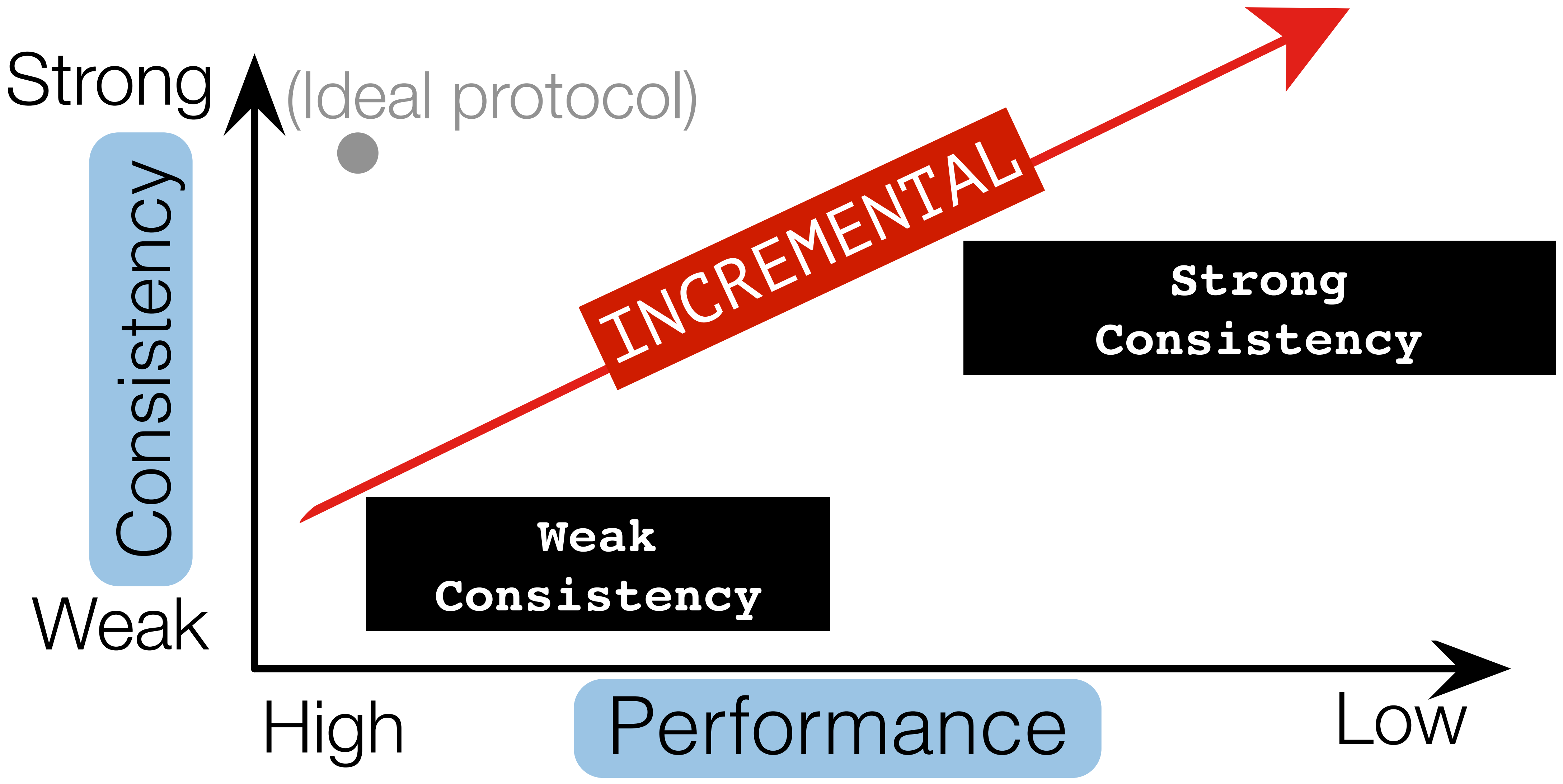
resolve
asynchronously
value
PROMISE
CORRECTABLE
value^1
value^2
value^n

PROGRESSIVELY STRONGER CONSISTENCY (INCREMENTAL)

PROGRESSIVELY HIGHER LATENCY

Consistency Models are **Complementary**



Weak consistency:

★ Fast

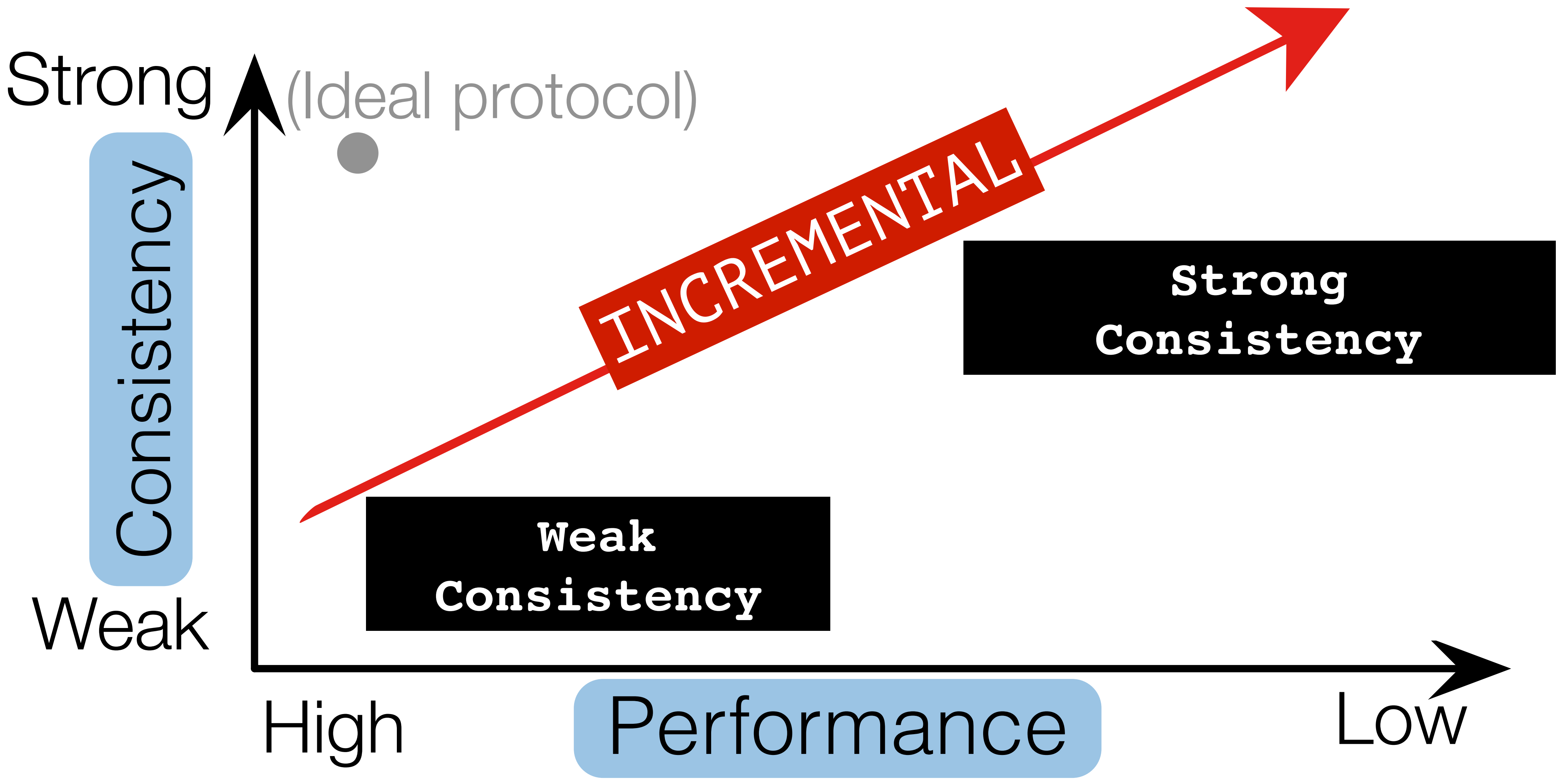
★ (Often correct)

Strong consistency:

★ Slower

★ (Correct with certainty)

Consistency Models are **Complementary**



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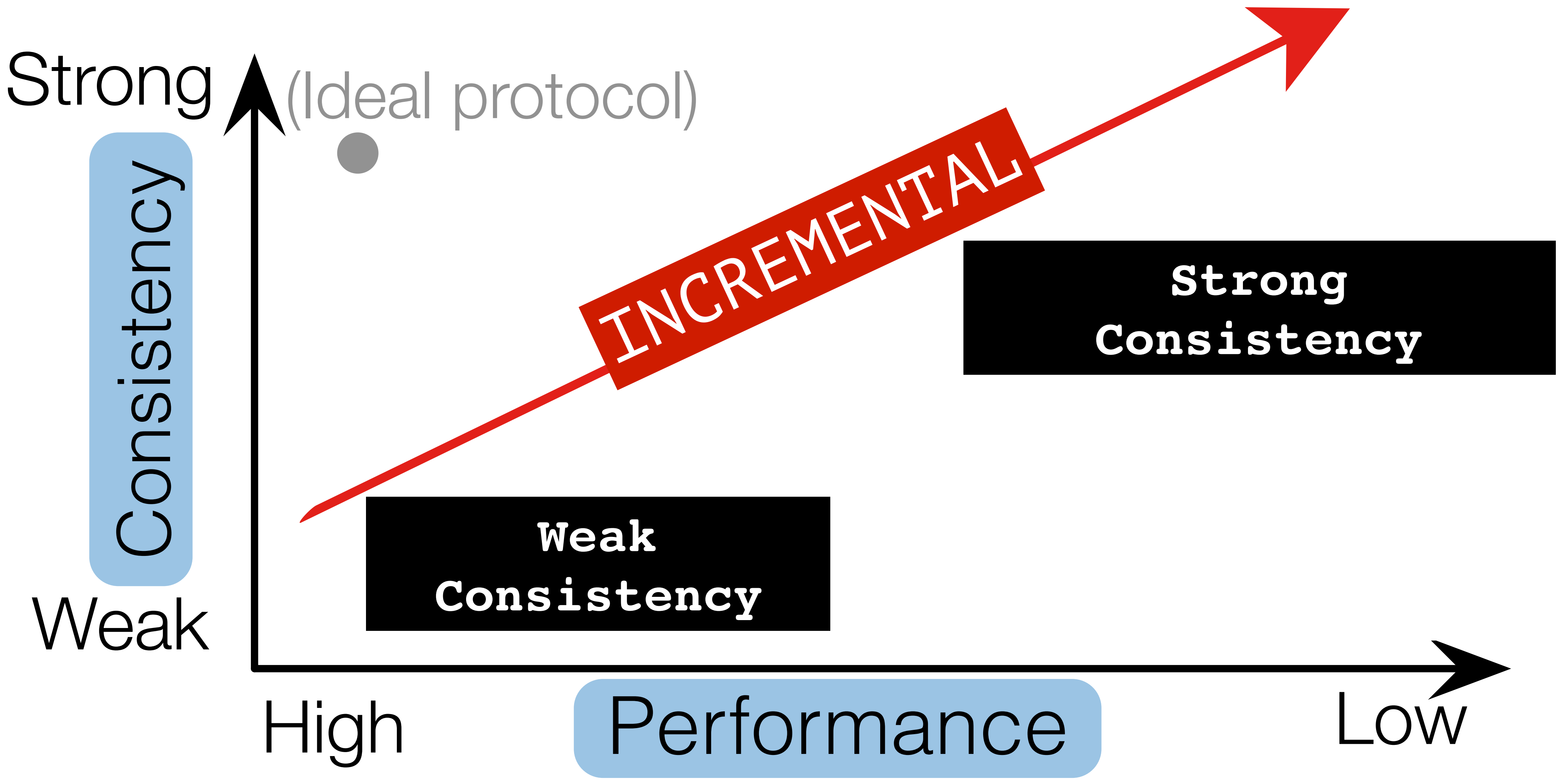

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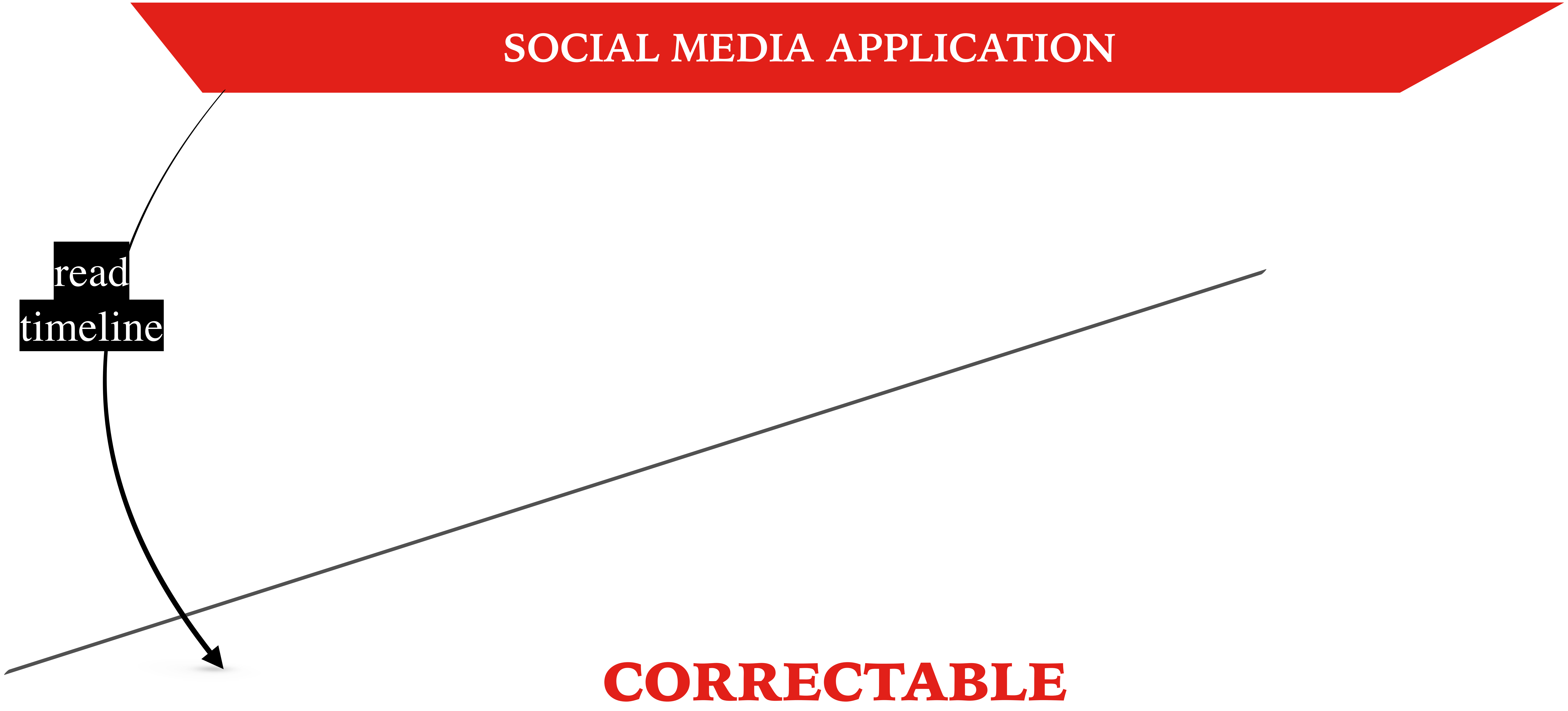
So what?

Latency optimizations

Speculating with Correctables



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read timeline

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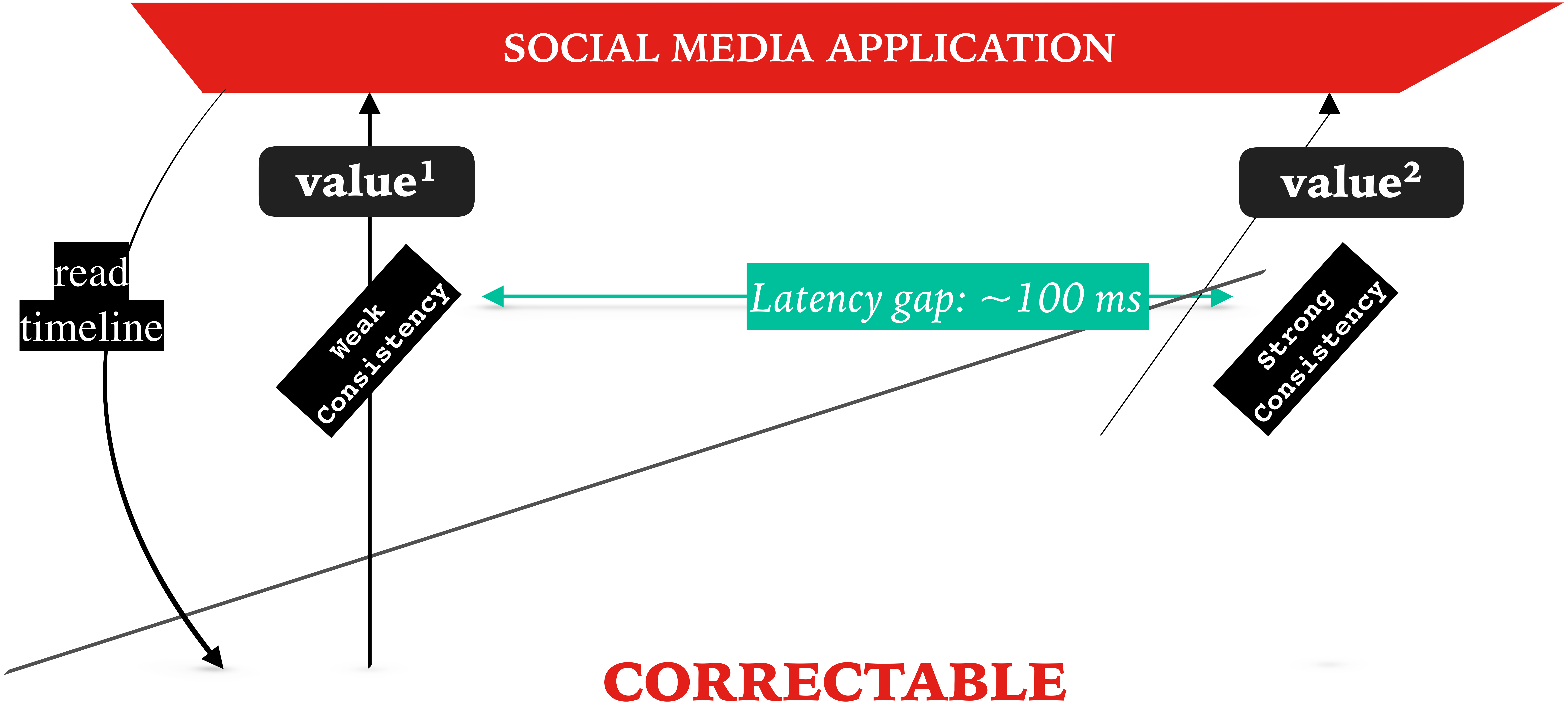
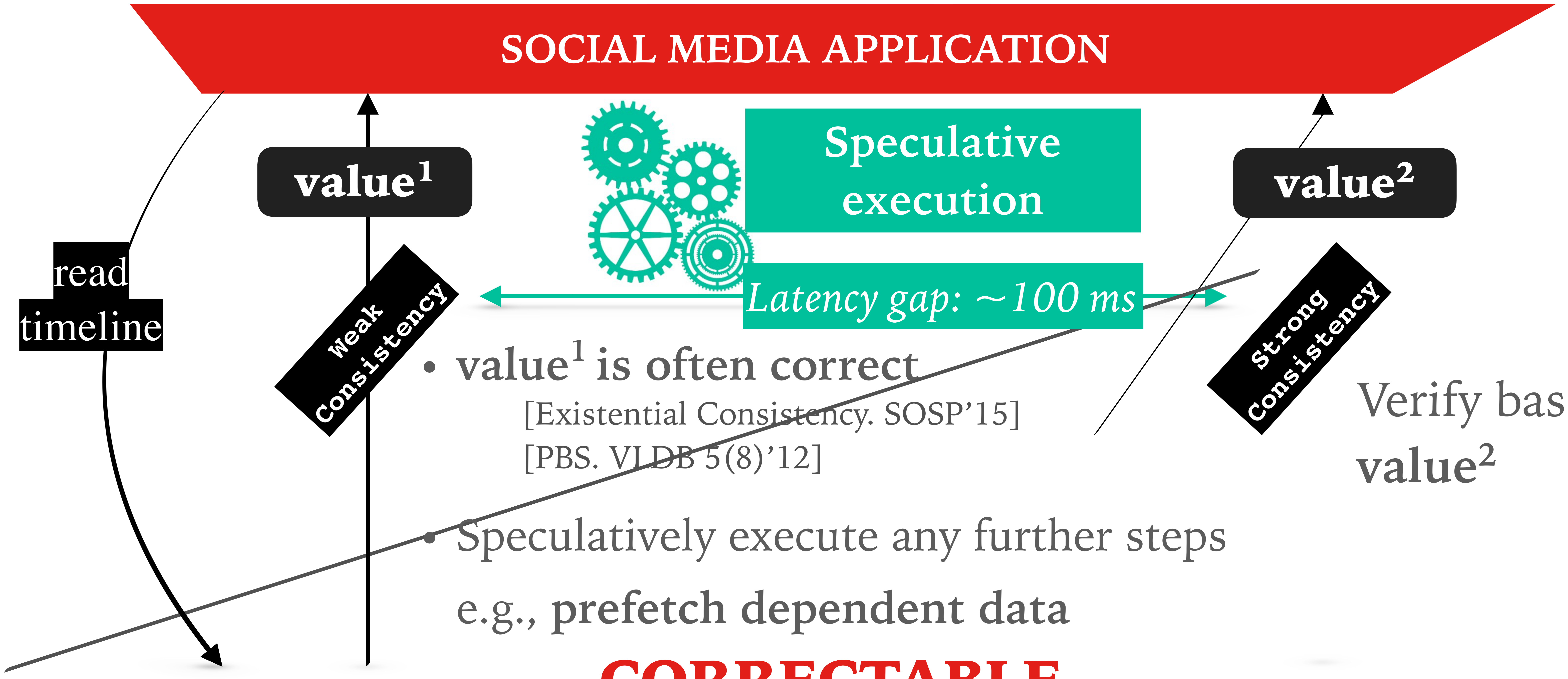
Speculating with Correctables



Speculating with Correctables

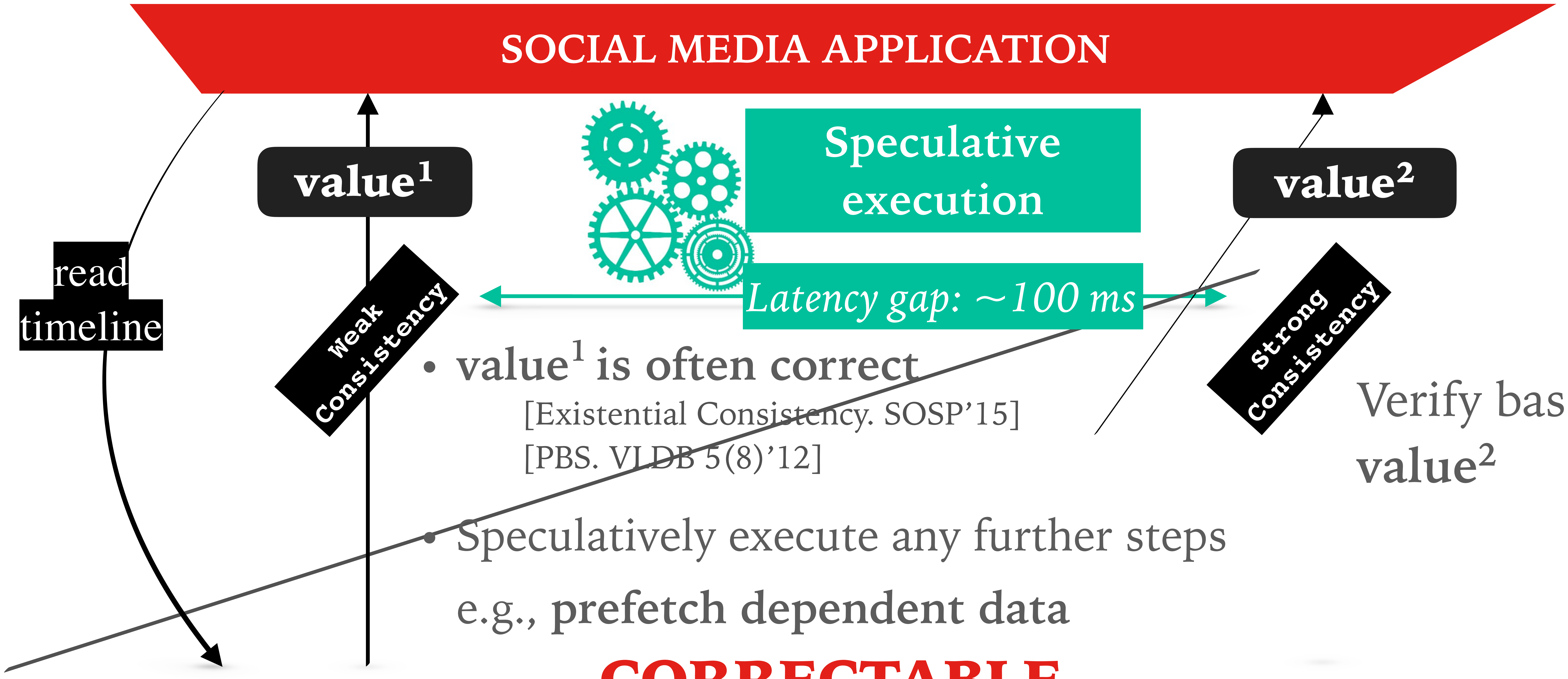


- **value^1 is often correct**
  [Existential Consistency. SOSP'15]
  [PBS. VLDB 5(8)'12]
- Speculatively execute any further steps e.g., **prefetch dependent data**

Verify based on **value^2**

CORRECTABLE

Speculating with Correctables



SOCIAL MEDIA APPLICATION

read timeline

value^1

Weak Consistency

Speculative execution

Latency gap: ~100 ms

value^2

Strong Consistency

- **value^1 is often correct**
  [Existential Consistency. SOSP'15]
  [PBS. VLDB 5(8)'12]
- Speculatively execute any further steps
  e.g., **prefetch dependent data**

Verify based on **value^2**

CORRECTABLE

Lower latency of strong consistency

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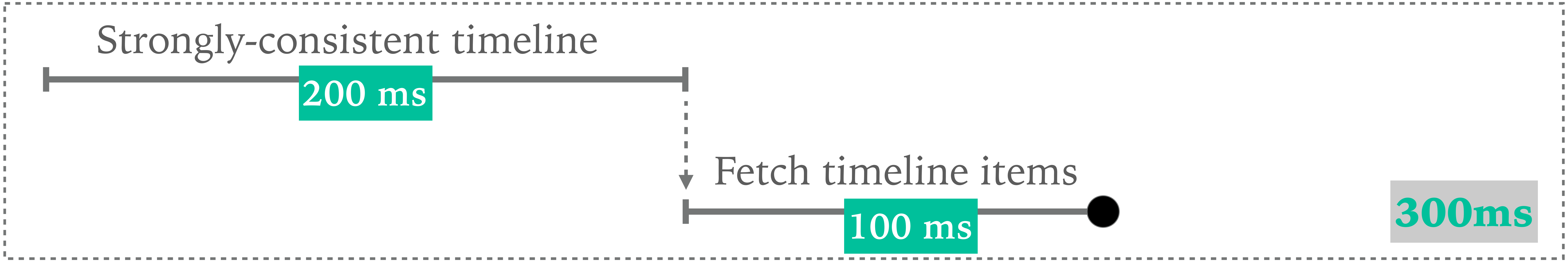
Traditional operation:



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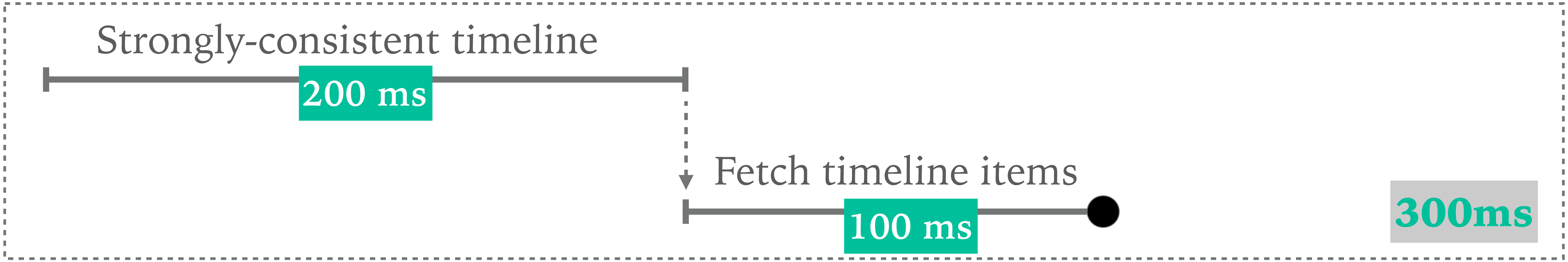
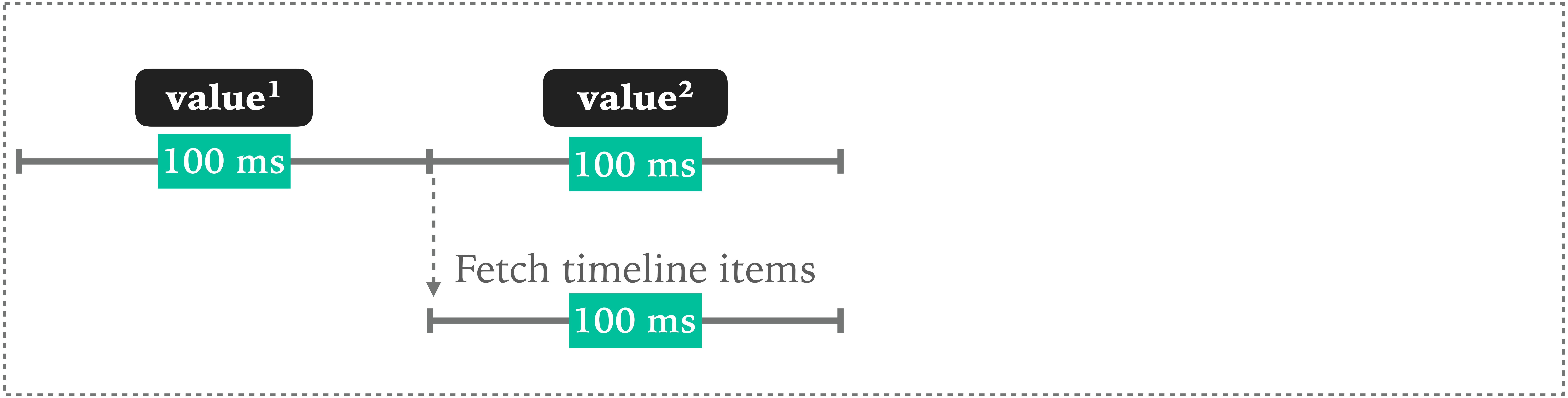


Speculative operation with ICG:



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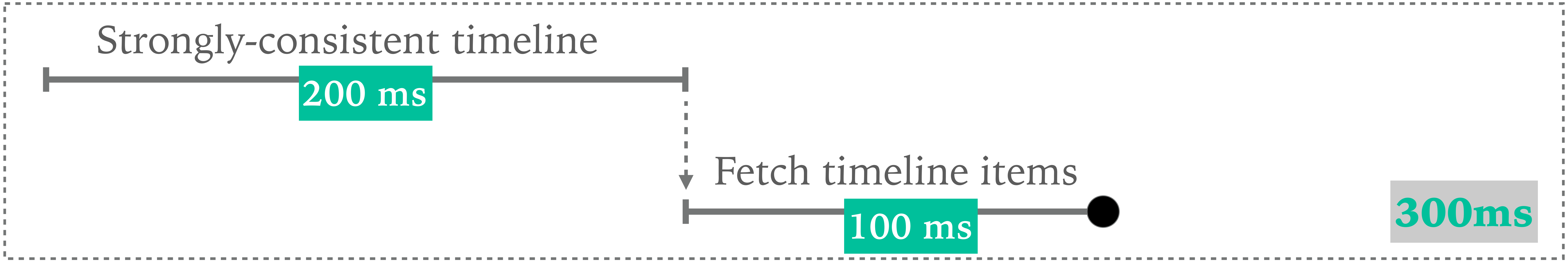


Strongly-consistent timeline

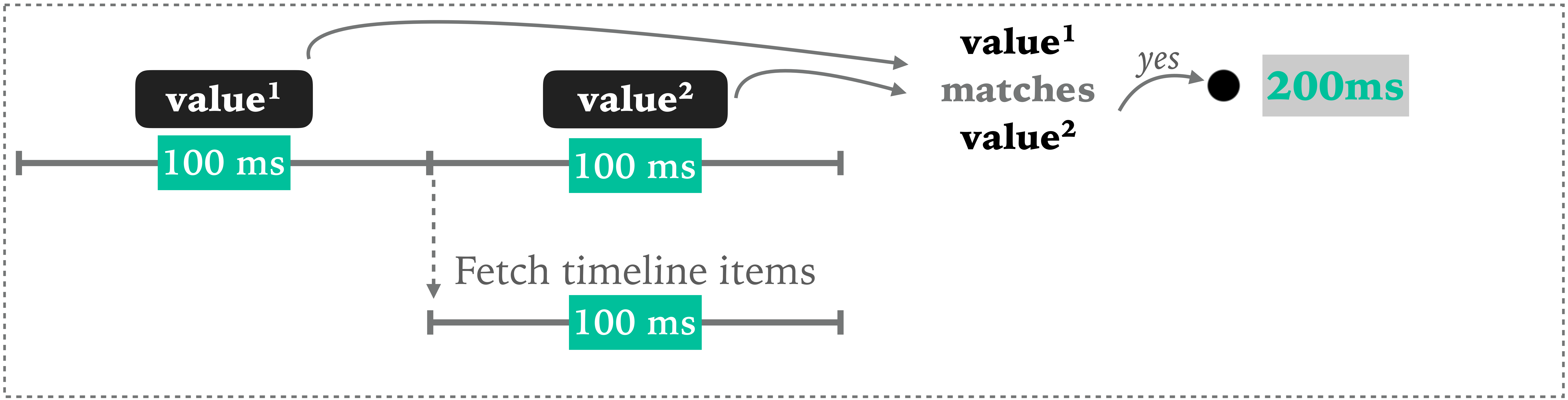
200 ms

Fetch timeline items

100 ms

300ms

Speculative operation with ICG:



value^{1}

100 ms

value^{2}

100 ms

Fetch timeline items

100 ms

value^{1}

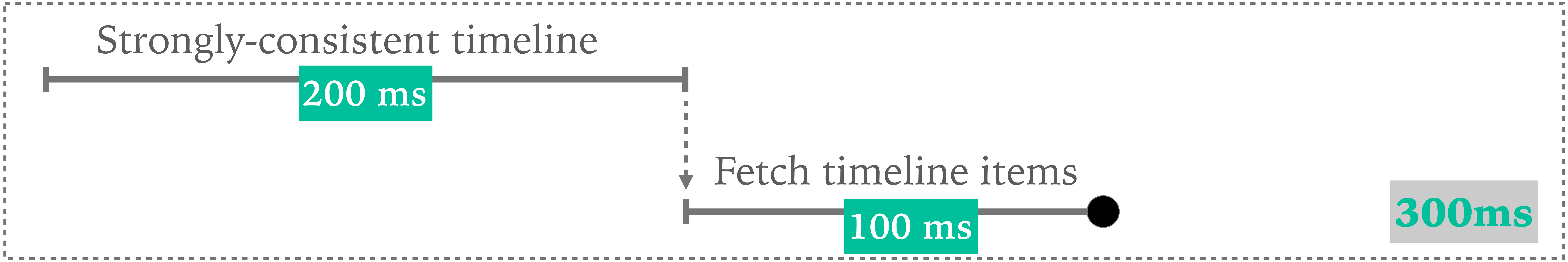
matches

value^{2}

yes

200ms

Traditional operation:



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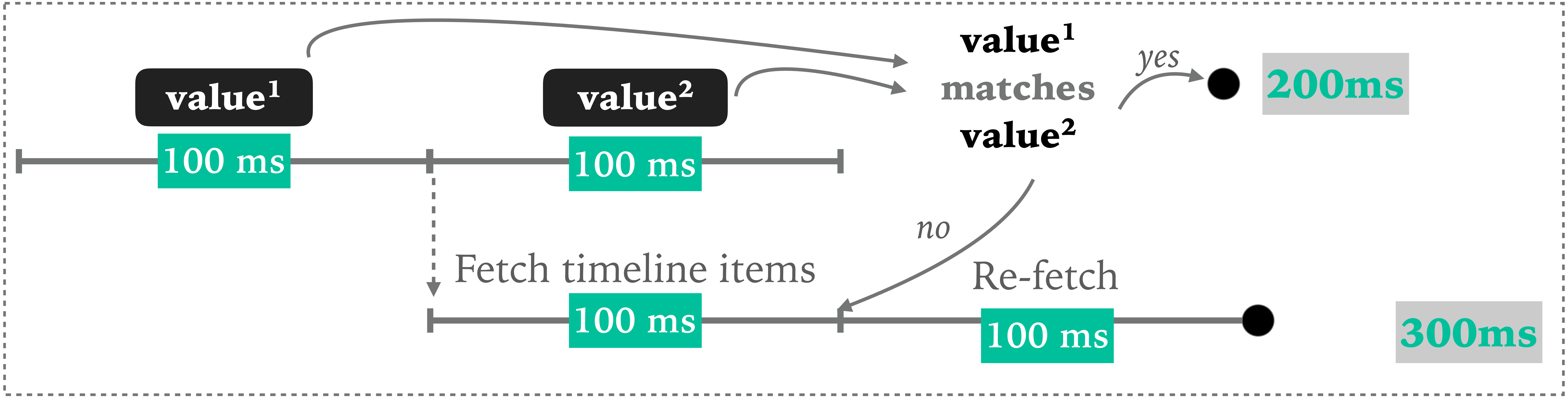


value^{1}

100 ms

value^{2}

100 ms

value^{1} matches value^{2}

yes

200ms

no

Fetch timeline items

100 ms

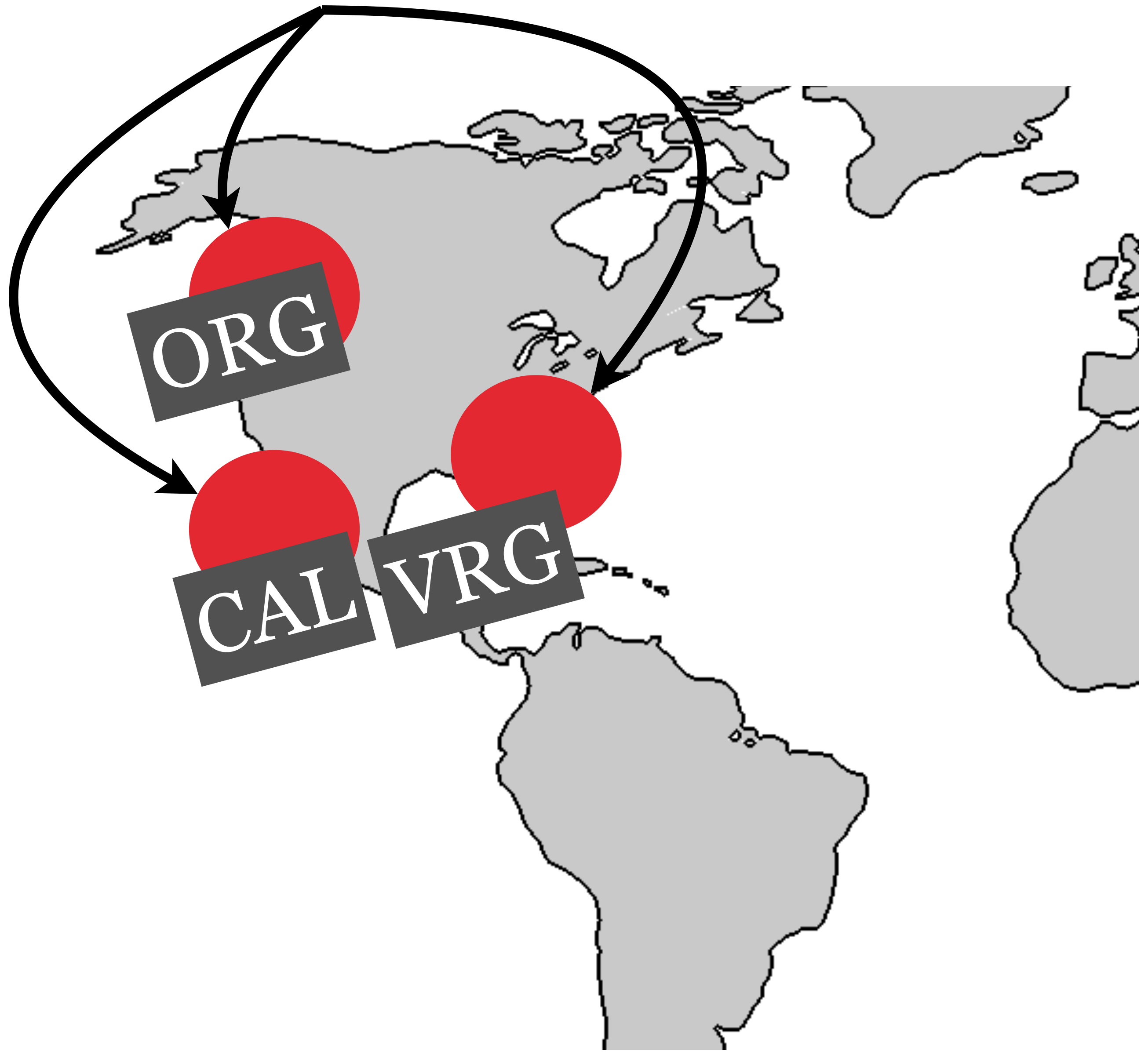
Re-fetch

100 ms

300ms

Speculation case-study

- Application: **Twissandra**
- Workload generated via YCSB
- Clients in Ireland
- Geo-replication on Amazon's EC2



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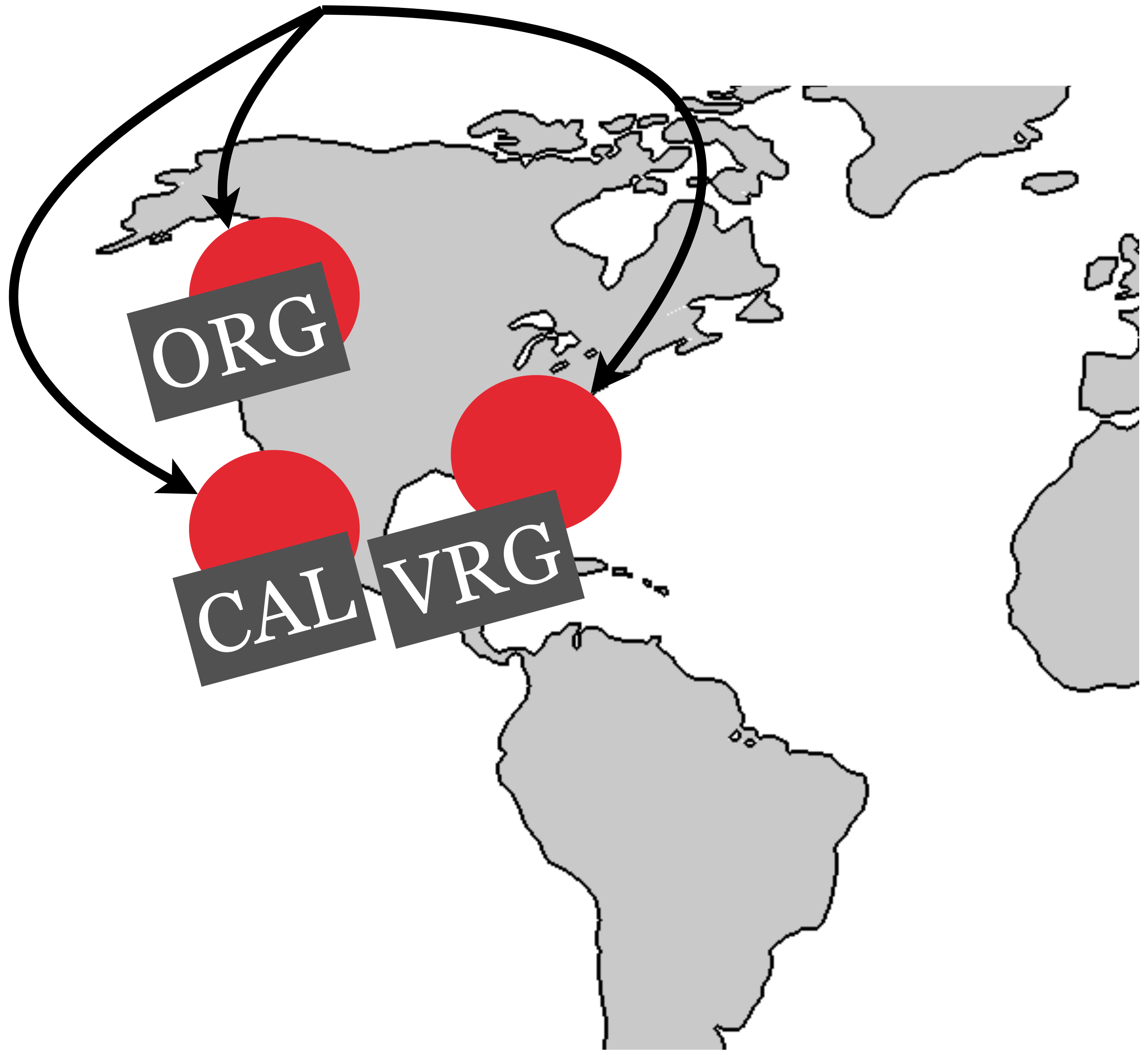

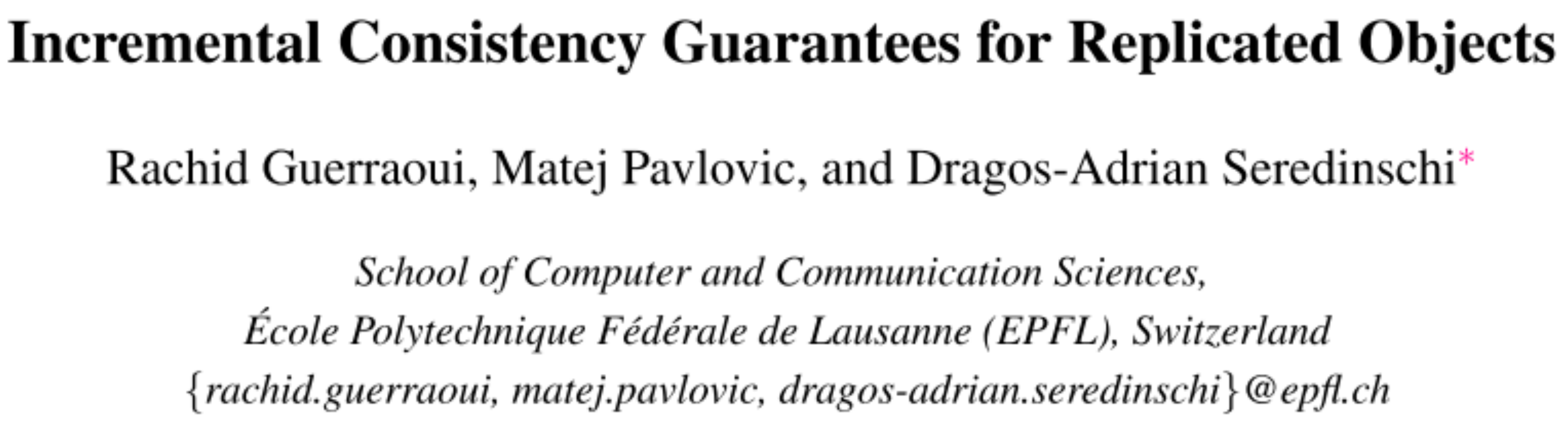

Incremental Consistency Guarantees for Replicated Objects

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École Polytechnique Fédérale de Lausanne (EPFL), Switzerland
{rachid.guerraoui, matej.pavlovic, dragos-adrian.seredinschi}@epfl.ch

check the paper

- ★ Advertising System
  — Speculation case-study
- ★ Ticket-selling System
  — Exploiting application semantics
- ★ Overheads evaluation
  & Optimizations
- ★ Latency gaps between consistency models

Decreasing latency of strong consistency

What is the
latency of the **fetch_timeline()** operation?

Decreasing latency of strong consistency

What is the
latency of the **fetch_timeline()** operation?

Baseline

Read using a quorum of 2/3 replicas

vs.

ICG

1. *Weak:* Read with 1/3 replicas
2. *"Strong:"* Read with quorum of 2/3 replicas

Decreasing latency of strong consistency

What is the
latency of the **fetch_timeline()** operation?

Workload A (50:50 read/write) **Workload B (95:5 read/write)** **Workload C (read-only)**

Baseline

Read using a quorum of 2/3 replicas

vs.

ICG

1. *Weak:* Read with 1/3 replicas
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Decreasing latency of strong consistency

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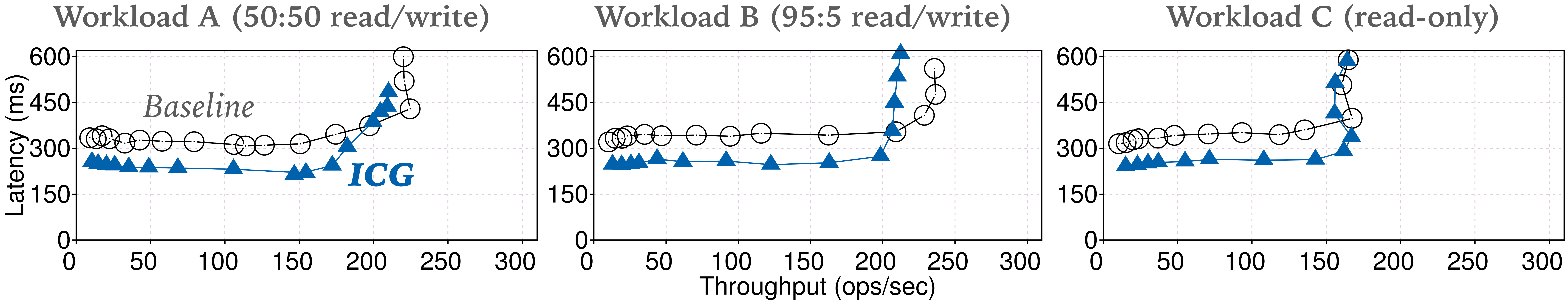

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Read using a quorum of 2/3 replicas

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1. *Weak:* Read with 1/3 replicas
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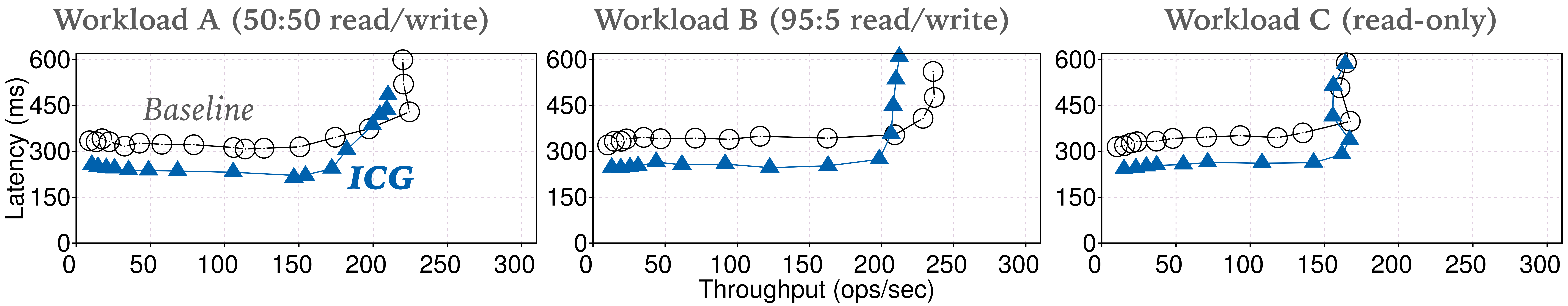
Decreasing latency of strong consistency

What is the
latency of the **fetch_timeline()** operation?

- ★ ***Latency decrease by 40%***
- ★ *Throughput drop by 6%*
- ★ *Same consistency model (2/3 replicas)*



Baseline

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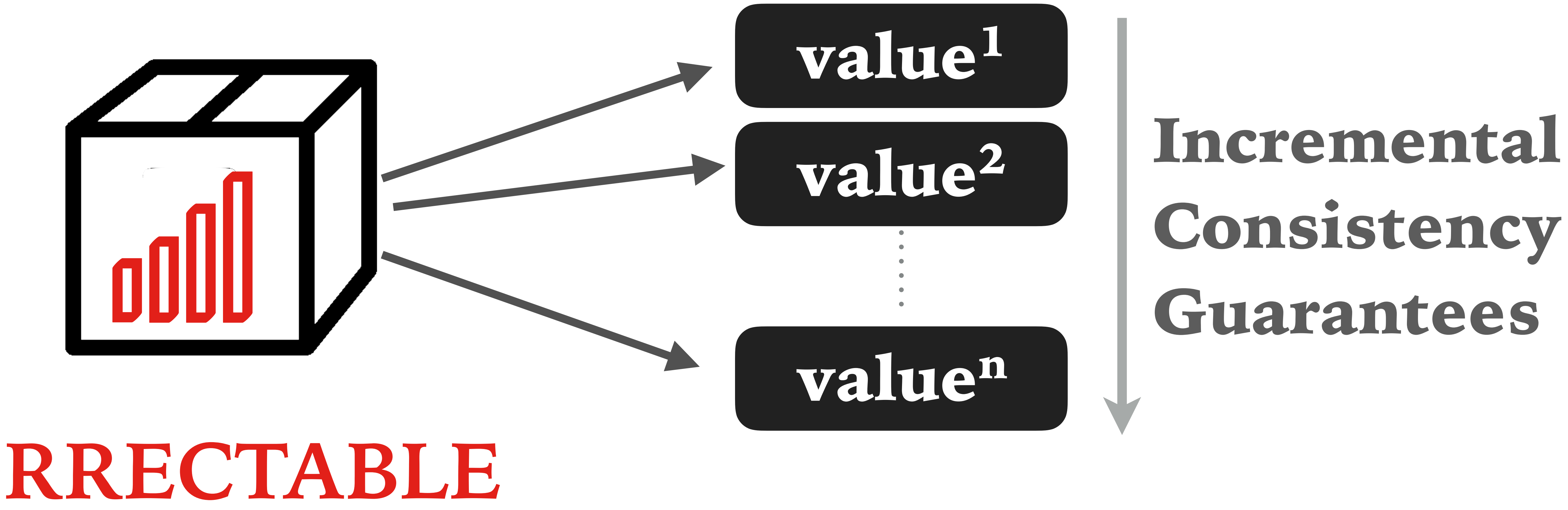
Conclusion

The Correctables abstraction enables you to:

1. **Leverage consistency models incrementally**
2. **Lower latency of strong consistency**



CORRECTABLE

value^1

value^2

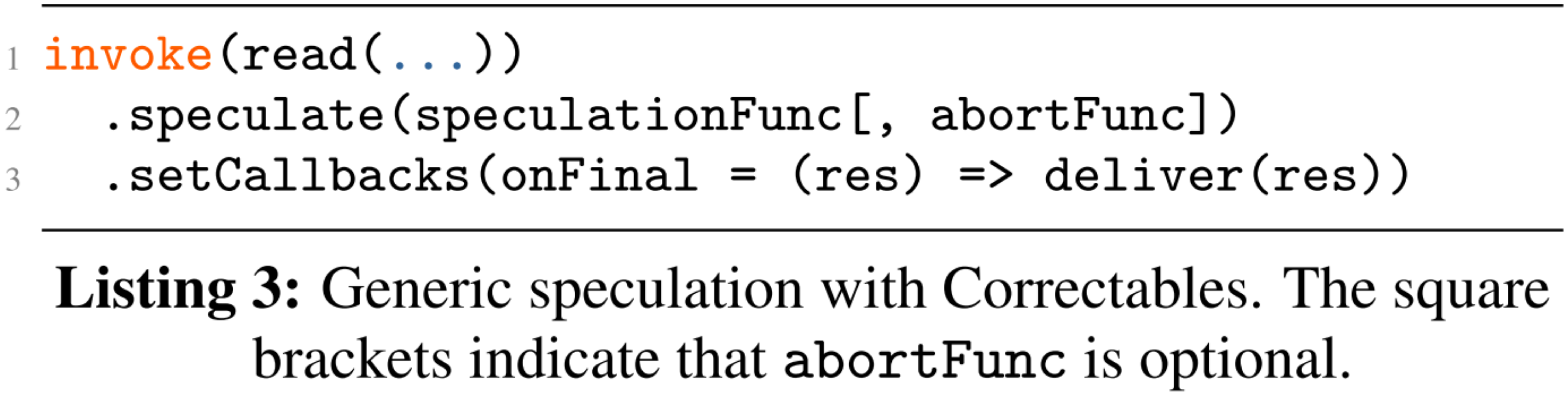
value^n

Incremental Consistency Guarantees

@adizere

backup slides

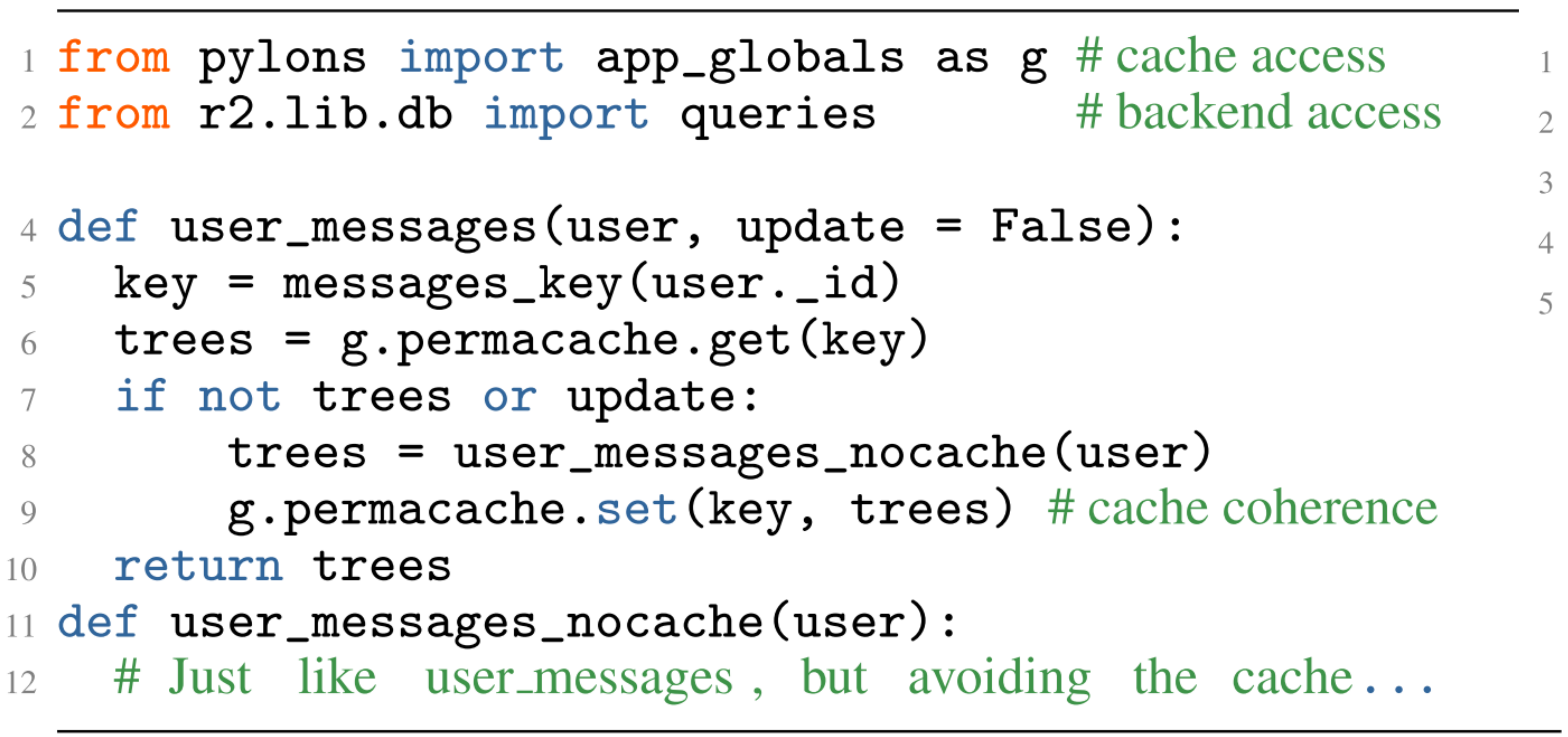
Speculation // Syntactic sugar



```
invoke(read(...))
  .speculate(speculationFunc[, abortFunc])
  .setCallbacks(onFinal = (res) => deliver(res))
```

Listing 3: Generic speculation with Correctables. The square brackets indicate that `abortFunc` is optional.

Legacy code vs. Correctables



```
from pylons import app_globals as g # cache access
from r2.lib.db import queries       # backend access

def user_messages(user, update = False):
  key = messages_key(user._id)
  trees = g.permacache.get(key)
  if not trees or update:
      trees = user_messages_nocache(user)
      g.permacache.set(key, trees) # cache coherence
  return trees
def user_messages_nocache(user):
  # Just like user_messages , but avoiding the cache...
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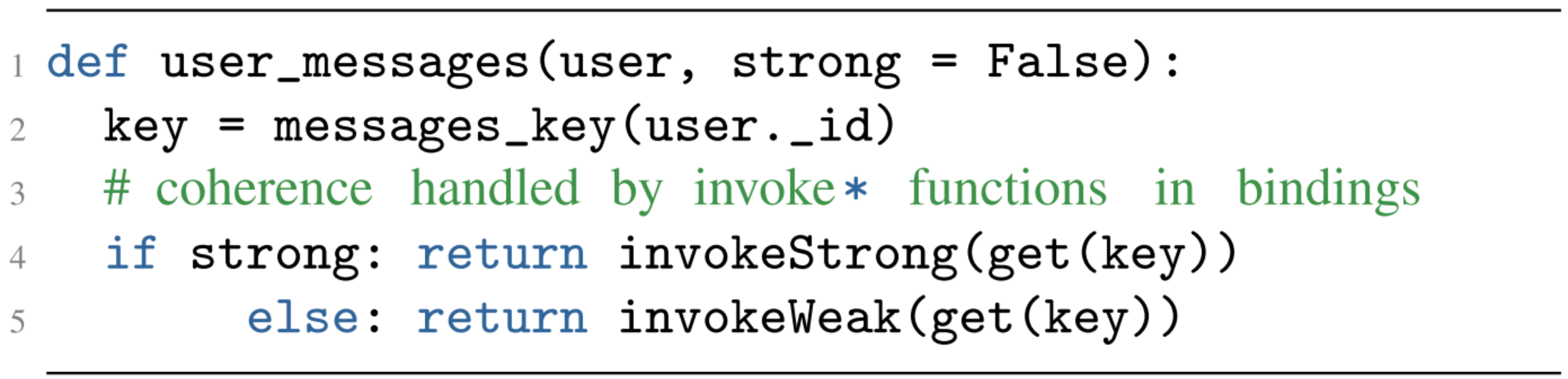
Listing 1: Different consistency guarantees in Reddit [13], as an example of tight coupling between applications and storage. Developers must manually handle the cache and the backend.



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def user_messages(user, strong = False):
  key = messages_key(user._id)
  # coherence handled by invoke* functions in bindings
  if strong: return invokeStrong(get(key))
         else: return invokeWeak(get(key))
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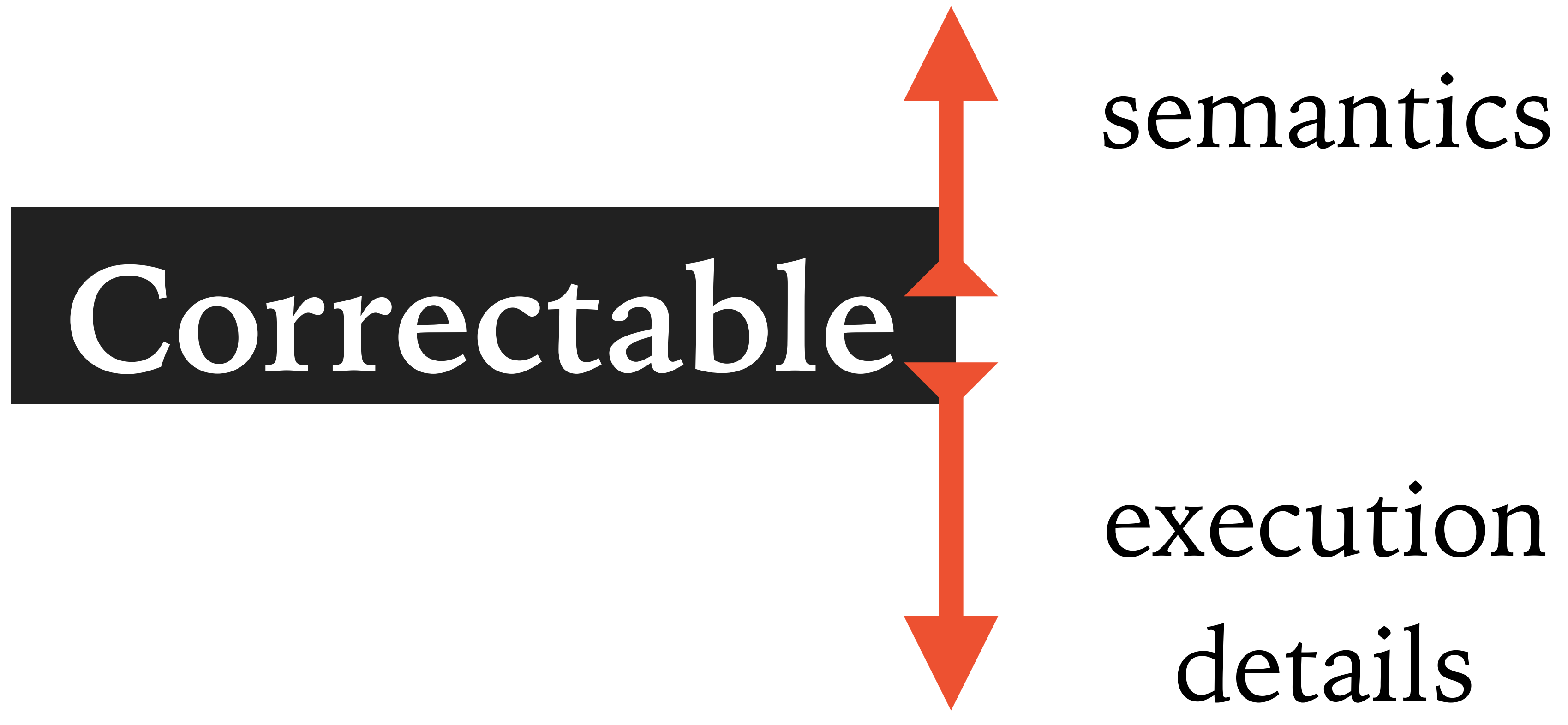
Listing 2: Reddit code rewritten using Correctables.



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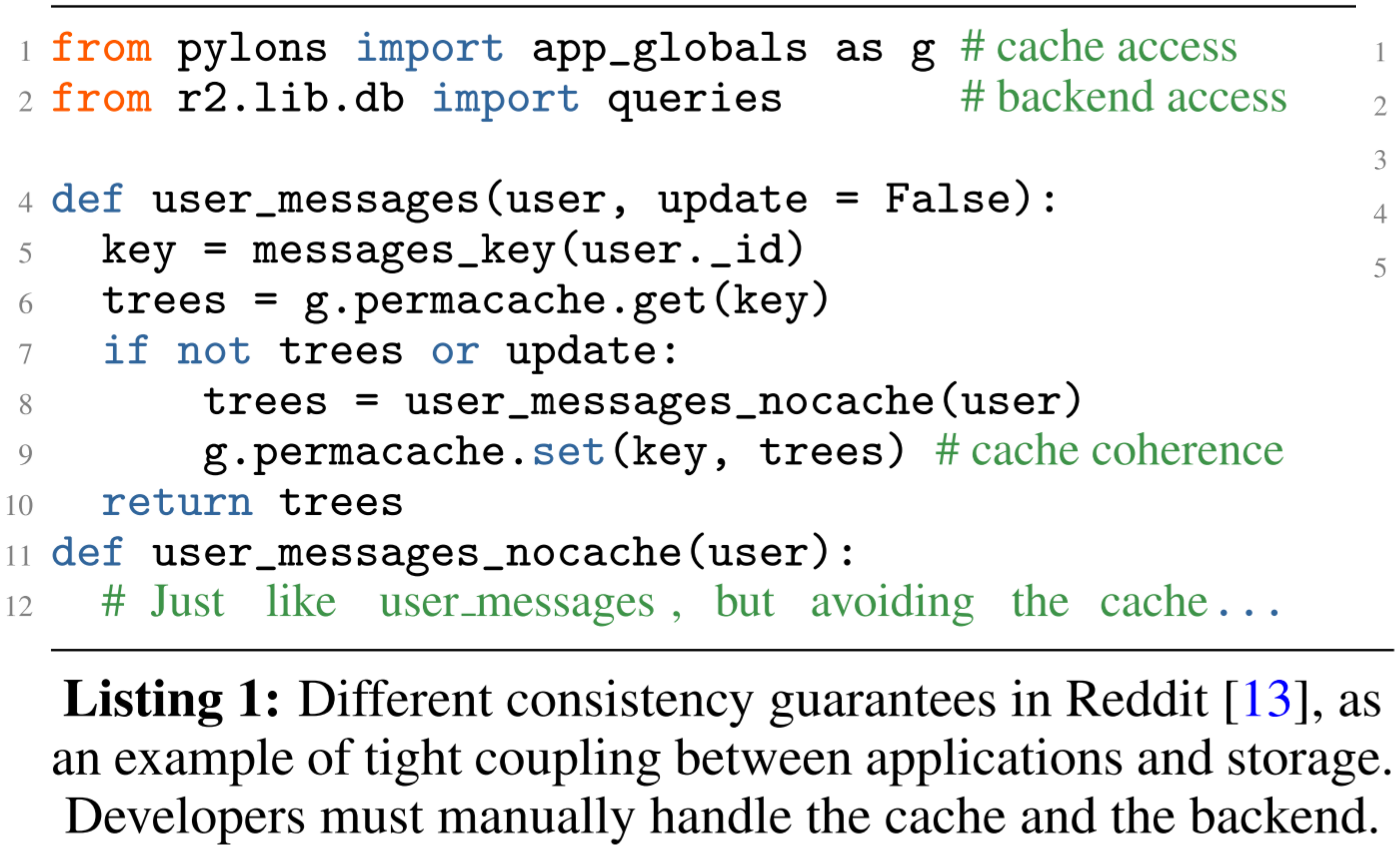

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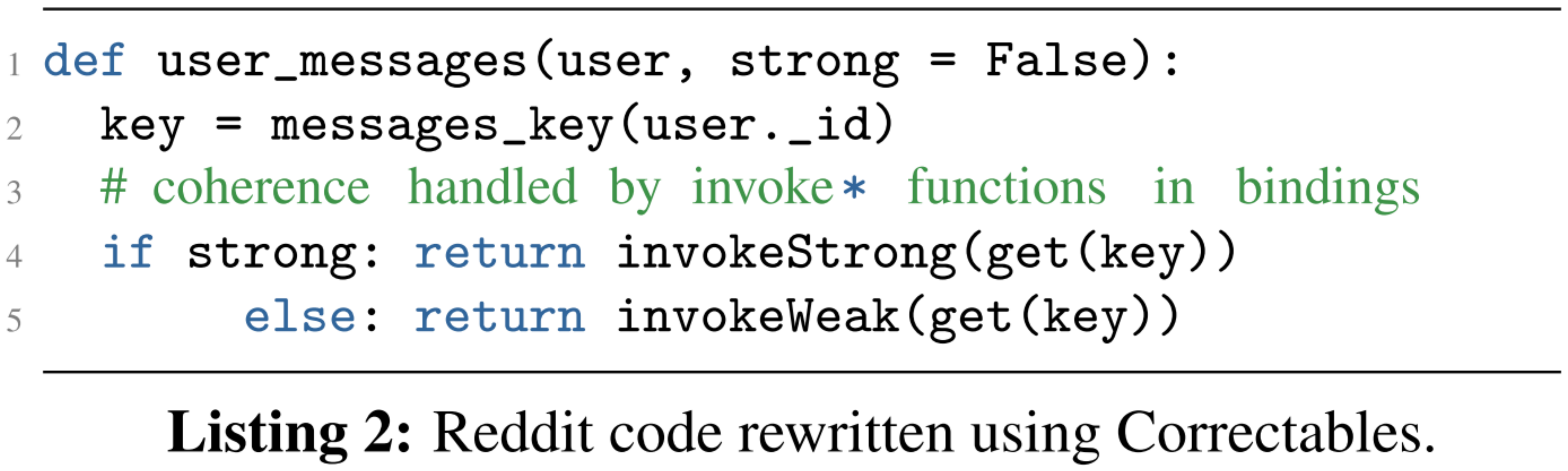

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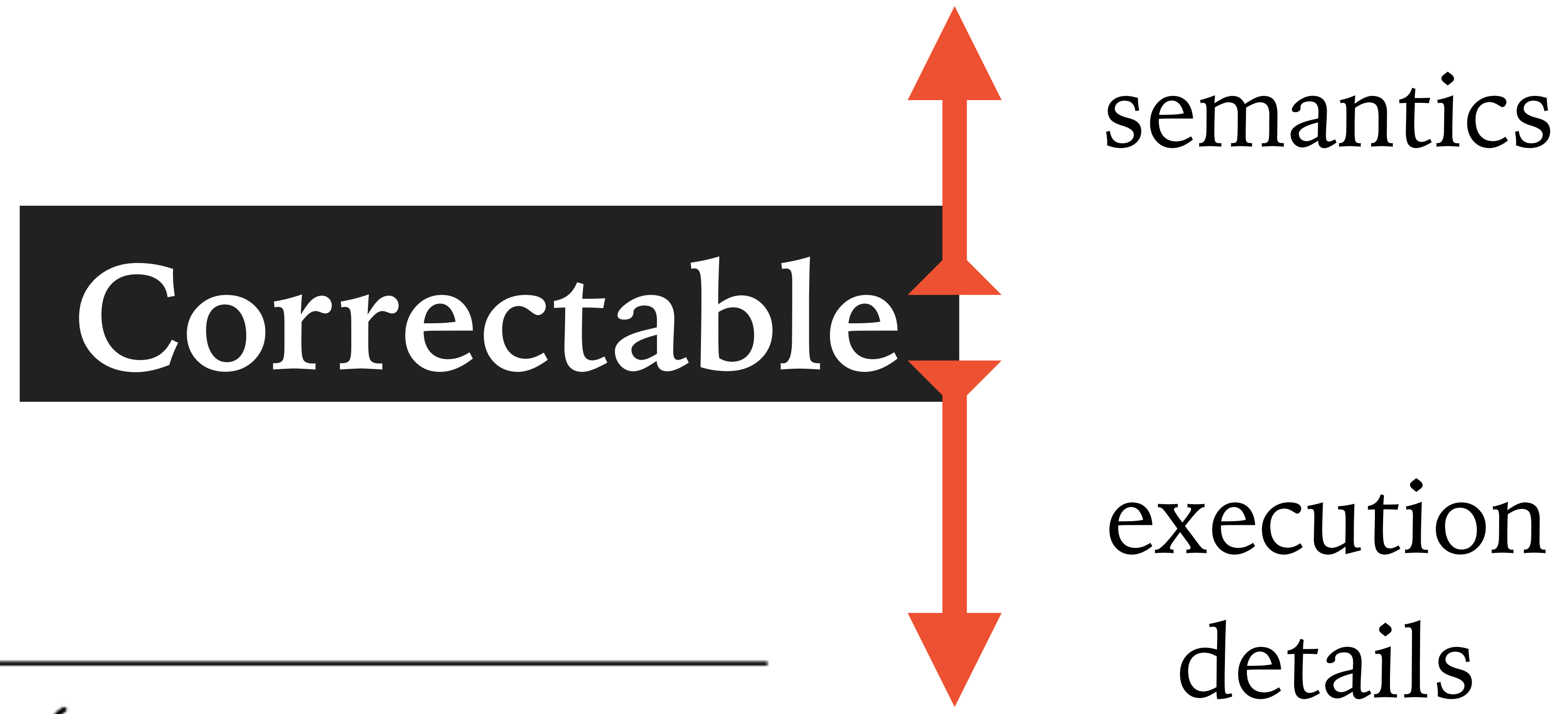
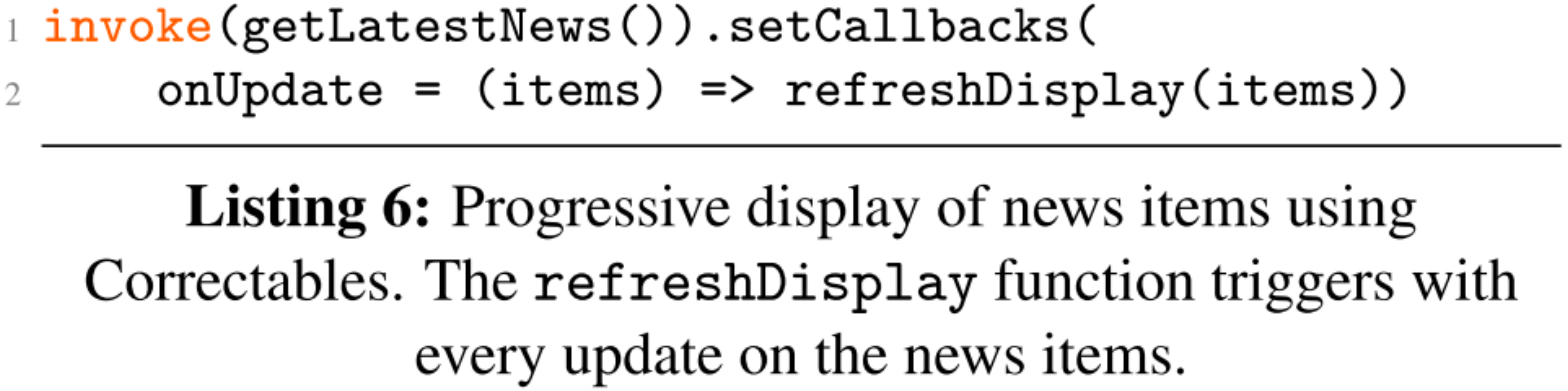


Correctable

semantics

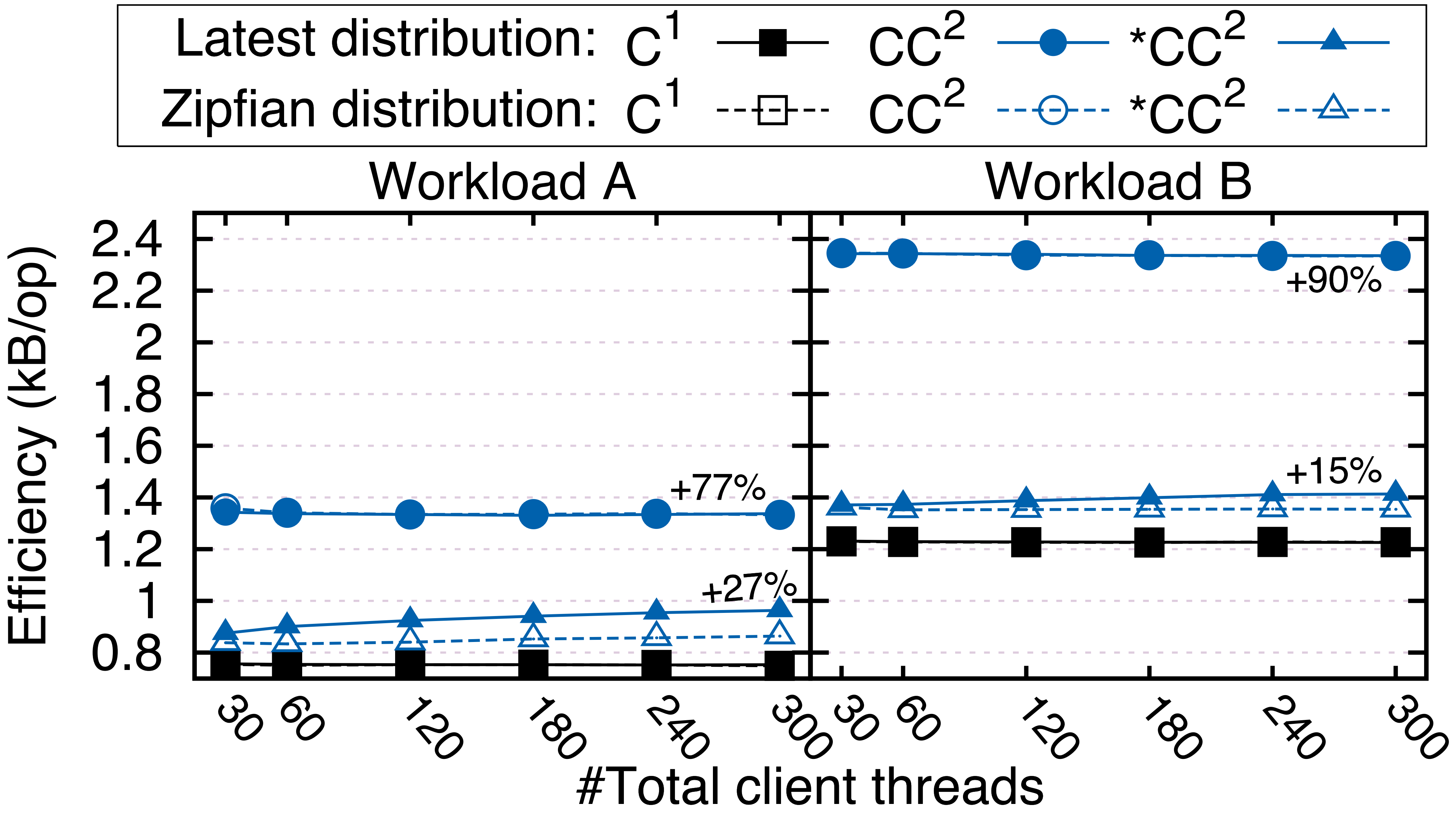
execution details



```
invoke(getLatestNews()).setCallbacks(
    onUpdate = (items) => refreshDisplay(items))
```

Listing 6: Progressive display of news items using Correctables. The `refreshDisplay` function triggers with every update on the news items.

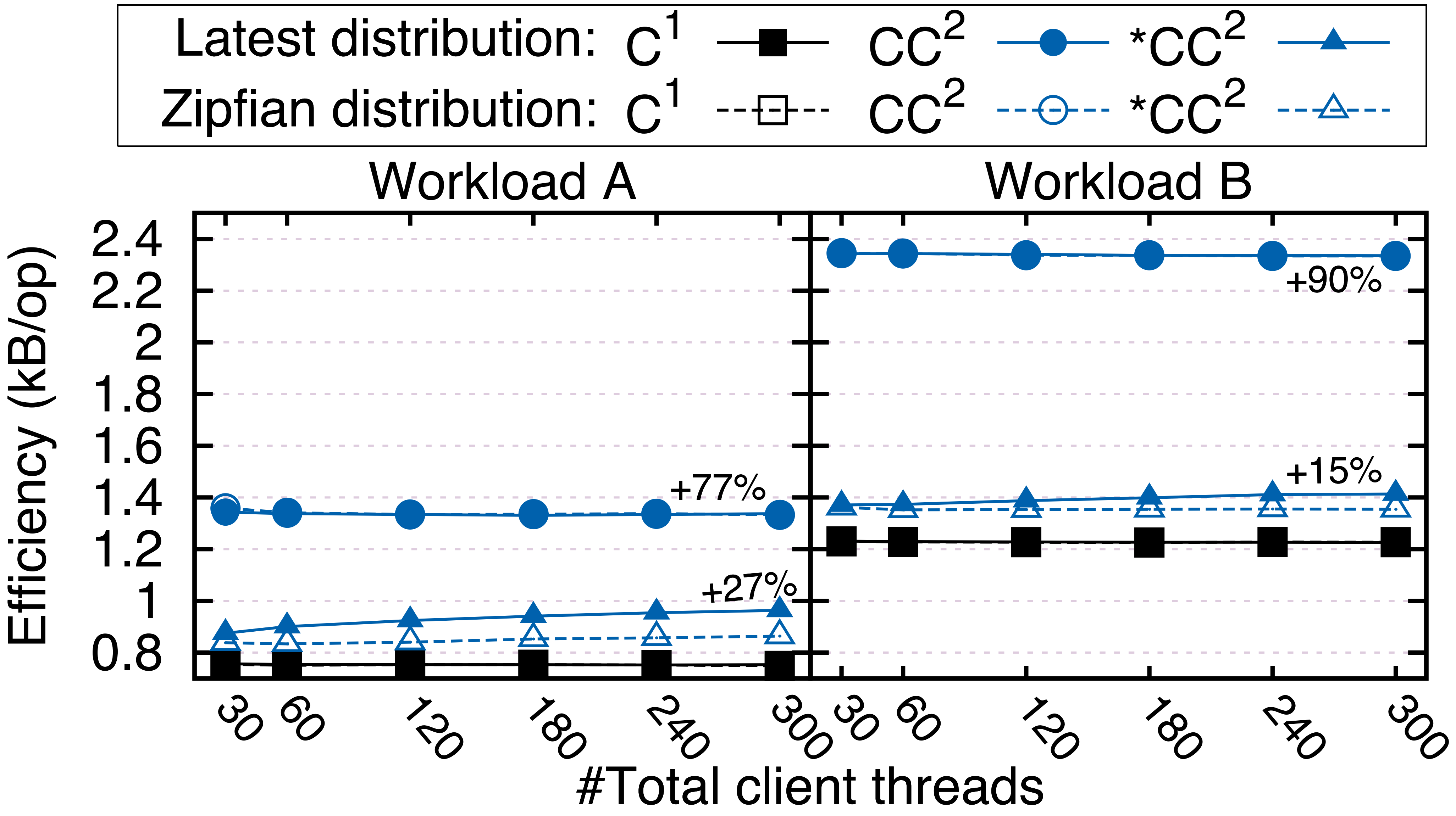
Overheads



- ➤ Cassandra
- ➤ YCSB workload, various configurations
- ➤ Client in Ireland
- ➤ Replicas in Virginia, Frankfurt, and Ireland

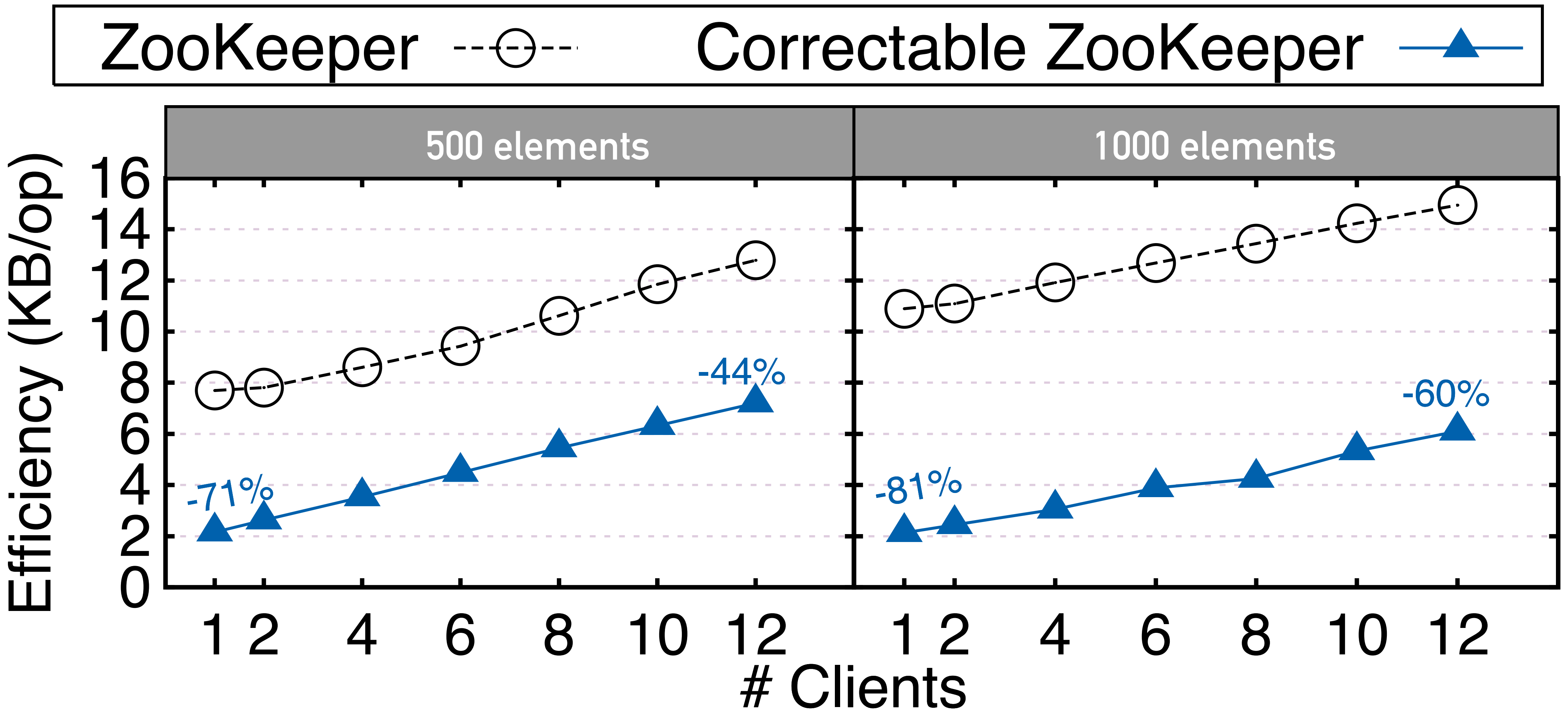
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Overheads



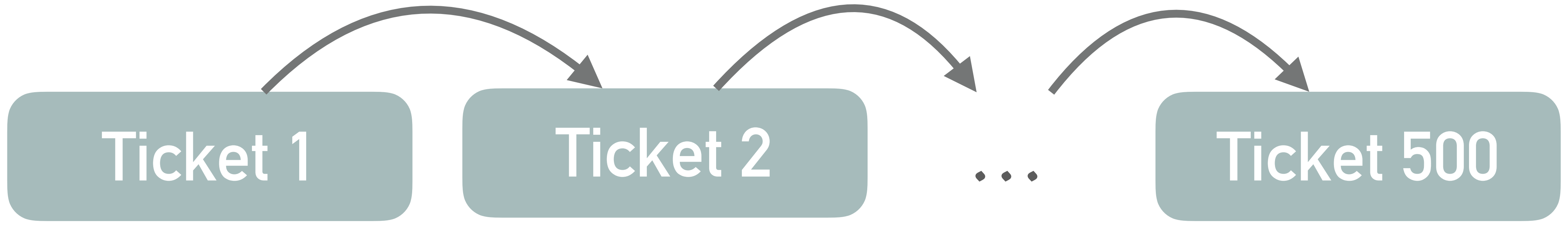
- ➤ Cassandra
- ➤ YCSB workload, various configurations
- ➤ Client in Ireland
- ➤ Replicas in Virginia, Frankfurt, and Ireland

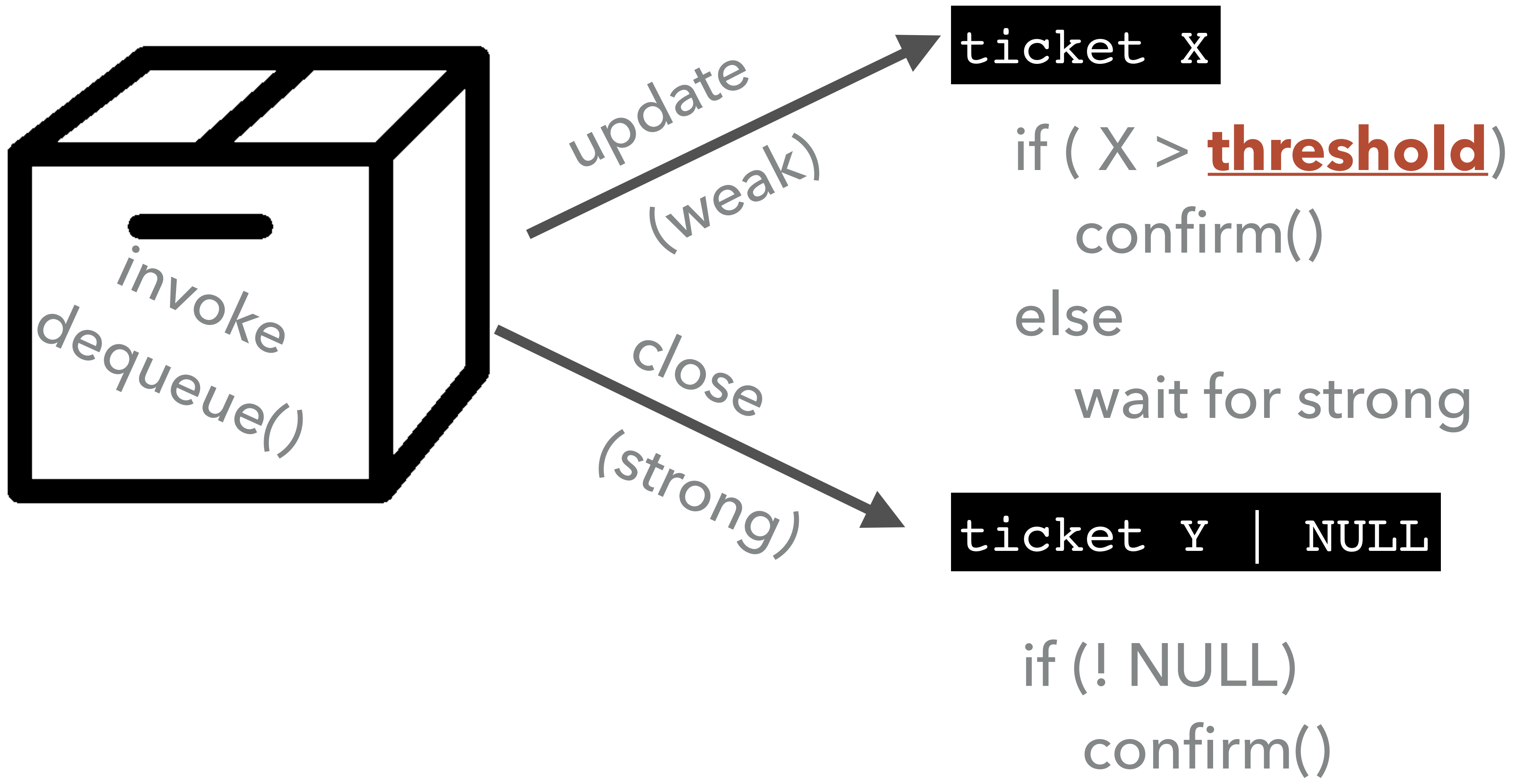
- ➤ ZooKeeper queue implementation
- ➤ Wasteful implementation (by default)
- ➤ We were able to improve — negative overhead



Exploiting application semantics

- Ticket selling application
  - Implemented through a ZooKeeper queue
  - Buy ticket = dequeue operation



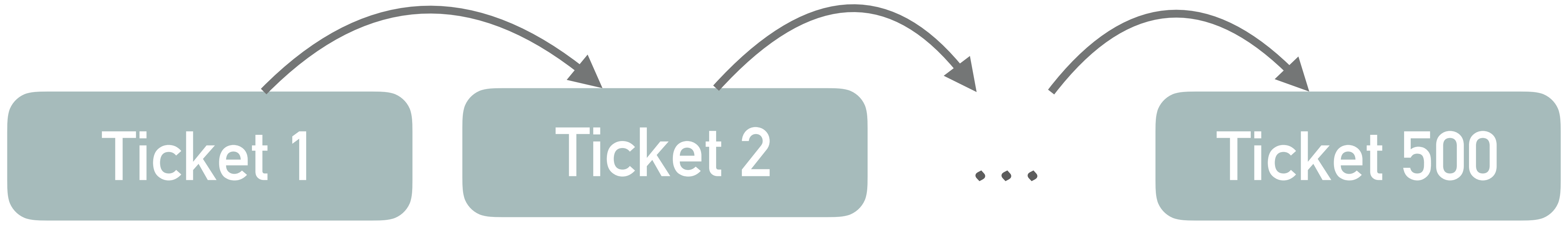


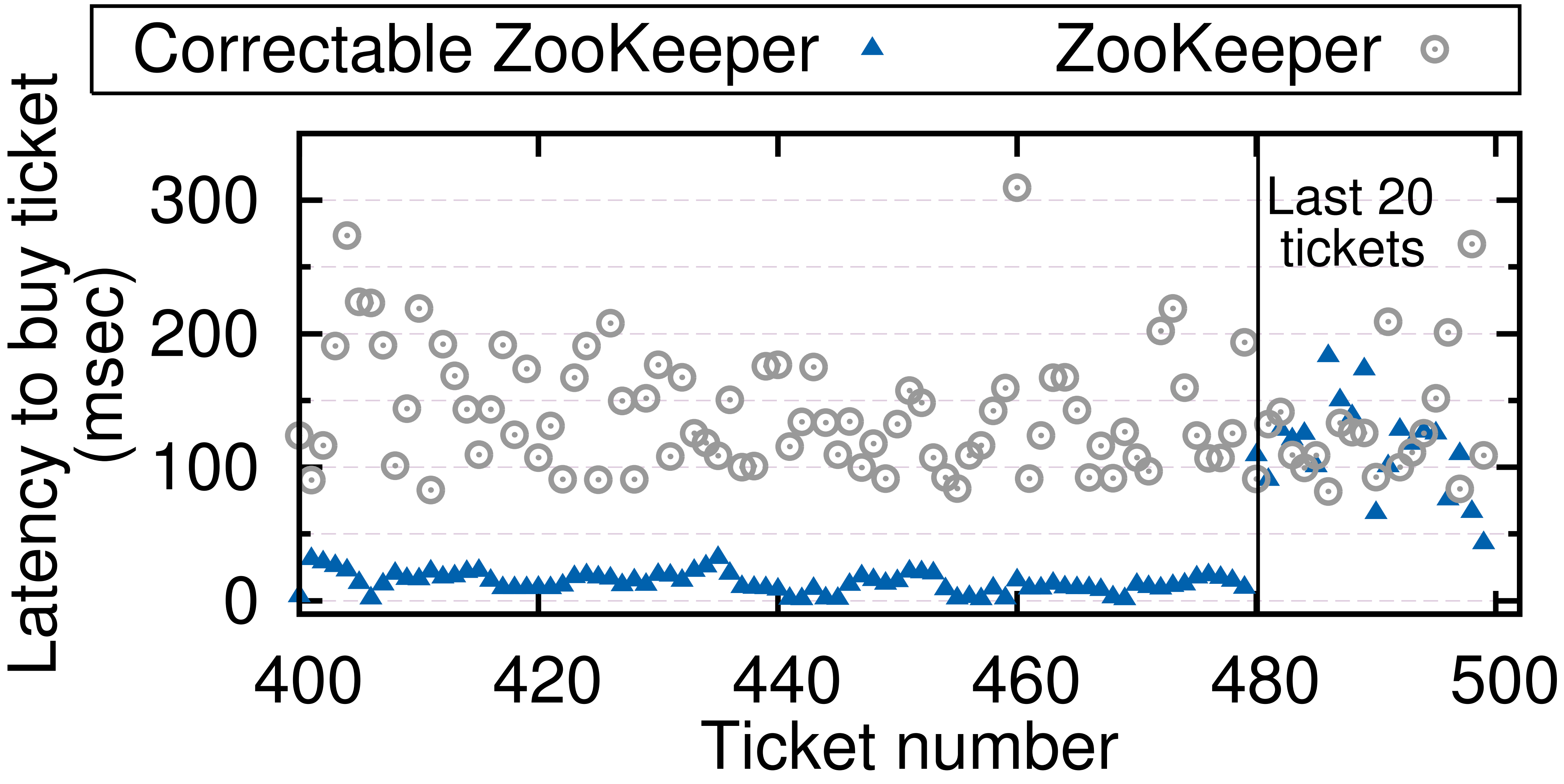
```
if ( X > threshold)
    confirm()
else
    wait for strong
```

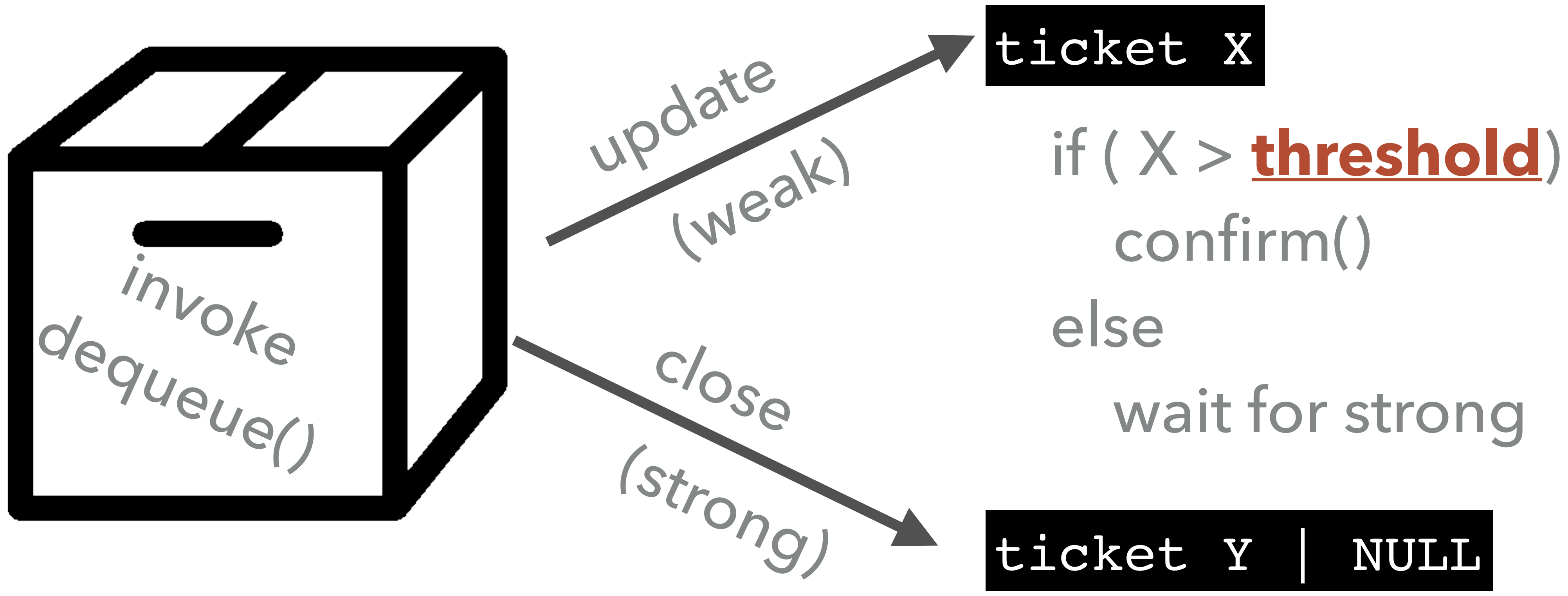
```
if (! NULL)
    confirm()
```

Exploiting application semantics

- Ticket selling application
  - Implemented through a ZooKeeper queue
  - Buy ticket = dequeue operation







```
if ( X > threshold)
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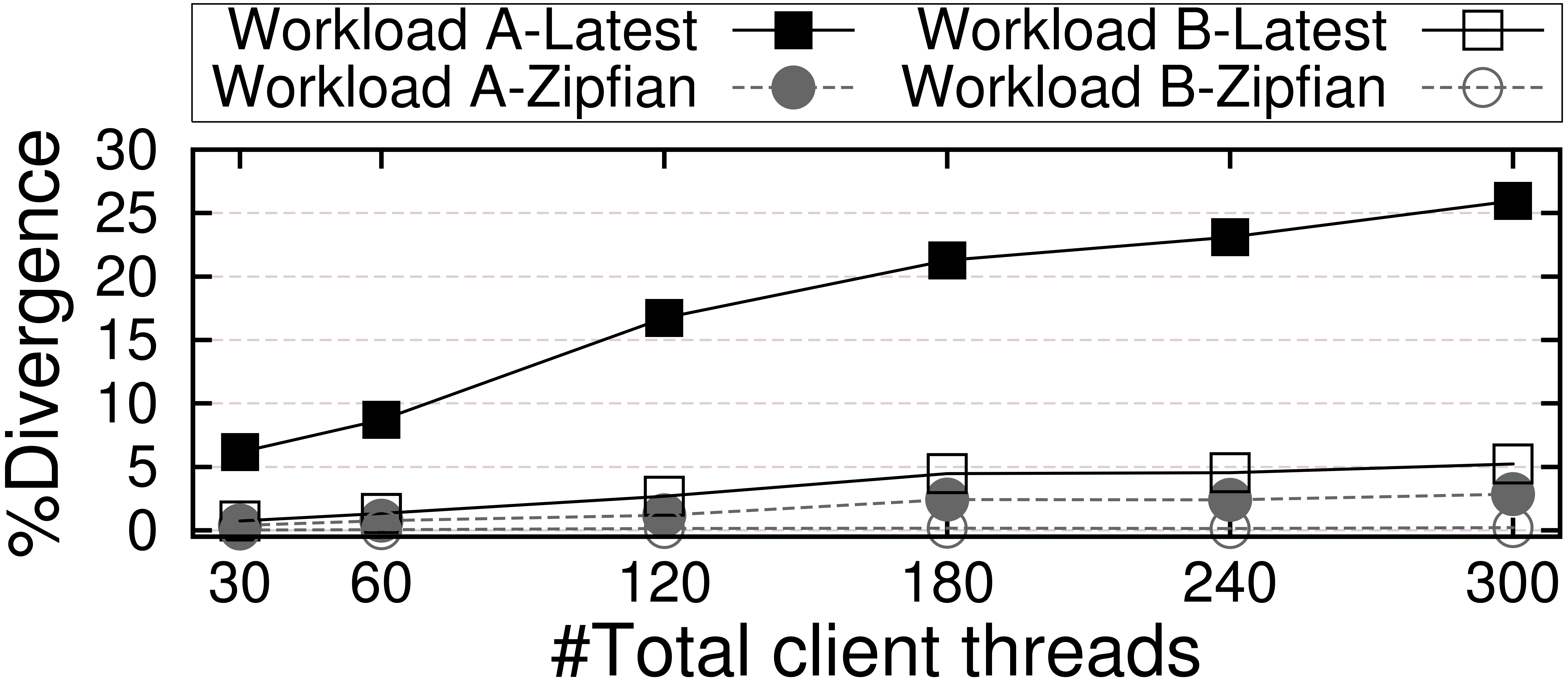
```

Divergence between weak and strong consistency

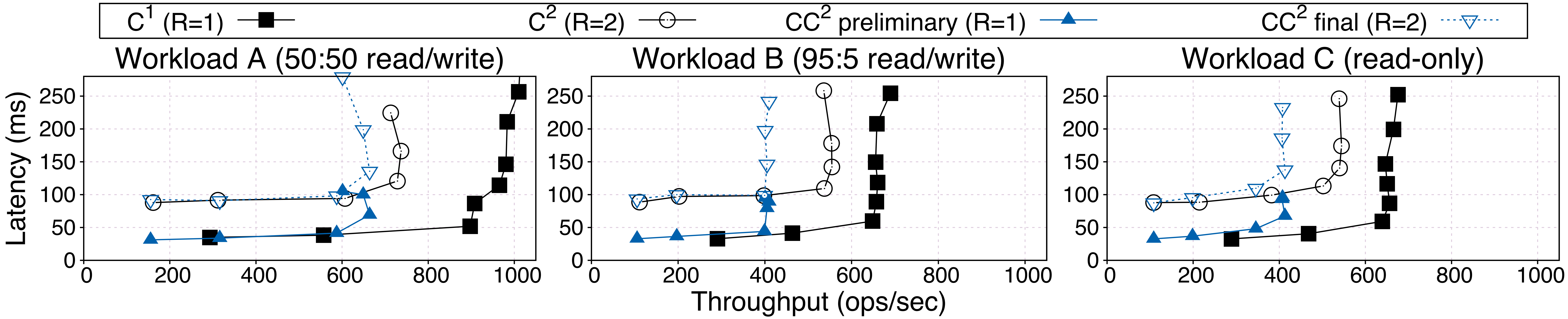


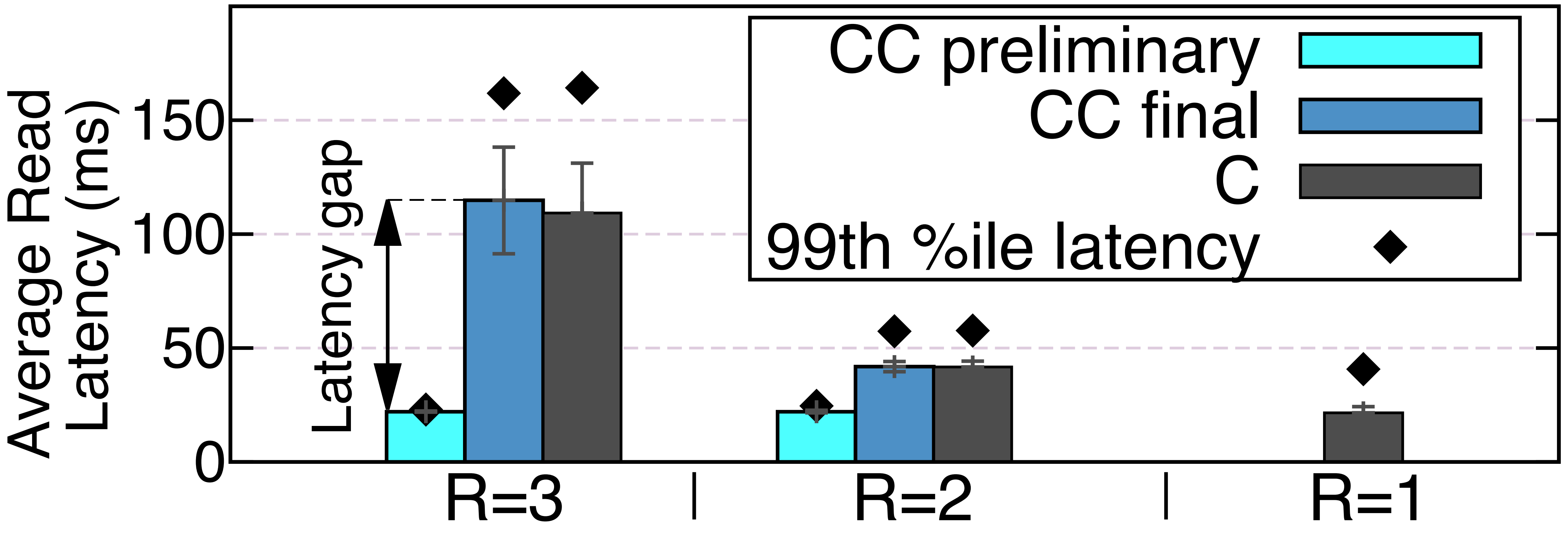
➤ Extremely high

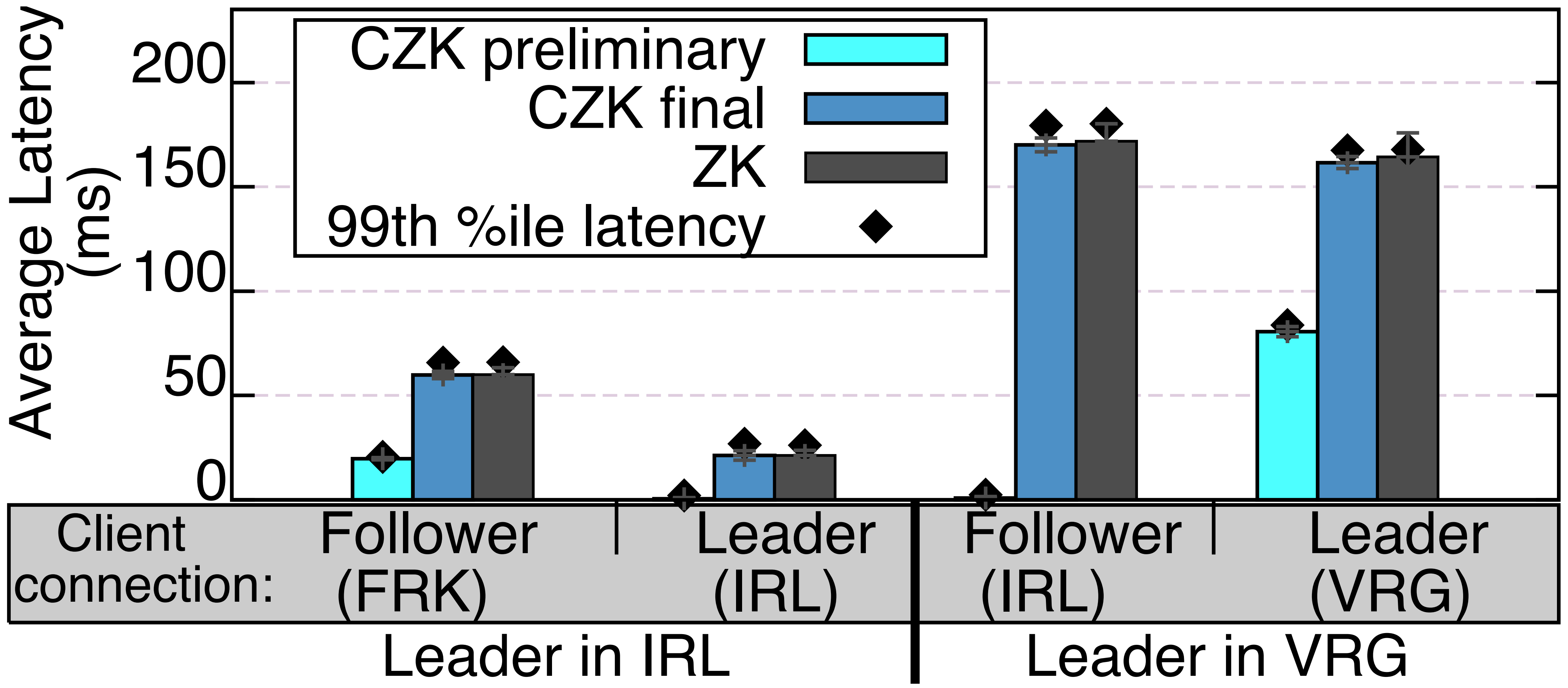
➤ Unusual

} 0.1% — 5% typical range

Latency gaps between consistency models







Efficiency of Multiple Responses

SOCIAL MEDIA APPLICATION

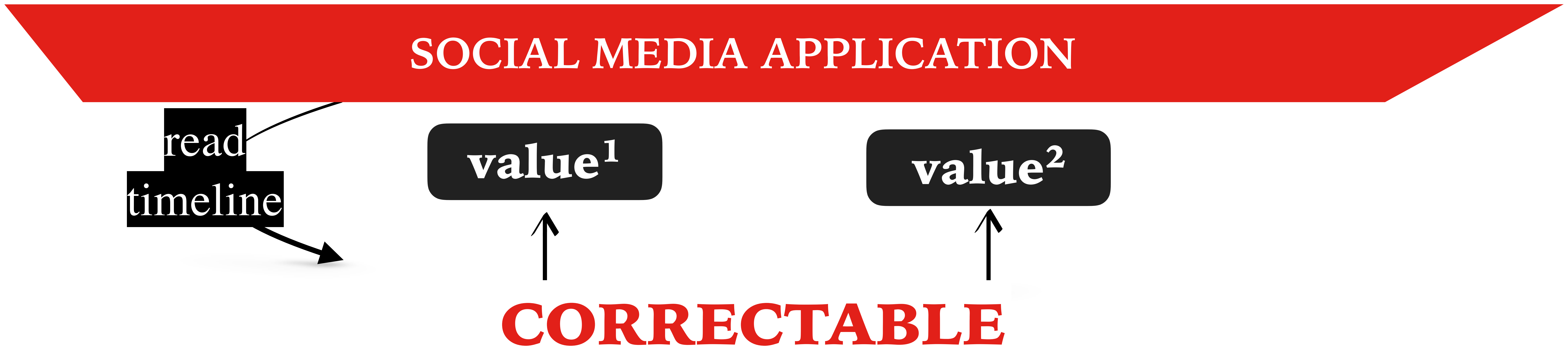
read timeline

value^1

value^2

CORRECTABLE

Efficiency of Multiple Responses



SOCIAL MEDIA APPLICATION

read timeline

value^1

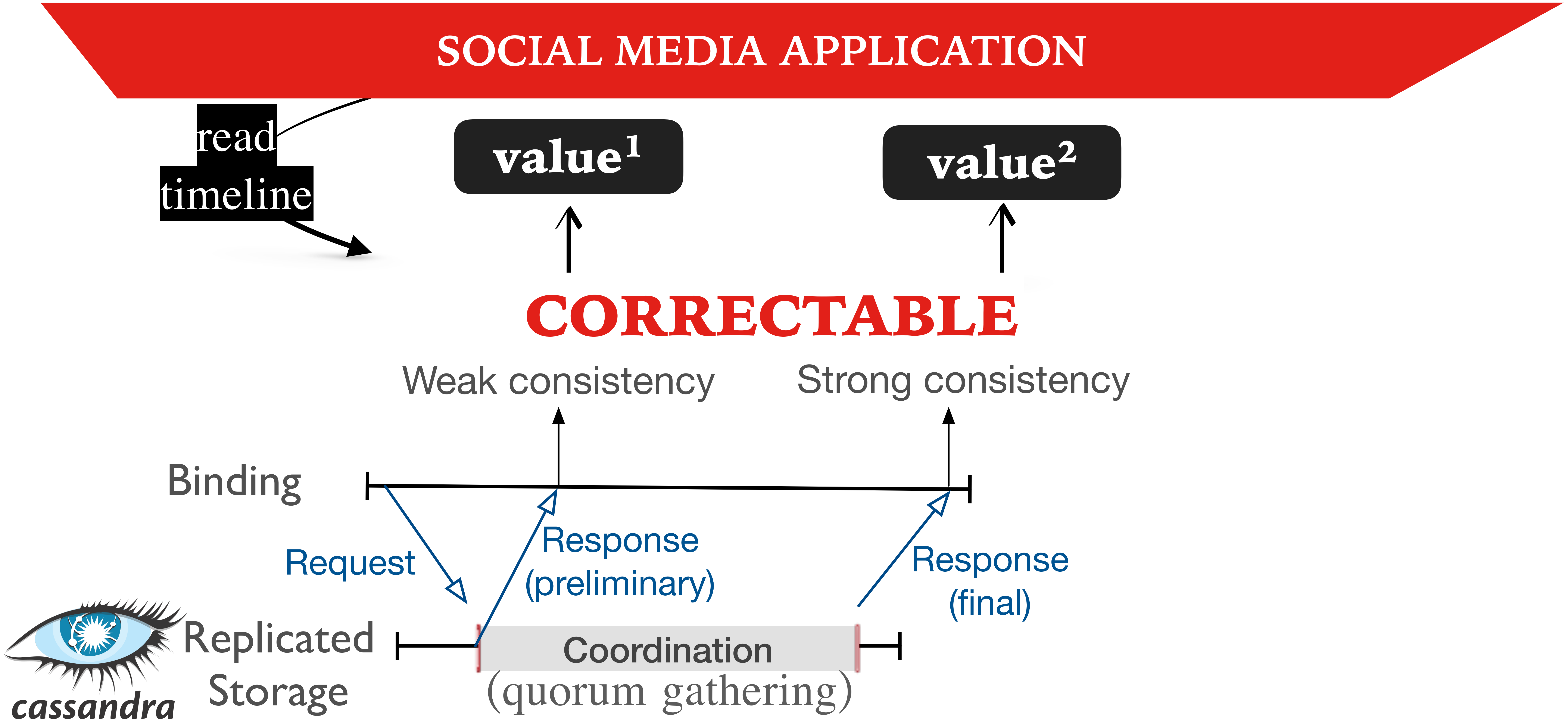
value^2

CORRECTABLE

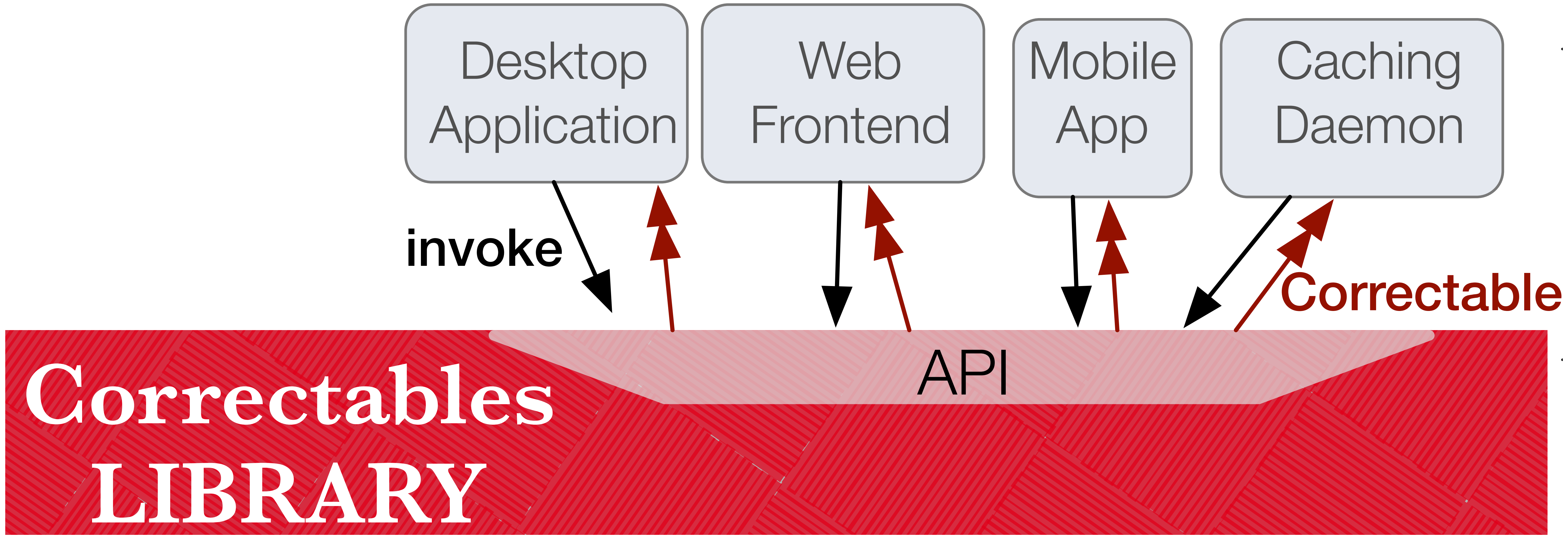
Binding

Replicated Storage

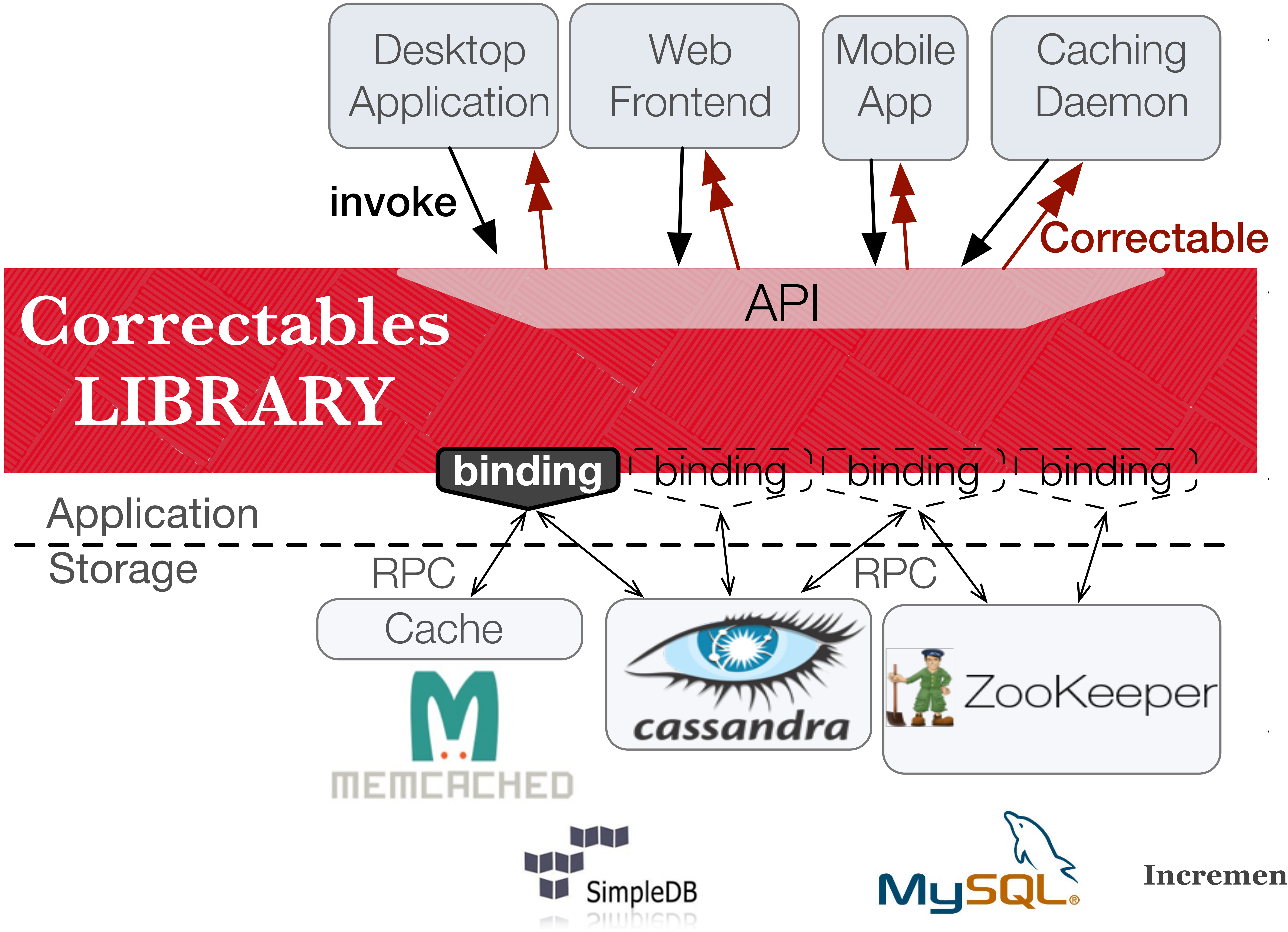
Efficiency of Multiple Responses



Correctables / **Library**

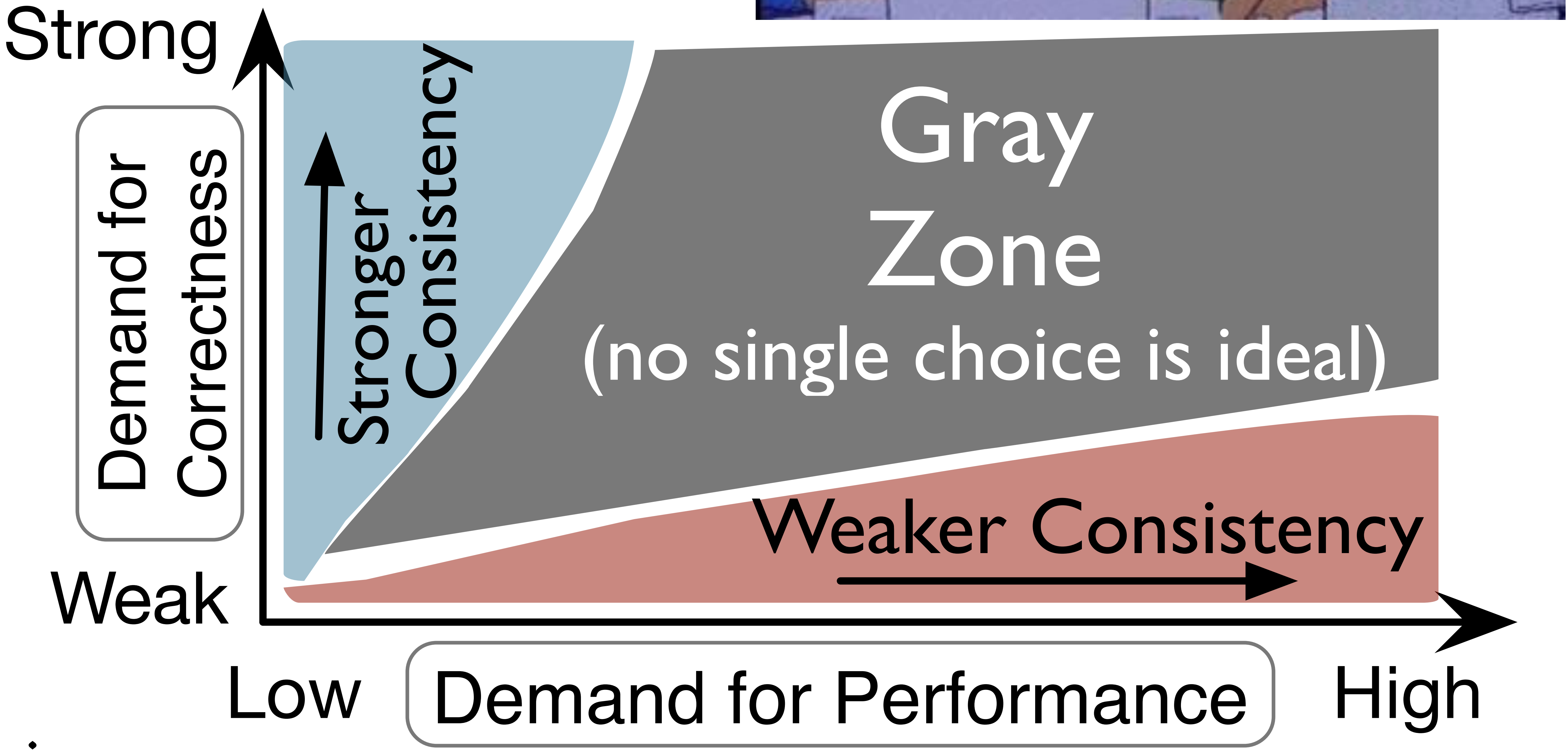


Correctables / **Library**



- Infrastructure services
- Stock tickers
- Trading applications

- E-mail
- Calendar
- Social networks
- Online shopping
- Ad serving
- News reading
- Collaborative editing



Strong

Weak

Demand for Correctness

Stronger Consistency

Gray Zone

(no single choice is ideal)

Weaker Consistency

Low

Demand for Performance

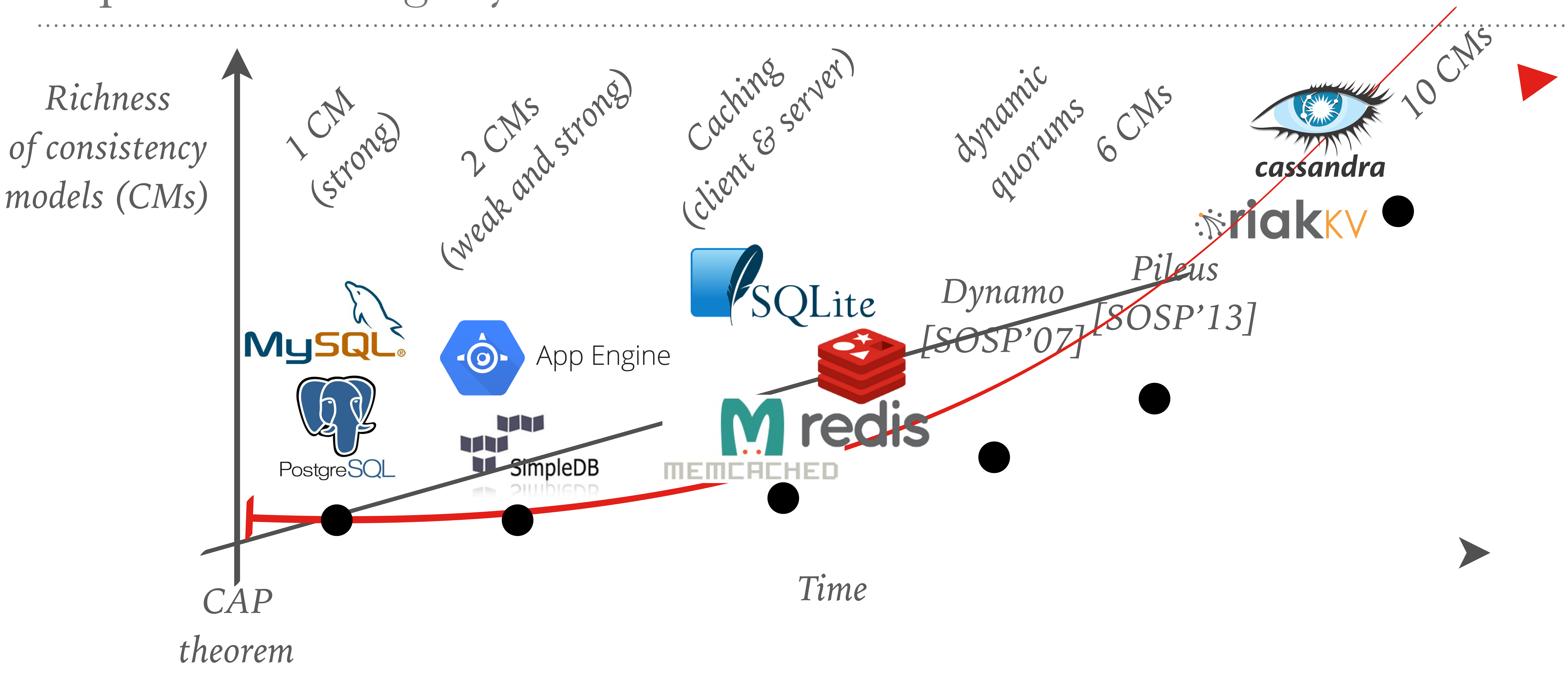
High

Performance is a second-order concern

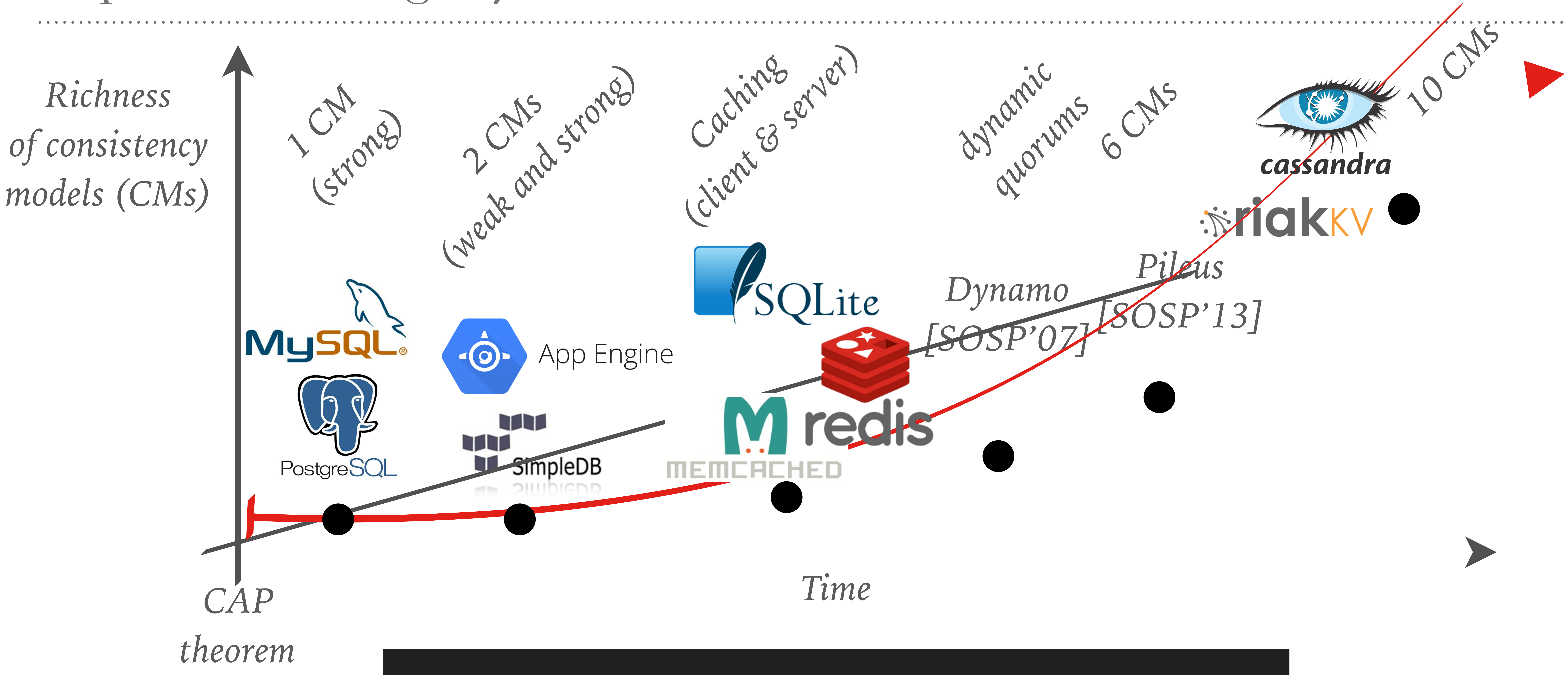
- Computation on static content
- Cold data analysis
- Disconnected operations in mobile applications

Semantics allow to bypass the need for strong consistency

Replicated storage systems



Replicated storage systems



No single consistency model is ideal
→ expose multiple choices