Making Geo-Replicated Systems Fast when Possible, Consistent if Necessary

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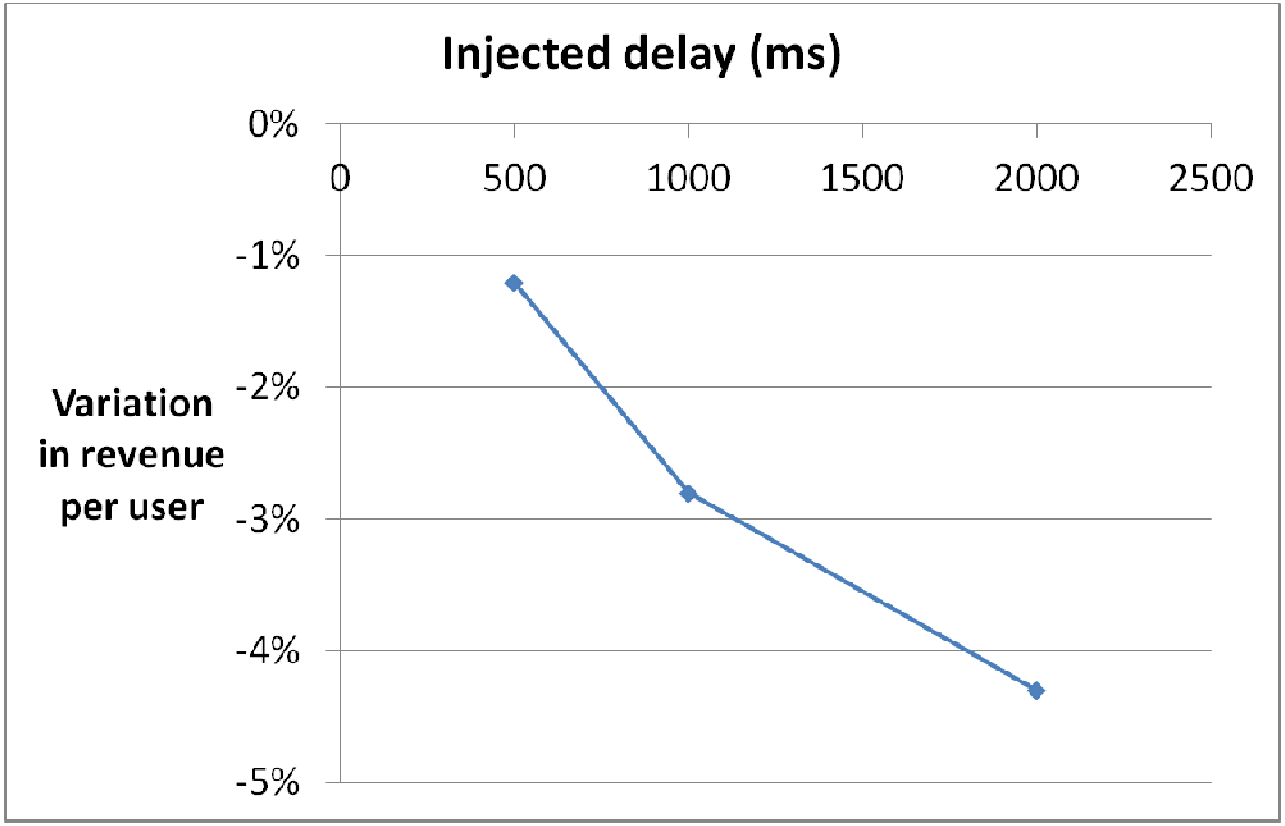
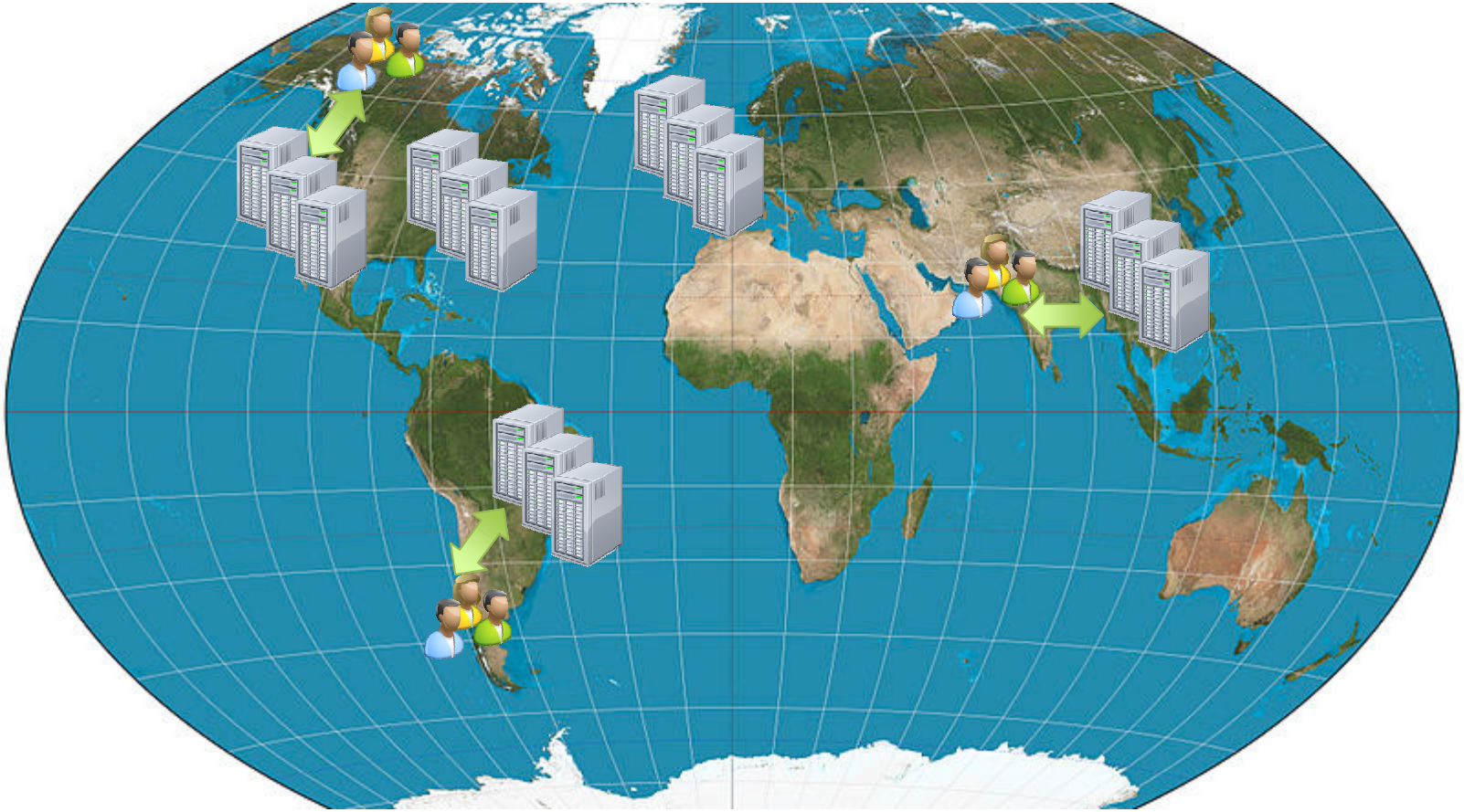
Higher latency ⇒ Lower revenue



Bing: 2-sec slowdown reduced revenue per user by 4.3%

Consequence: Geo-replication



Flip-side of geo-replication

- Geographically disperse replicas are expensive to synchronize
- Leads to existence of various different levels of geo-replication: the *geo-replication hierarchy*

The geo-replication hierarchy

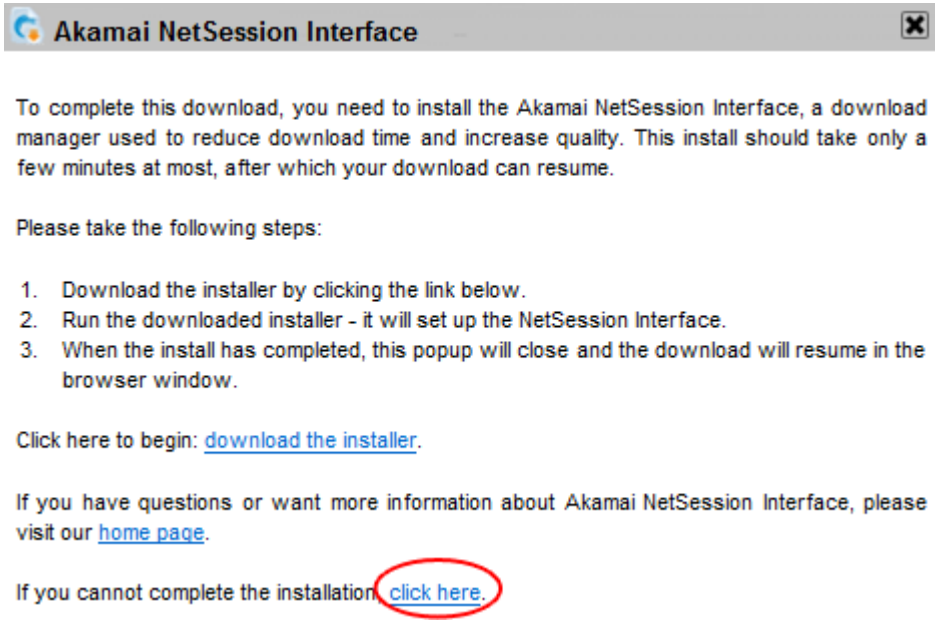
- First level: centralized server
- Second level: replicas at distant data centers
- The two levels can co-exist:
  - Updates are funneled through primary
  - Secondary replicas process read requests

The geo-replication hierarchy (cont.)

- Third level: replicas deployed in conventional CDN infrastructures
- Examples:
  - Akamai (static content): 105,000 servers in 78 countries
  - Google (mostly youtube)

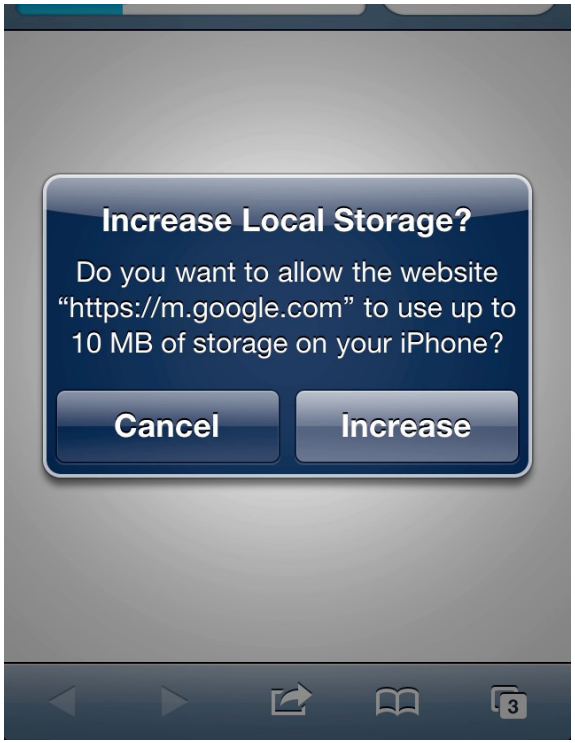
The geo-replication hierarchy (cont.)

- Fourth level: peer-to-peer / hybrid CDNs
- Lower cost of maintaining CDN by leveraging voluntary contributions of clients
- Example: Akamai netsession

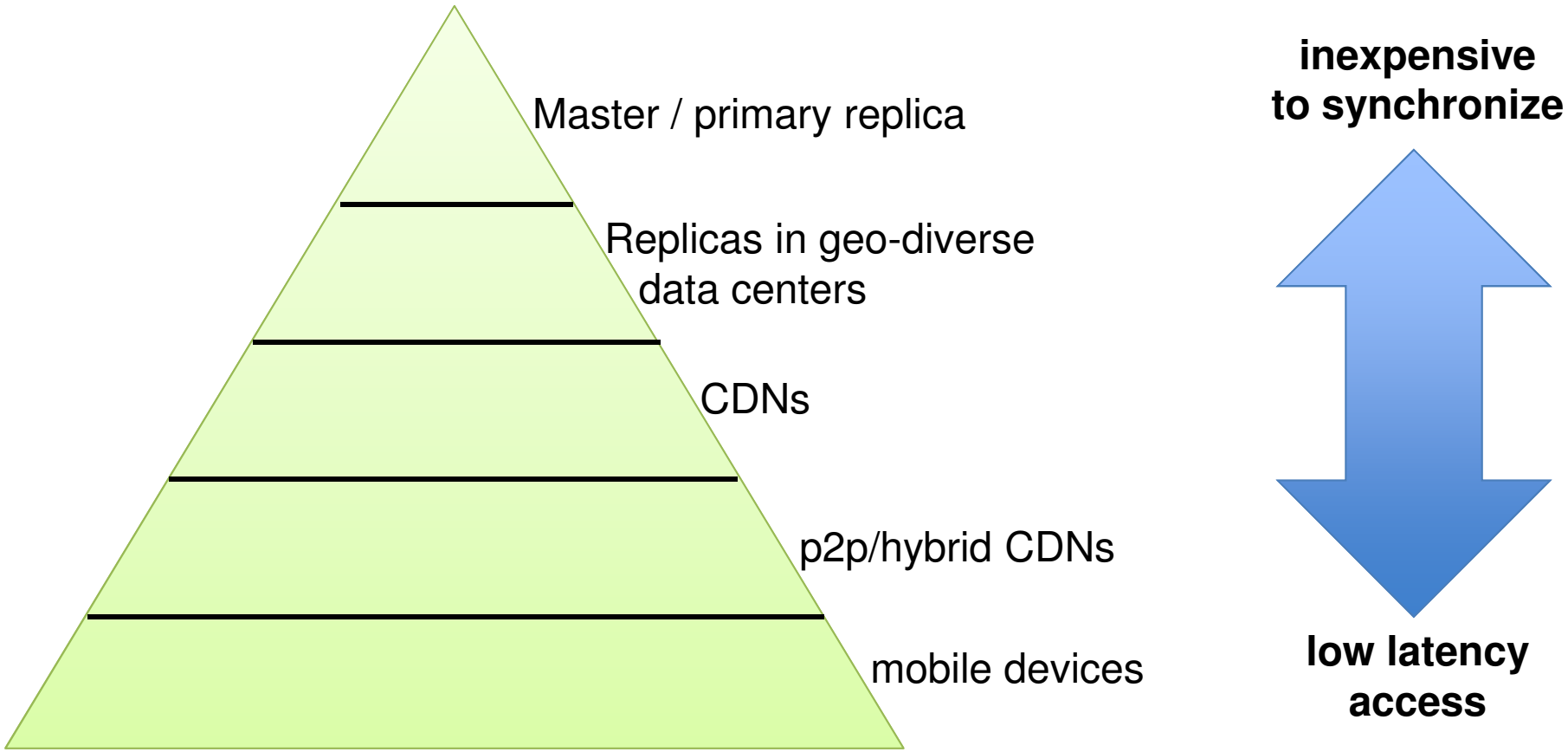


The geo-replication hierarchy (cont.)

- Fifth level: replicas on mobile devices
- Local replication overcomes the high latency / low throughput / weak connectivity
- Example:



The geo-replication hierarchy



Challenge

- Finding a set of principles for designing distributed systems that are aware of the geo-replication hierarchy
  - Much like our operating systems must be aware of the storage hierarchy
- This talk: more narrow aspect of the problem
  - Managing replicas in separate data centers

Current practice: examples and limitations

- Facebook + PNUTS: single master, read-only mirror replicas
  - Works well when there is a single updater
  - Not the case, e.g., in social networking services
- Amazon: Eventual consistency
  - Assumes a seamless merge strategy and may allow undesirable behaviors
  - Folklore: Eventual consistency is no consistency

An observation and a challenge

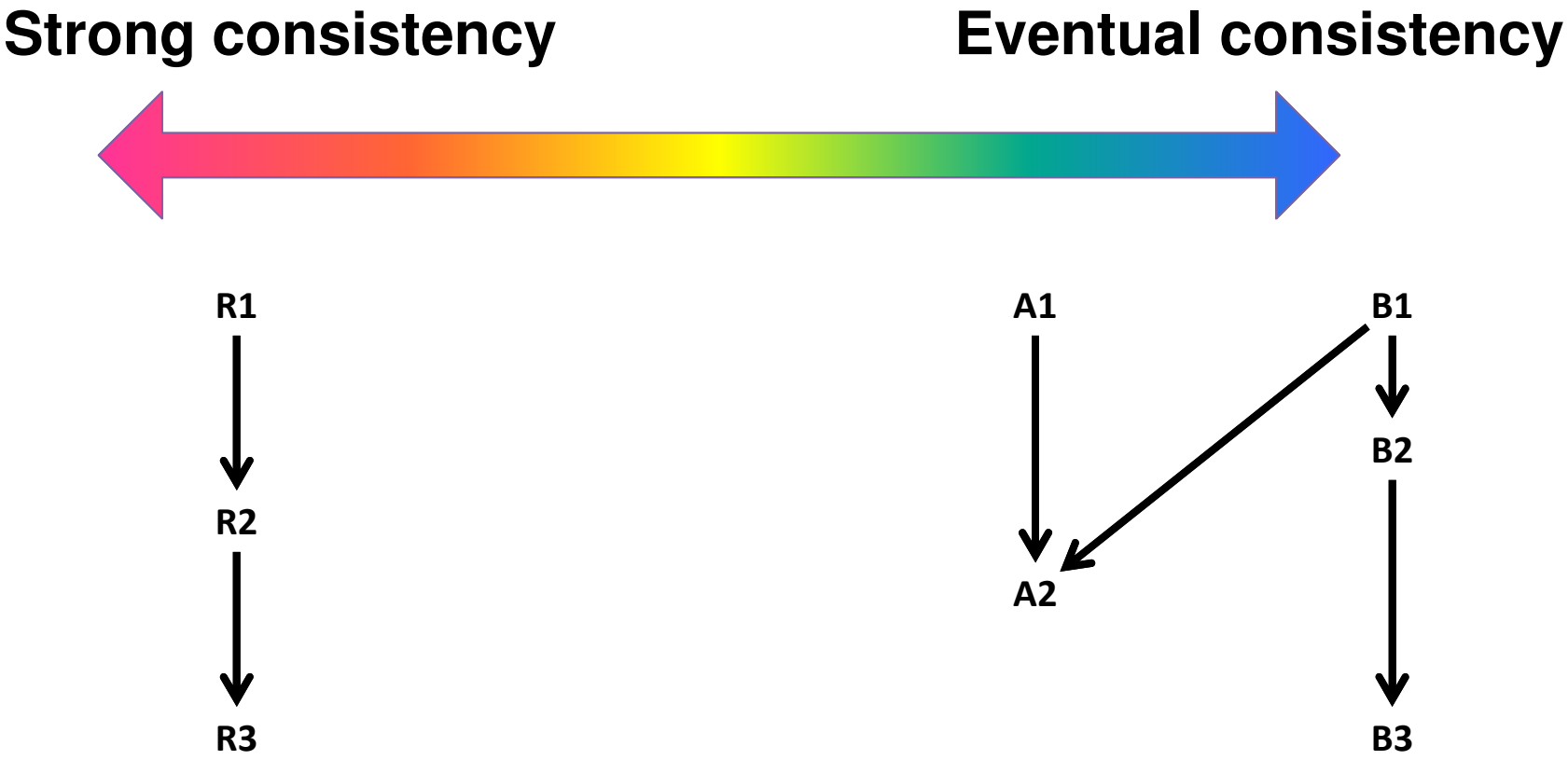
- Eventual consistency works most of the time, but need some strongly consistent operations
- Must let both weakly and strongly consistent operations co-exist [LazyReplication:PODC90,Walter:SOSP11]
  - But which level of consistency to use for an operation?

Need to find principled ways to build systems that are **fast as possible, consistent when needed**

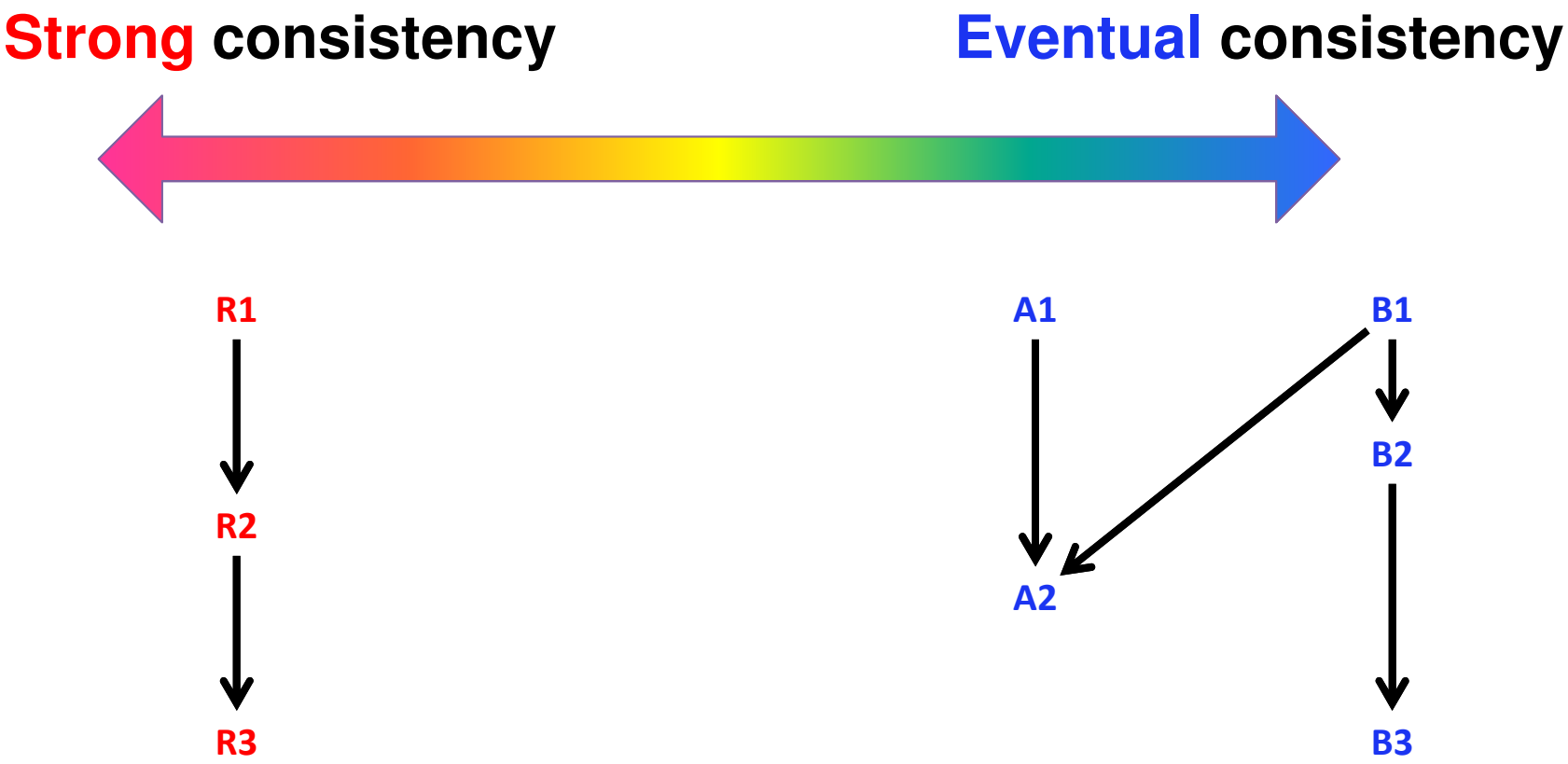
Outline

- Mixing strong and eventual consistency in a single system
- Transforming applications to safely leverage eventual consistency when possible
- Evaluation

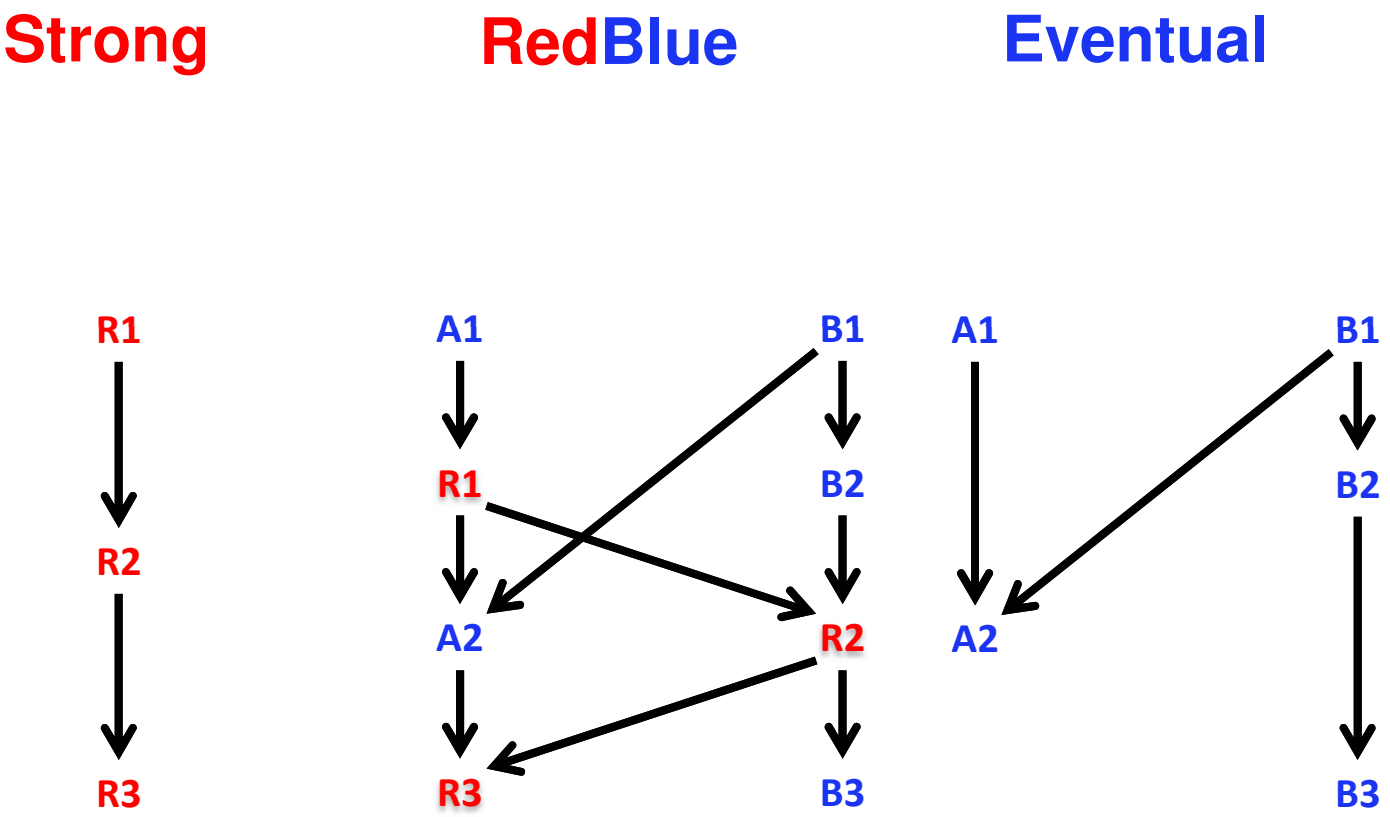
Balance strong/eventual consistency



Balance strong/eventual consistency

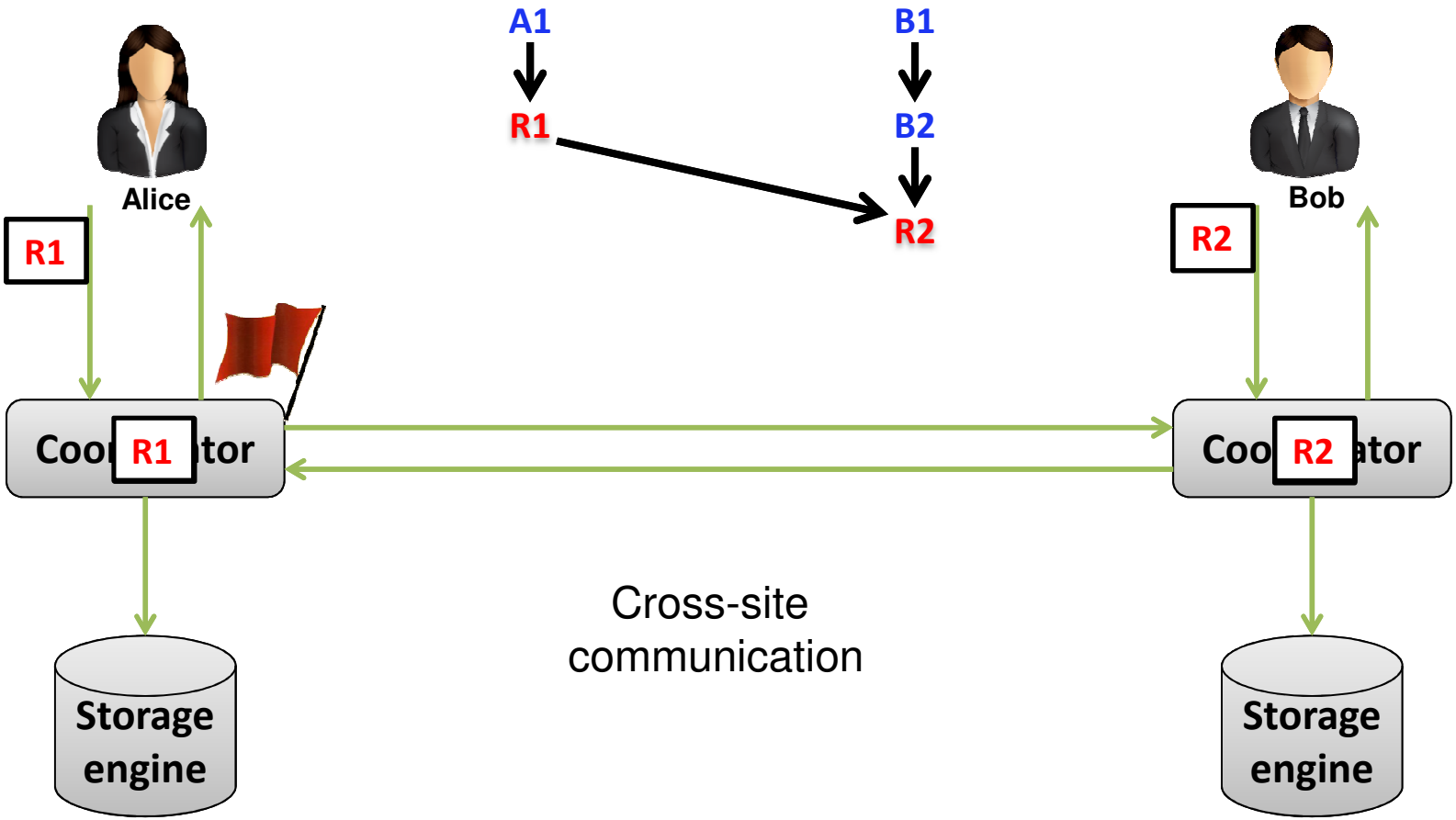


Balance strong/eventual consistency

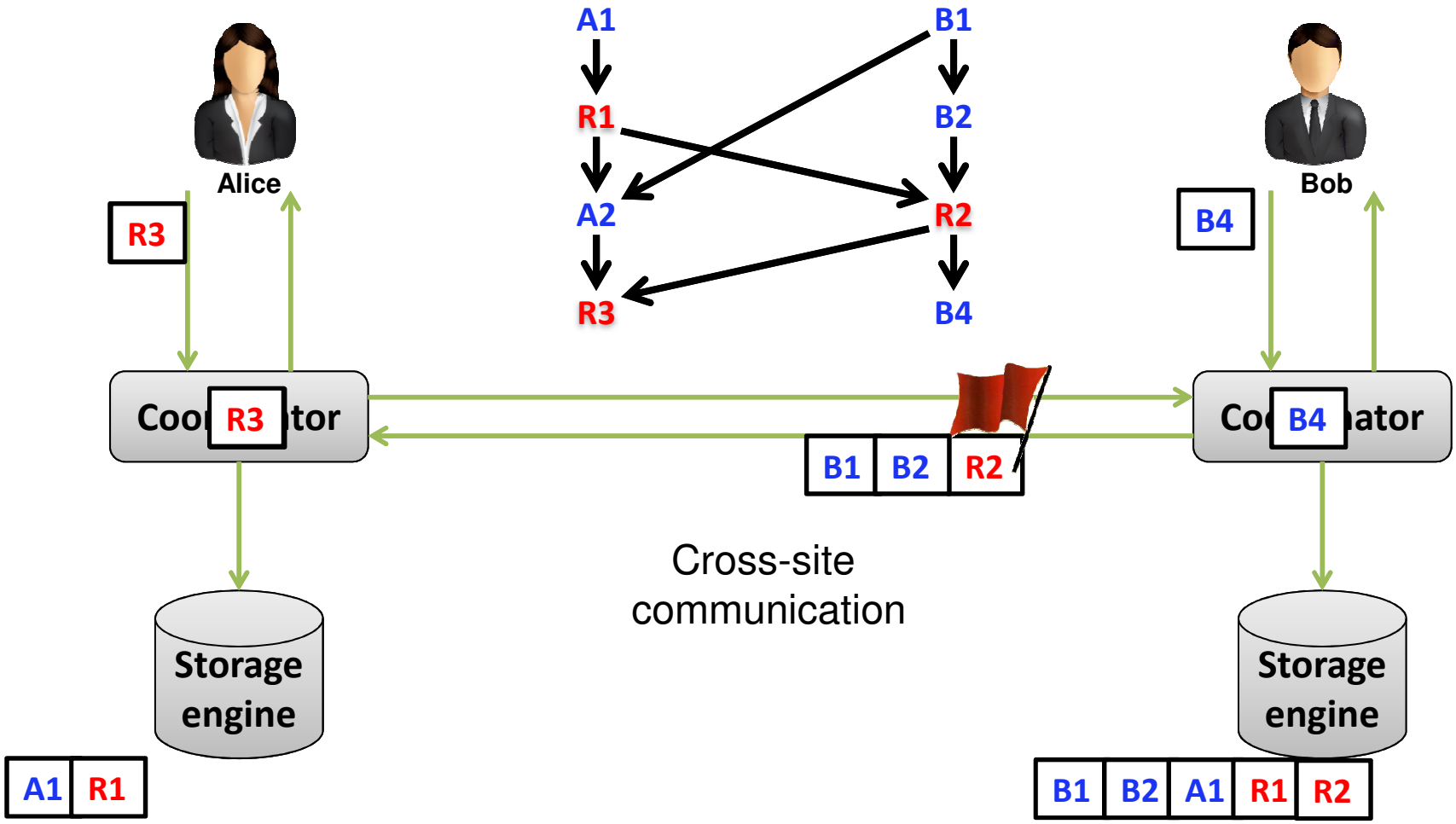


- Low latency of eventual consistency when possible
- Coordination for strong consistency only when necessary

Gemini coordination system



Gemini coordination system



A RedBlue consistent bank system

A RedBlue consistent bank system

- **Problem**: Different execution orders lead to divergent state.
- **Cause**: *accrueinterest* doesn't commute with *deposit*.
- **Implication**: Convergence requires **Red**, but **Red** is slow.

126 ≠ 125

```
float balance, interest;

eposit(float m){
  balance = balance + m;

ccrueinterest(){
  float delta=balance × interest;
  balance=balance + delta;

ithdraw(float m){
  if(balance-m>=0)
     balance=balance - m;
  else
     print "Error"
}
```

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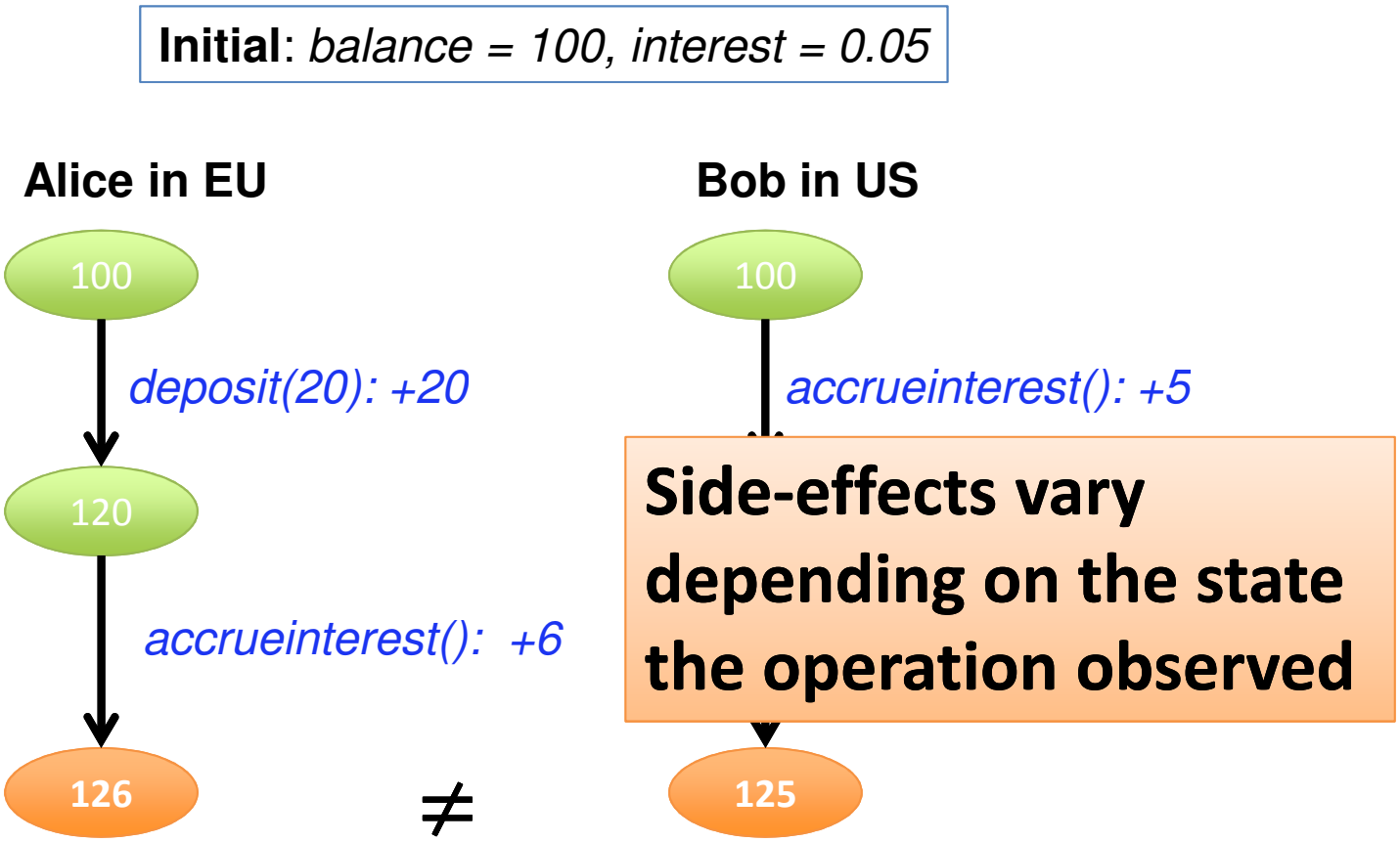
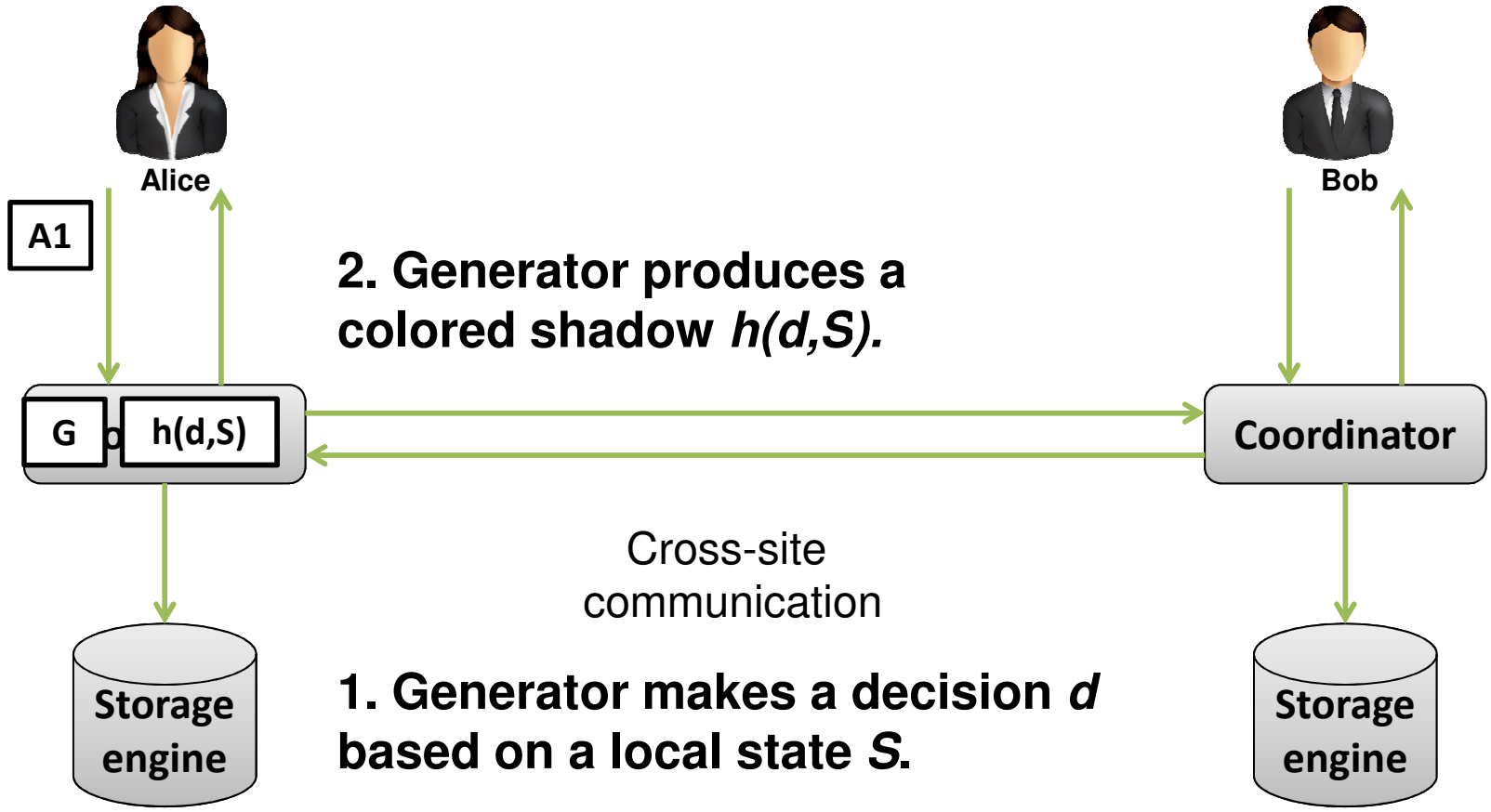
Problem of replicating operations



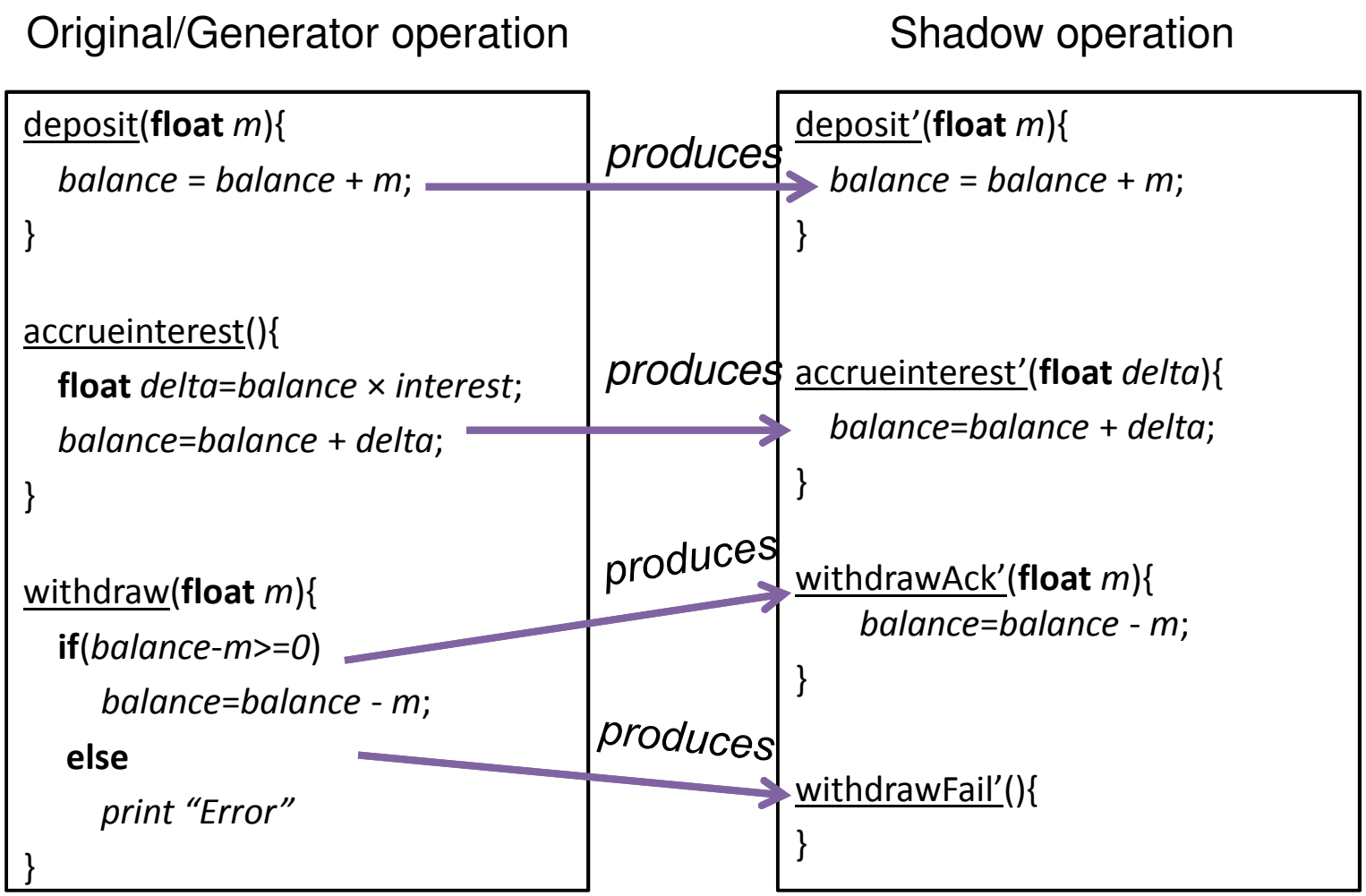
Generator/Shadow operation

- Intuitively, the execution of *accrueinterest* can be divided into:
  - A generator operation
    - decides *how much interest to be accrued*
    - has *no side effects*
  - A shadow operation
    - adds *the decided interest to the balance*

Generate once, shadow everywhere



Bank generator/shadow operations



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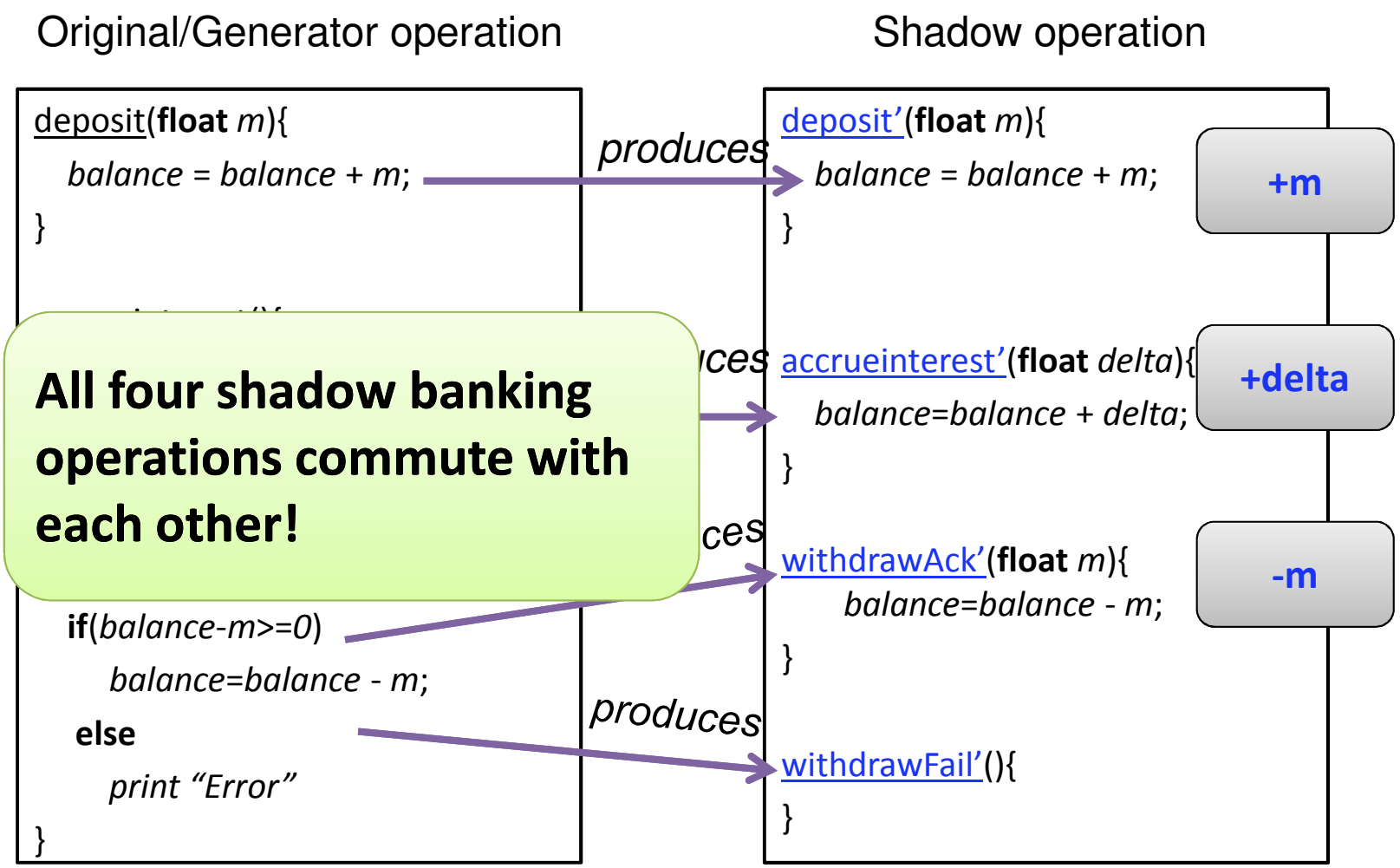
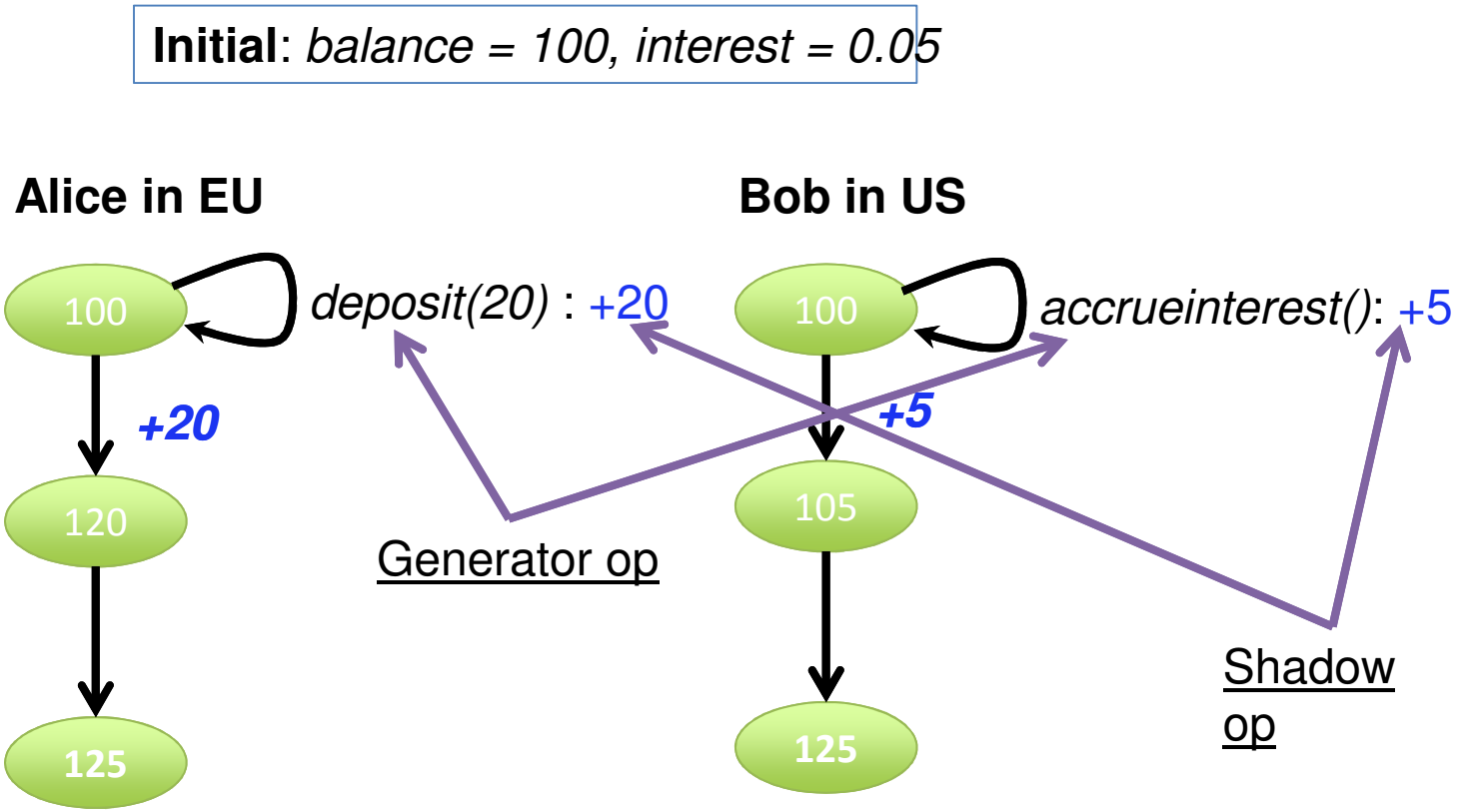
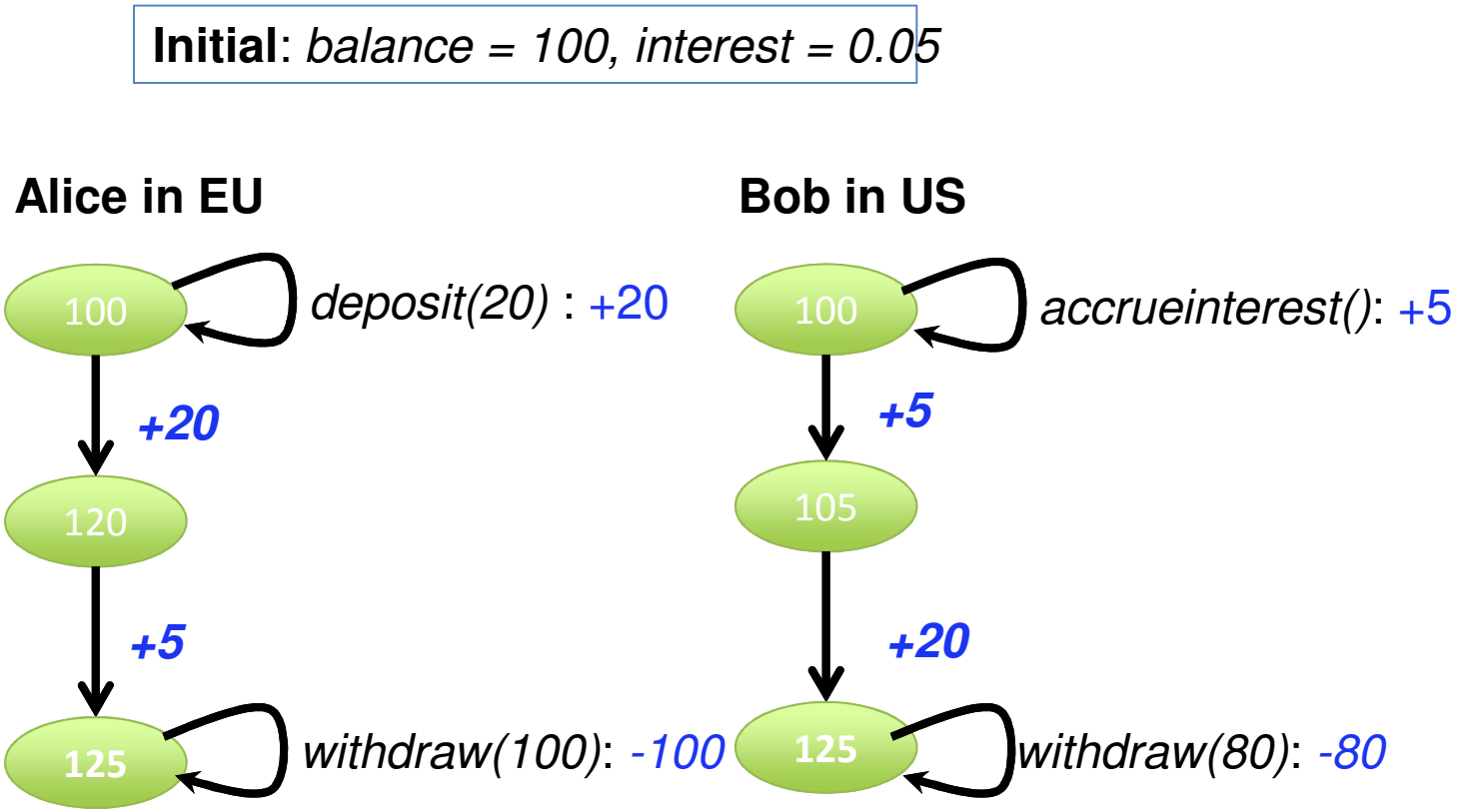


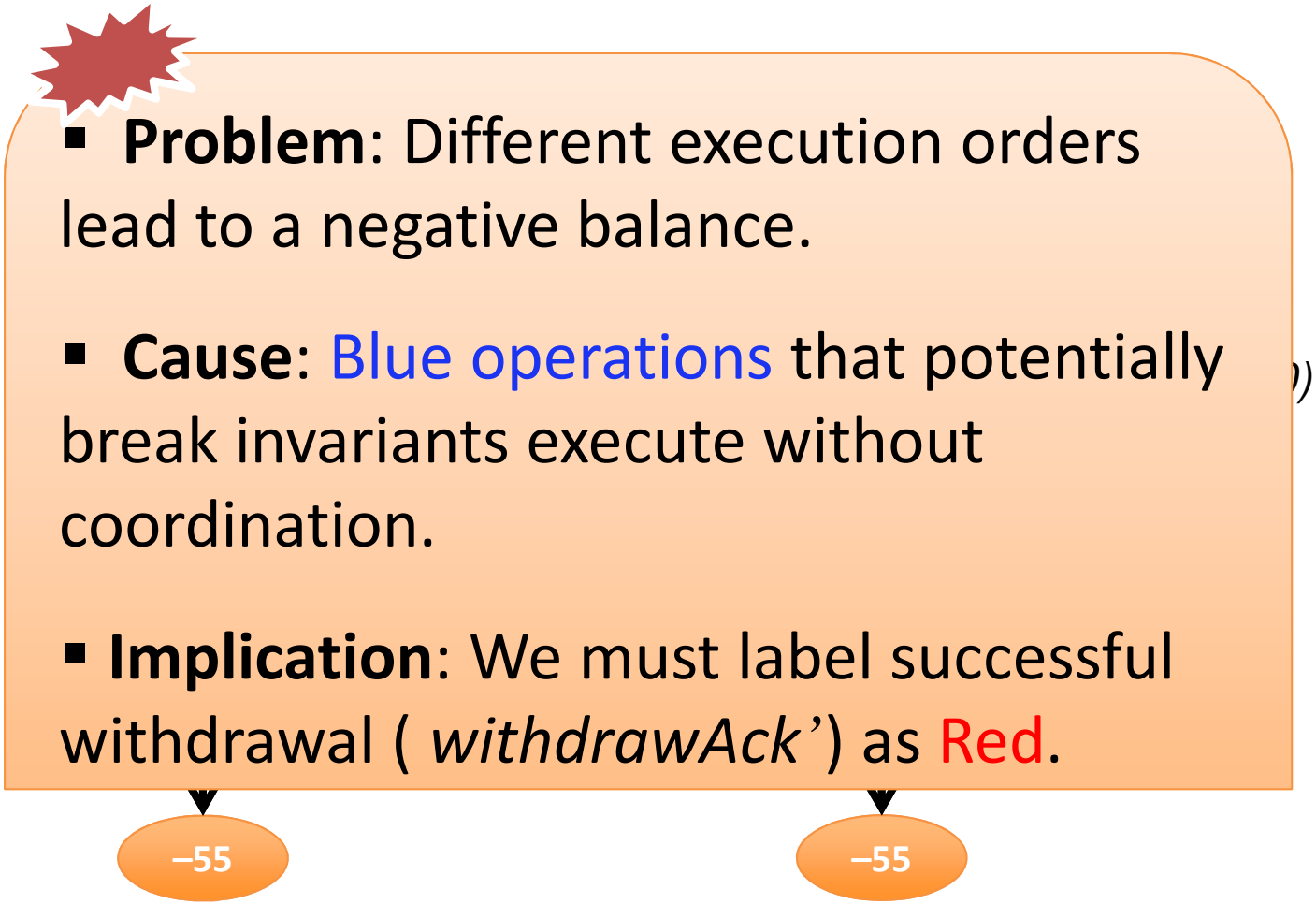
Fast and consistent bank



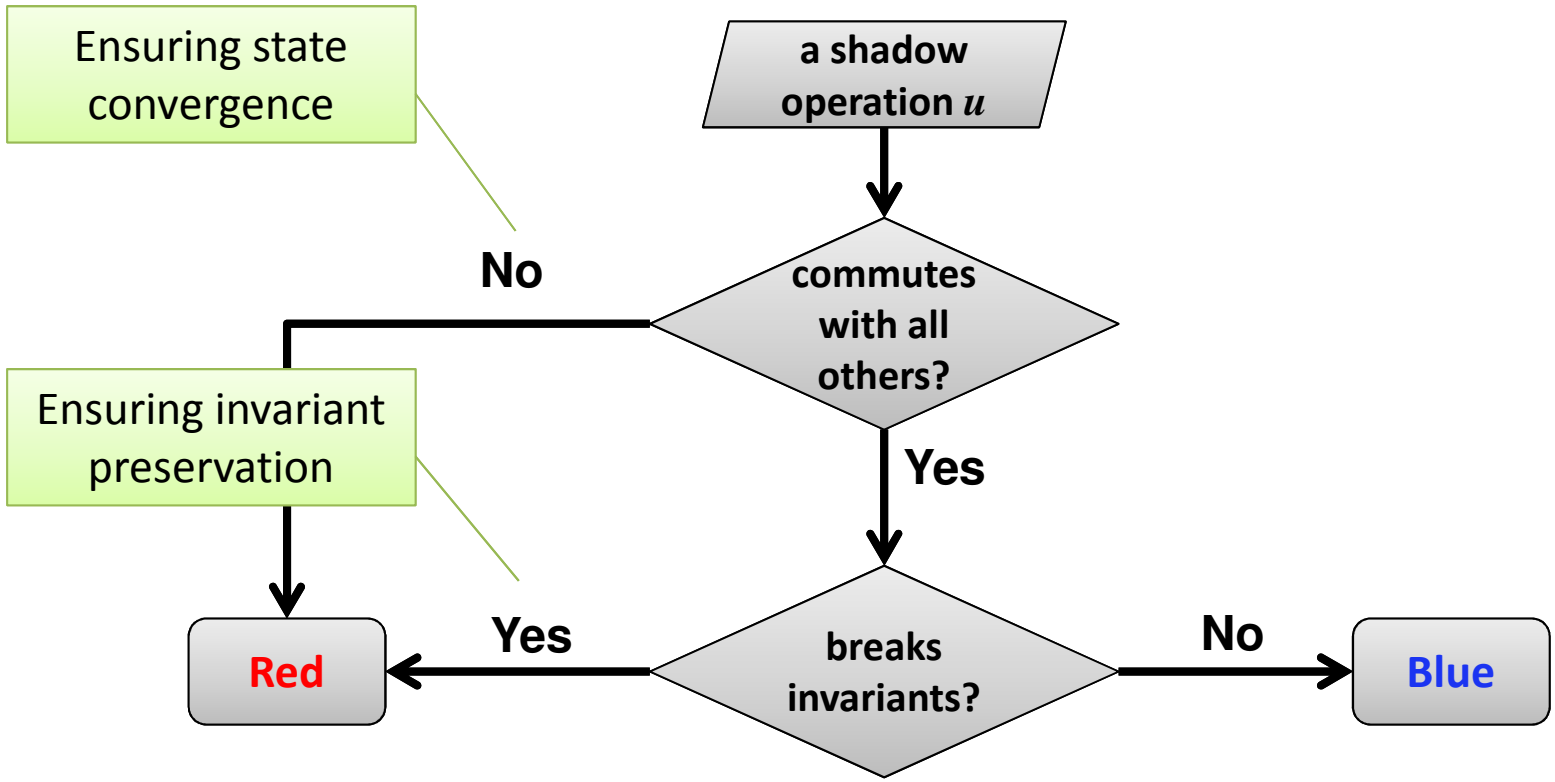
Not so fast …


Initial: *balance = 100, interest = 0.05*
Alice in EU
100
deposit(20) : +20
+20
120
+5
125
withdraw(100): -100
Bob in US
100
accrueinterest(): +5
+5
105
+20
125
withdraw(80): -80

Not so fast …


▪ **Problem**: Different execution orders lead to a negative balance.
▪ **Cause**: Blue operations that potentially break invariants execute without coordination.
▪ **Implication**: We must label successful withdrawal (*withdrawAck'*) as Red.
–55
–55

Which must be Red or can be Blue?



Key ideas so far

- RedBlue consistency combines strong and eventual consistency into a single system.
- The decomposition of generator/shadow operations expands the space of possible Blue operations.
- A simple rule for labeling is provably state convergent and invariant preserving.

Evaluation

Questions

- How common are Blue operations?
- Does RedBlue consistency improve user-observed latency?
- Does throughput scale with the number of sites?

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Case studies

- Applications:
  - Two e-commerce benchmarks: TPC-W, RUBiS
  - One social networking app: Quoddy

Apps	# Original update txns	# Blue/Red update ops
TPC-W	7	**0**/**7**
RUBiS	5	**0**/**5**
Quoddy	4	**0**/**4**

Case studies

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Apps	# Original update txns	# Blue/Red update ops	# Shadow ops	# Blue/Red update ops
TPC-W	7	**0**/**7**	16	**14**/**2**
RUBiS	5	**0**/**5**	9	**7**/**2**
Quoddy	4	**0**/**4**	4	**4**/**0**

How common are Blue operations?

Runtime Blue/Red ratio in different applications with different workloads:

Apps	workload	Originally	
		Blue (%)	Red(%)
TPC-W	Browsing mix	**96.0**	**4.0**
	Shopping mix	**85.0**	**15.0**
	Ordering mix	**63.0**	**37.0**
RUBiS	Bidding mix	**85.0**	**15.0**
Quoddy	a mix with 15% update	**85.0**	**15.0**

How common are Blue operations?

Runtime Blue/Red ratio in different applications with different workloads:

Apps	workload	Originally		With shadow ops	
		Blue (%)	Red(%)	Blue (%)	Red(%)
TPC-W	Browsing mix	**96.0**	**4.0**	**99.5**	**0.5**
	Shopping mix	**85.0**	**15.0**	**99.2**	**0.8**
	Ordering mix	**63.0**	**37.0**	**93.6**	**6.4**
RUBiS	Bidding mix	**85.0**	**15.0**	**97.4**	**2.6**
Quoddy	a mix with 15% update	**85.0**	**15.0**	**100**	**0**

The vast majority of operations are Blue.

Questions

- How common are Blue operations?
- Does RedBlue consistency improve user-observed latency?
- Does throughput scale with the number of sites?

Experimental setup

- Experiments with:
  - TPC-W, RUBiS and Quoddy
- Deployment in Amazon EC2
  - spanning 5 sites (US-East, US-West, Ireland, Brazil, Singapore)
  - locating users in all five sites and directing their requests to closest server

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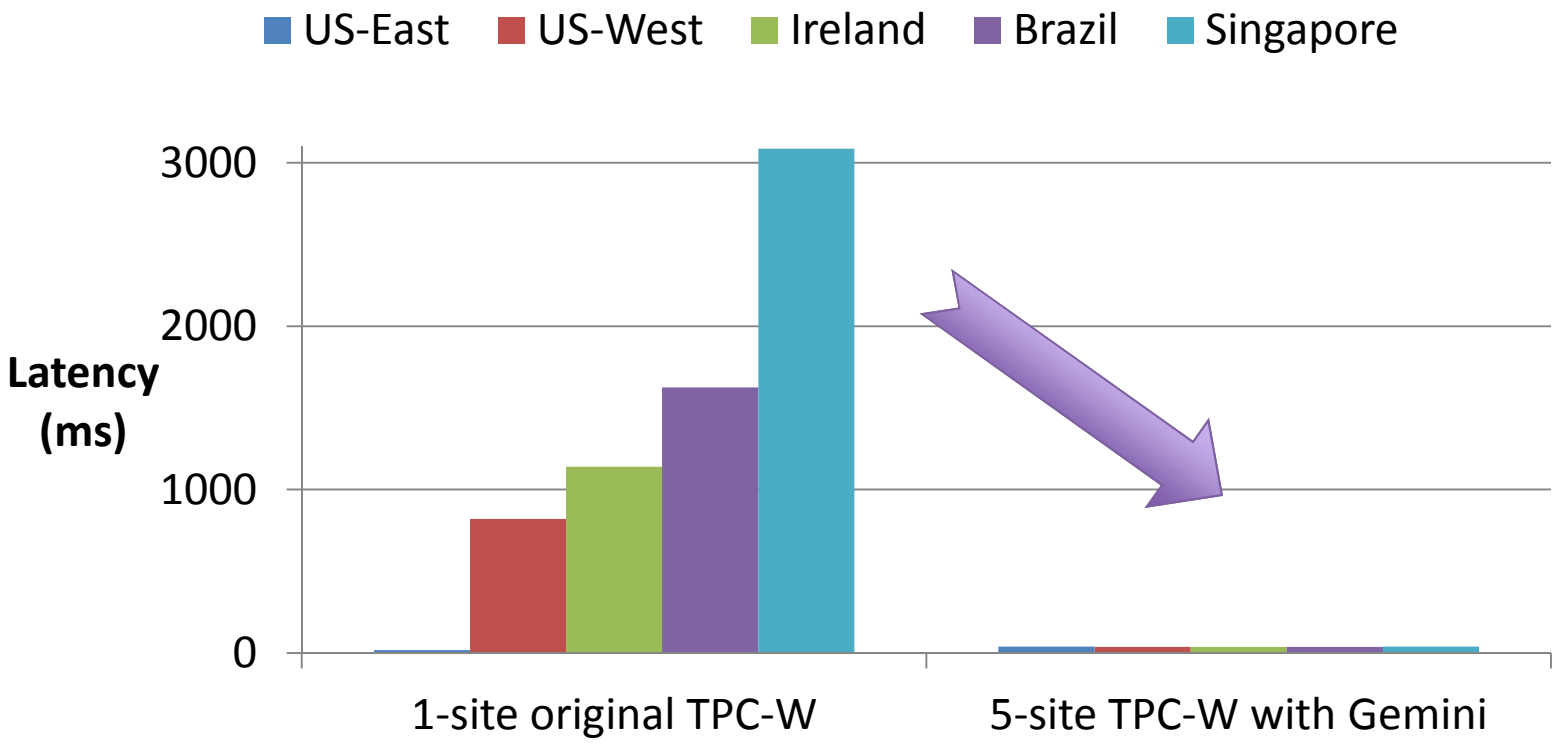
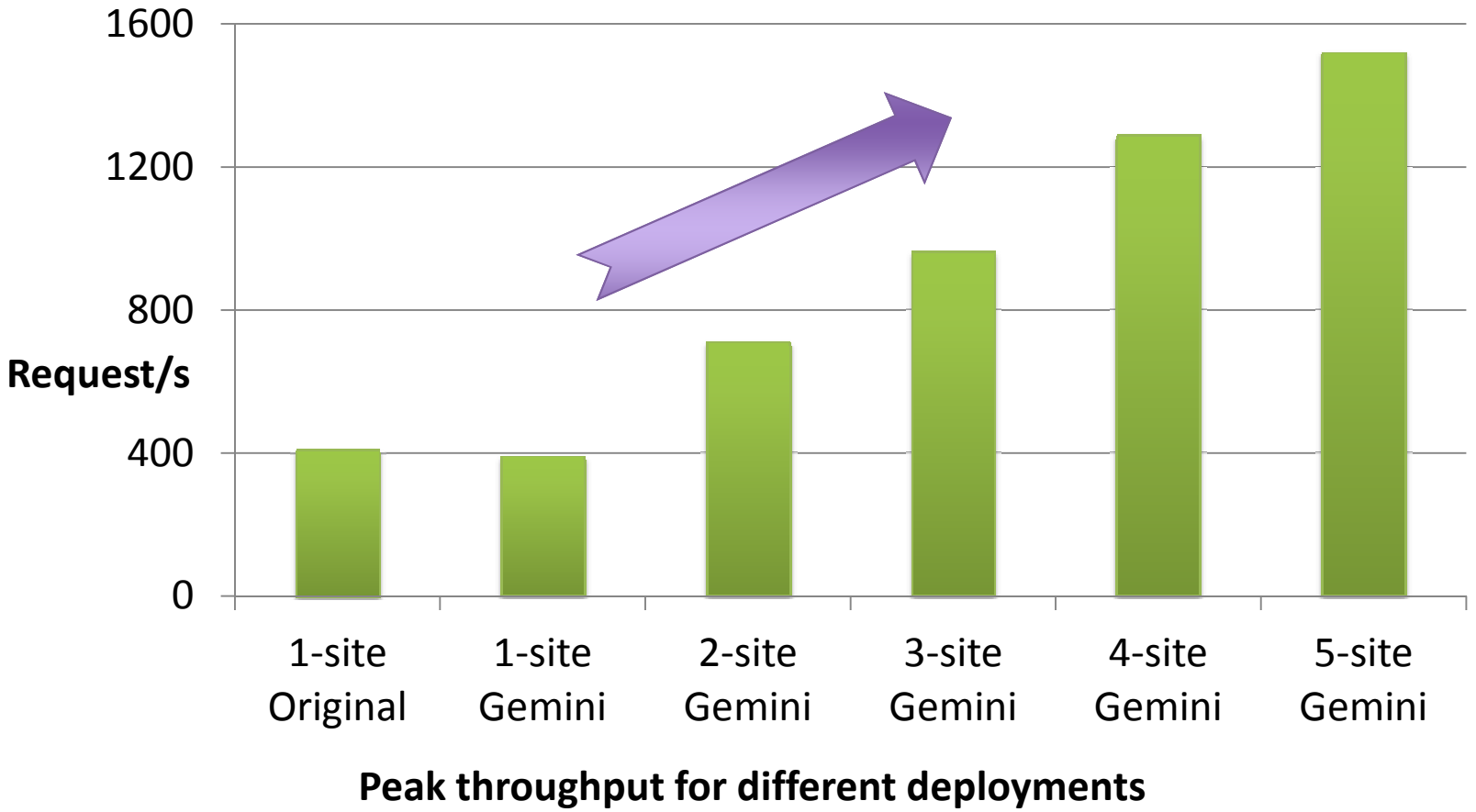
Does RedBlue consistency improve user-observed latency?



Average latency for users at all five sites

Does throughput scale with the number of sites?



Conclusion

- RedBlue consistency allows strong consistency and eventual consistency to coexist.
- Generator/shadow operation extends the space of fast operations.
- A precise labeling methodology allows for systems to be fast and behave as expected.
- Experimental results show our solution improves both latency and throughput.

Making Geo-Replicated Systems Fast when Possible, Consistent if Necessary

THANK YOU!