Eventually-Consistent Data Structures

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@seancribbs #CRDT
StrangeLoop 2012

I work for Basho

We make riak

Riak is Eventually Consistent

So are Voldemort and Cassandra

No ACID!

Duals or Duels?

Duals or Duels?

object-oriented / functional

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object-oriented / functional

static / dynamic

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object-oriented / functional

static / dynamic

consistency / availability

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safety / liveness

Safety / Liveness

Proving the Correctness of Multiprocess Programs - Leslie Lamport
(March 1977)

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- **Safety:** “nothing bad happens” (partial correctness)

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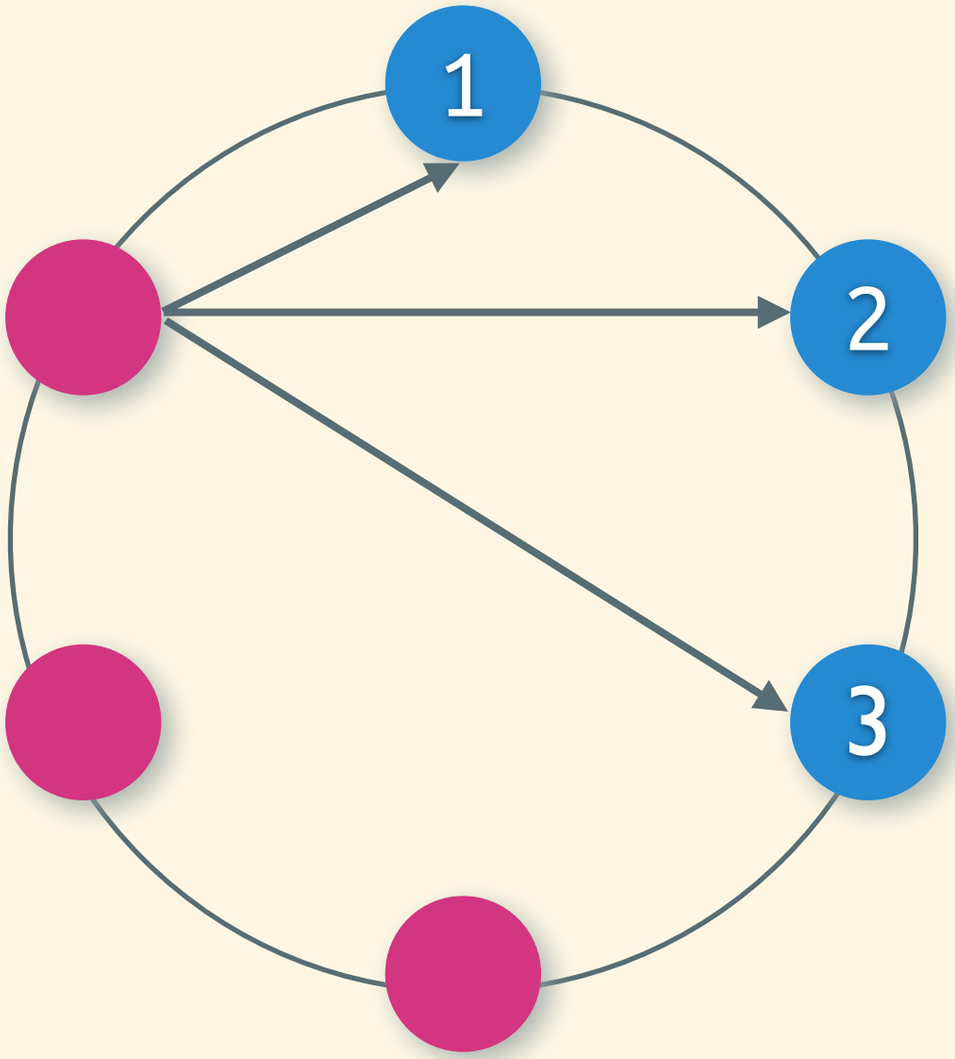
- **Safety:** “nothing bad happens” (partial correctness)
- **Liveness:** “something good eventually happens” (termination)

“Safety and liveness: Eventual consistency is not safe” - Peter Bailis
http://www.bailis.org/blog/safety-and-liveness-eventual-consistency-is-not-safe/

Eventual Consistency



Replicated

Loose coordination

Convergence

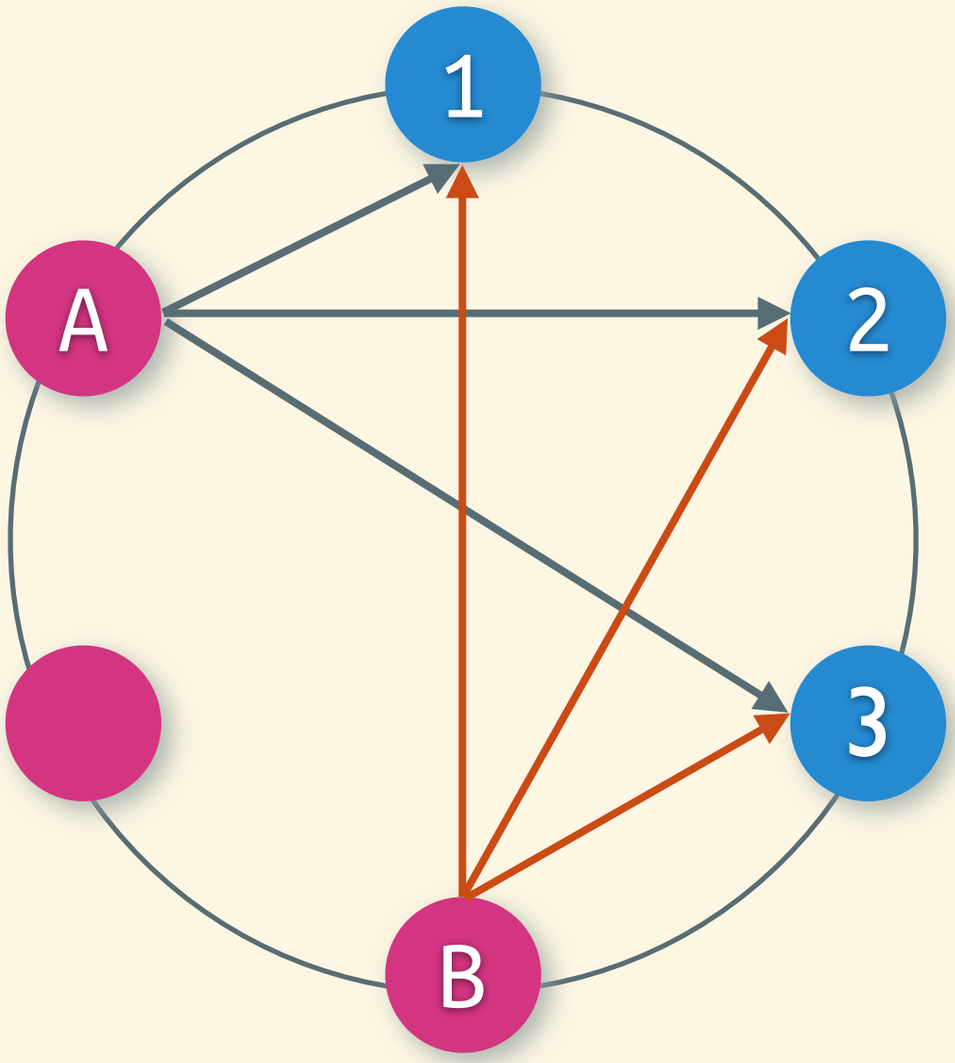
Eventual is Good

✔ Fault-tolerant

✔ Highly available

✔ Low-latency

Consistency?

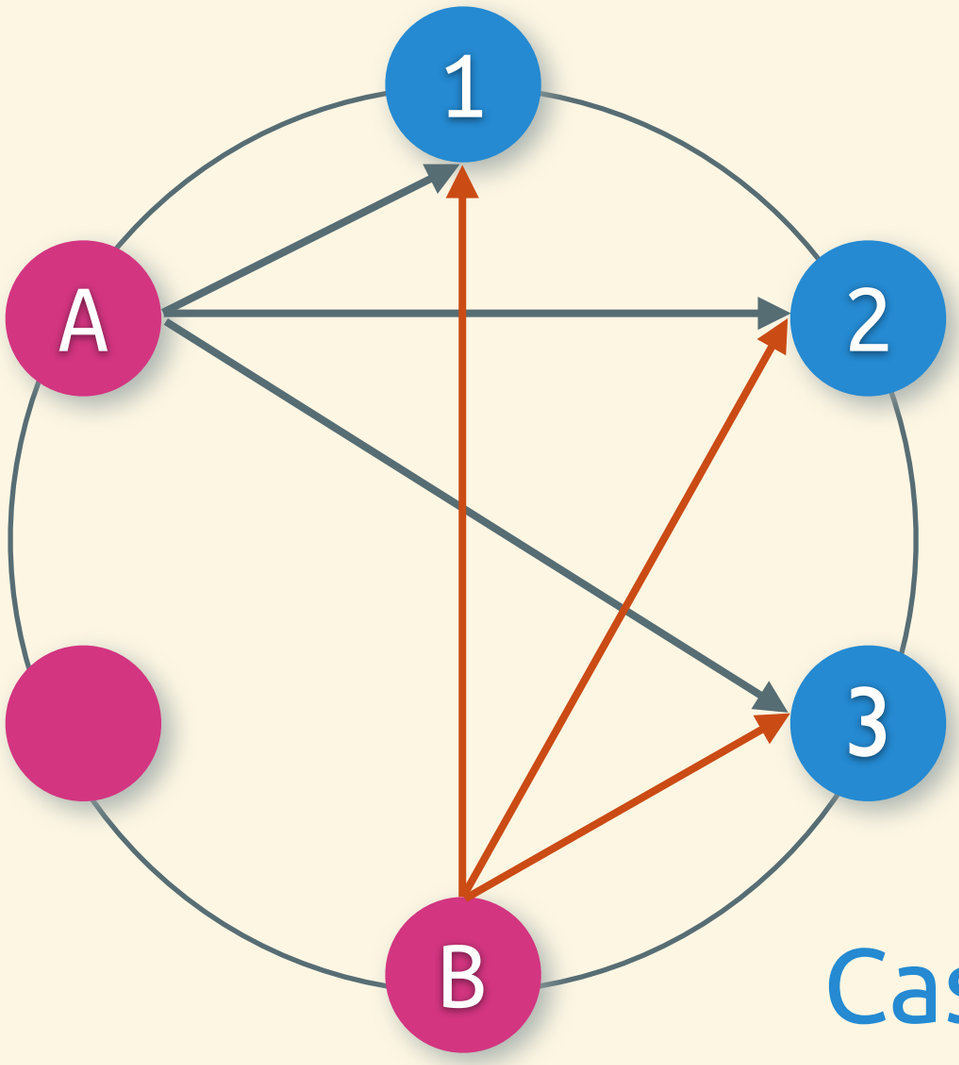


No clear winner!

Throw one out?

Keep both?

Consistency?



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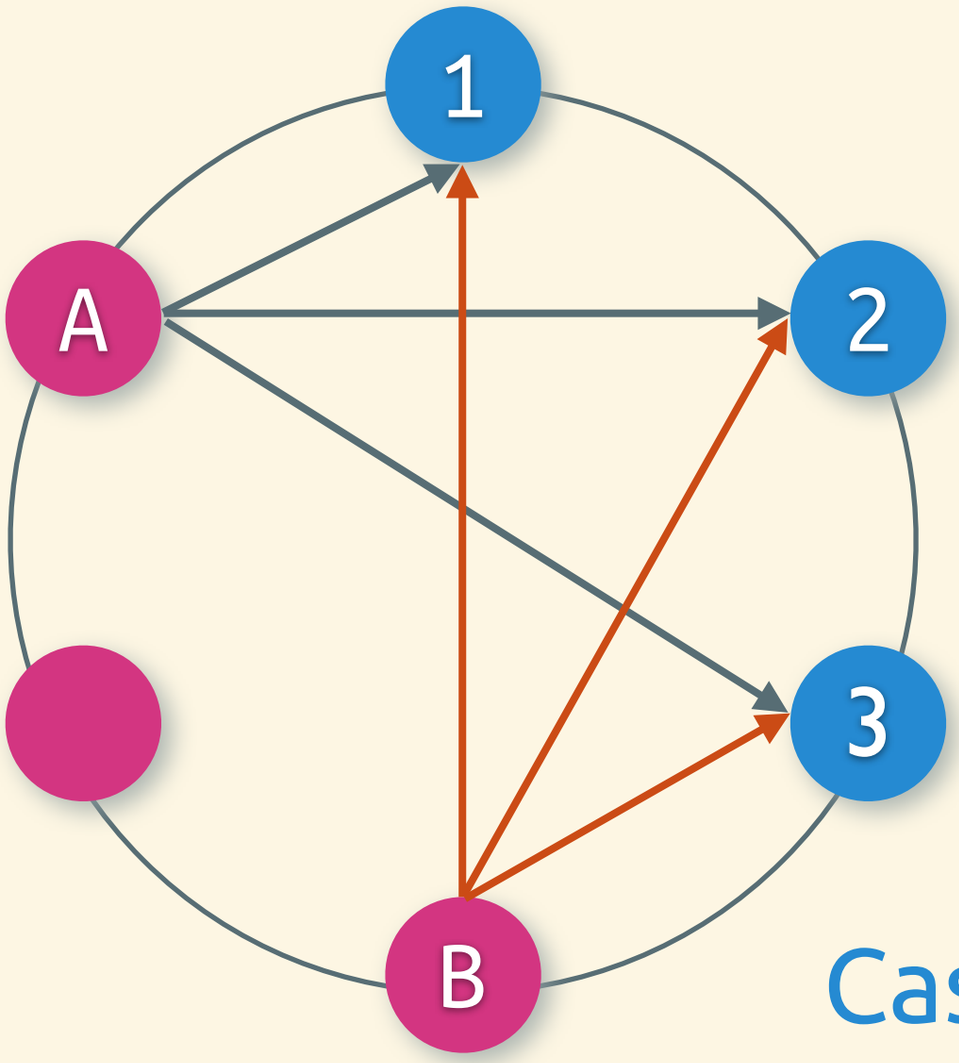
Cassandra

Consistency?



No clear winner!

Throw one out?

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Cassandra

Riak & Voldemort

Conflicts!

A!

B!

Semantic Resolution

- Your app knows the domain - use business rules to resolve
- Amazon Dynamo’s shopping cart

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"Ad hoc approaches have proven brittle and error-prone"

Conflict-Free Replicated Data Types

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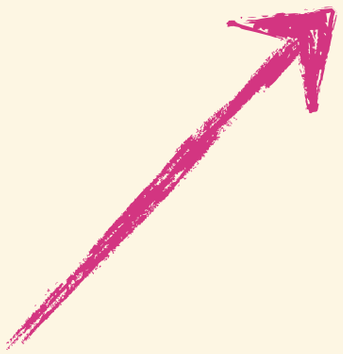
useful abstractions

Conflict-Free Replicated Data Types



multiple independent copies

useful abstractions

resolves automatically
toward a single value

Conflict-Free Replicated Data Types

multiple independent
copies

useful abstractions

Logic and Lattices for Distributed Programming

Neil Conway
William Marczak
Peter Alvaro
Joseph M. Hellerstein
David Maier

http://db.cs.berkeley.edu/papers/UCB-lattice-tr.pdf

Bounded Join Semi-Lattices

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$\langle S, \sqcup, \bot \rangle$

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- S is a set

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- $\forall x, y \in S: x \leq_S y \Leftrightarrow x \sqcup y = y$

Bounded Join Semi-Lattices

$\langle S, \sqcup, \bot \rangle$

- S is a set
- $\sqcup$ is a least-upper bound (join/merge) on S
- $\bot \in S$
- $\forall x, y \in S: x \leq_S y \Leftrightarrow x \sqcup y = y$
- $\forall x \in S: \; x \sqcup \bot = x$

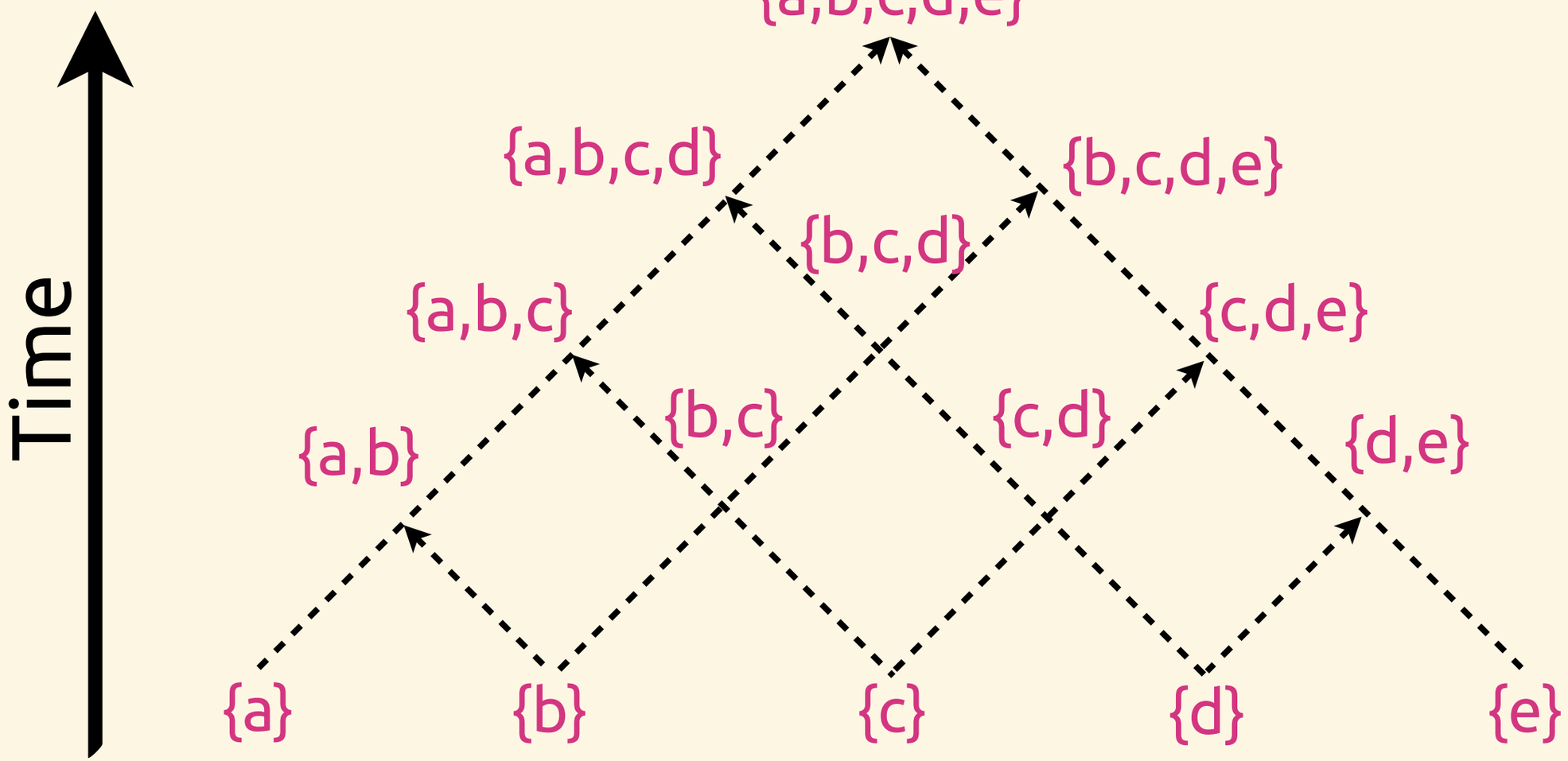
lmax Lattice

$$S := \mathscr{R}$$

$$a \sqcup b := \max(a,b)$$

$$\bot := -\infty$$

lset Lattice



INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

A comprehensive study of Convergent and Commutative Replicated Data Types

Marc Shapiro, INRIA & LIP6, Paris, France
Nuno Preguiça, CITI, Universidade Nova de Lisboa, Portugal
Carlos Baquero, Universidade do Minho, Portugal

Marek Zawirski, INRIA & UPMC, Paris, France

CRDT Flavors

- **Convergent:** State
  - Weak messaging requirements
- **Commutative:** Operations
  - Reliable broadcast required
  - Causal ordering sufficient

Convergent CRDTs

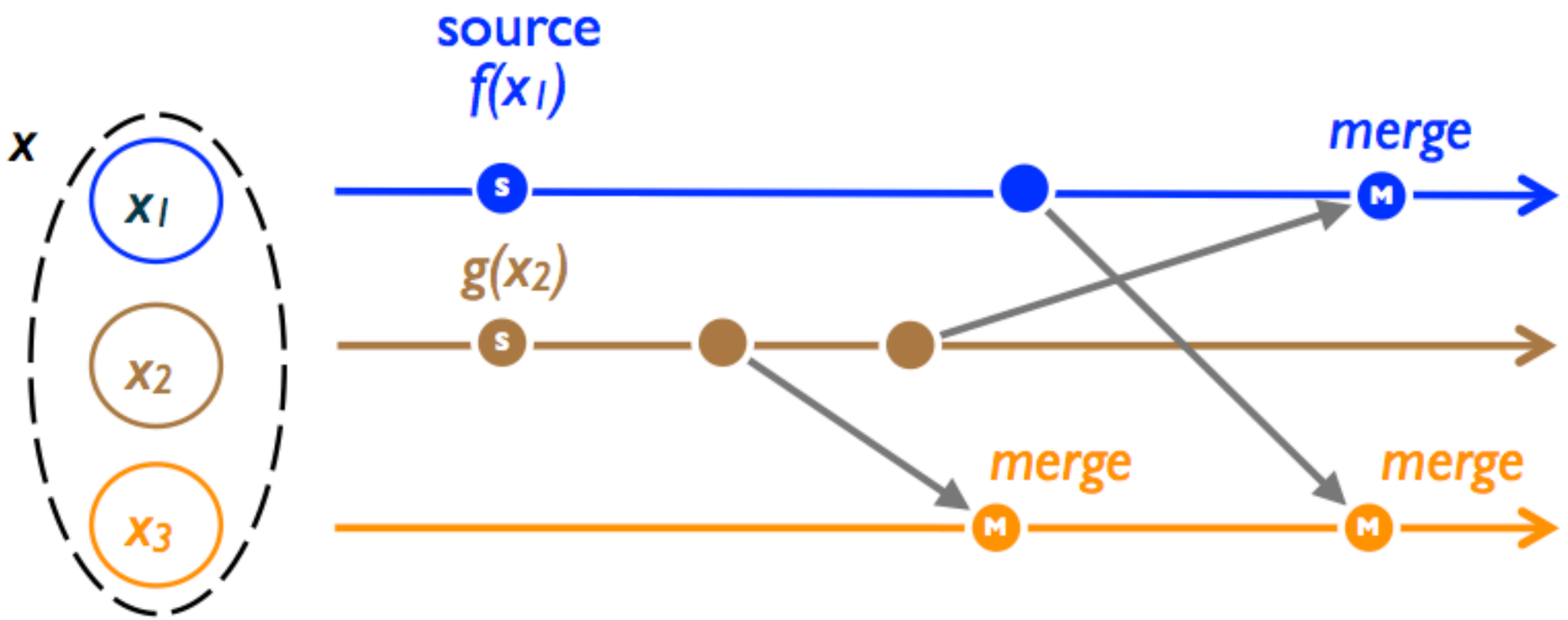


Figure 4: State-based replication

Commutative CRDTs

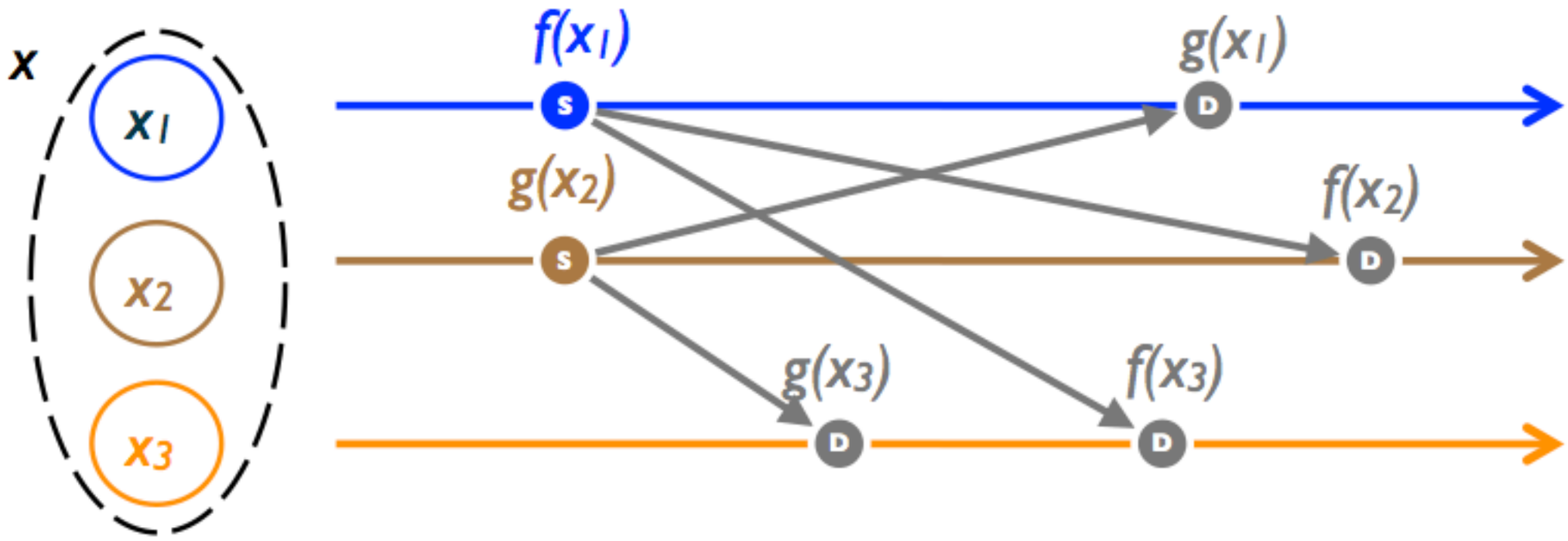


Figure 6: Operation-Based Replication

Registers

A place to put your stuff

Registers

- Last-Write Wins (LWW-Register)
  - e.g. Columns in Cassandra
- Multi-Valued (MV-Register)
  - e.g. Objects (values) in Riak

Counters

Keeping tabs

G-Counter

G-Counter

```
// Starts empty
[]
```

G-Counter

```
// Starts empty
[]

// A increments twice, forwarding state
[{a,1}]    // == 1
[{a,2}]    // == 2
```

G-Counter

```
// Starts empty
[]

// A increments twice, forwarding state
[{a,1}]    // == 1
[{a,2}]    // == 2

                    // B increments
                    [{b,1}]    // == 1
```

G-Counter

```
// Starts empty
[]

// A increments twice, forwarding state
[{a,1}]    // == 1
[{a,2}]    // == 2

                                  // B increments
                                  [{b,1}]    // == 1

// Merging
[{a,2}, {b,1}]                    [{a,1}, {b,1}]
```

G-Counter

```
// Starts empty
[]

// A increments twice, forwarding state
[{a,1}]    // == 1
[{a,2}]    // == 2

                                  // B increments
                                  [{b,1}]    // == 1

// Merging
[{a,2}, {b,1}]                    [{a,1}, {b,1}]
                                  [{a,2}, {b,1}]
// == 3, converged
```

PN-Counter

```
// A PN-Counter
{
   P = [{a,10},{b,2}],
   N = [{a,1},{c,5}]
}
// == (10+2)-(1+5) == 12-6 == 6
```

Sets

Members Only

G-Set

G-Set

```
// Starts empty
{}
```

G-Set

```
// Starts empty
{}

// A adds a and b, forwarding state
{a}
{a,b}
```

G-Set

```
// Starts empty
{}

// A adds a and b, forwarding state
{a}
{a,b}
```

```
// B adds c
{c}
```

G-Set

```
// Starts empty
{}

// A adds a and b, forwarding state
{a}
{a,b}
```

```
// B adds c
{c}
```

```
// Merging
{a,b,c}

// converged
```

```
{a,c}
{a,b,c}
```

2P-Set

2P-Set

```
// Starts empty
{A={},R={}}
```

2P-Set

```
// Starts empty
{A={},R={}}

// A adds a and b, forwarding state,
// removes a
{A={a},  R={}}     // == {a}
{A={a,b},R={}}   // == {a,b}
{A={a,b},R={a}}  // == {b}
```

2P-Set

```
// Starts empty
{A={},R={}}

// A adds a and b, forwarding state,
// removes a
{A={a},  R={}}     // == {a}
{A={a,b},R={}}   // == {a,b}
{A={a,b},R={a}}  // == {b}

                   // B adds c
                   {A={c},R={}} // == {c}
```

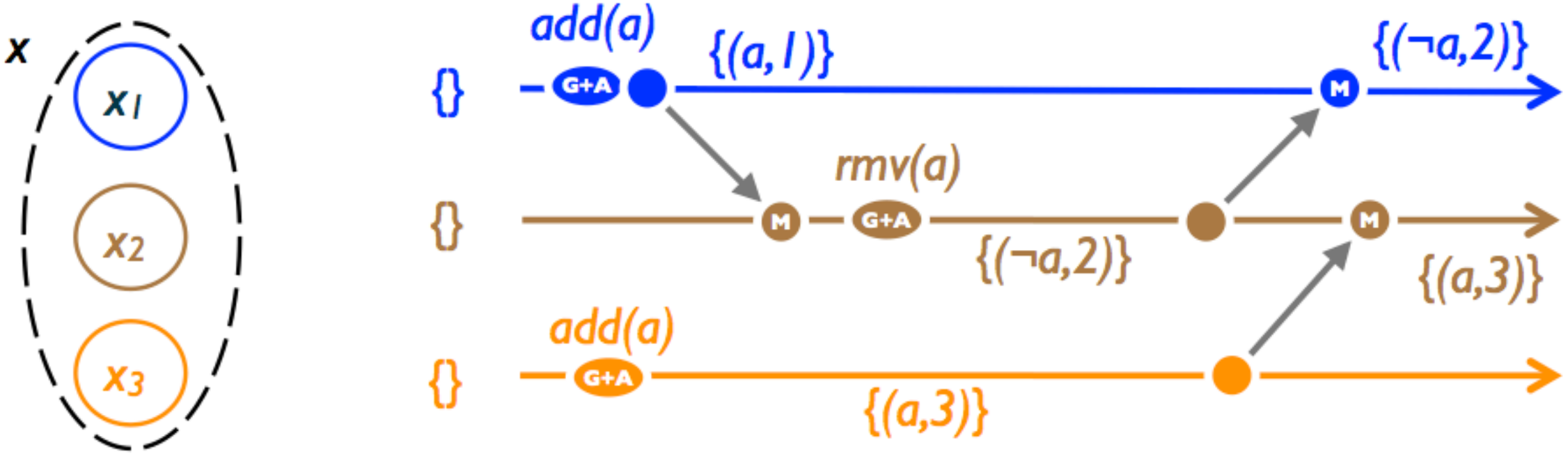
2P-Set

```
// Starts empty
{A={},R={}}

// A adds a and b, forwarding state,
// removes a
{A={a},  R={}}      // == {a}
{A={a,b},R={}}    // == {a,b}
{A={a,b},R={a}}  // == {b}

                                // B adds c
                                {A={c},R={}} // == {c}
// Merging
{A={a,b,c},R={a}}     {A={a,c},  R={}}
                                {A={a,b,c},R={}}
                                {A={a,b,c},R={a}}
// converged == {b,c}
```

LWW-Element-Set



OR-Set

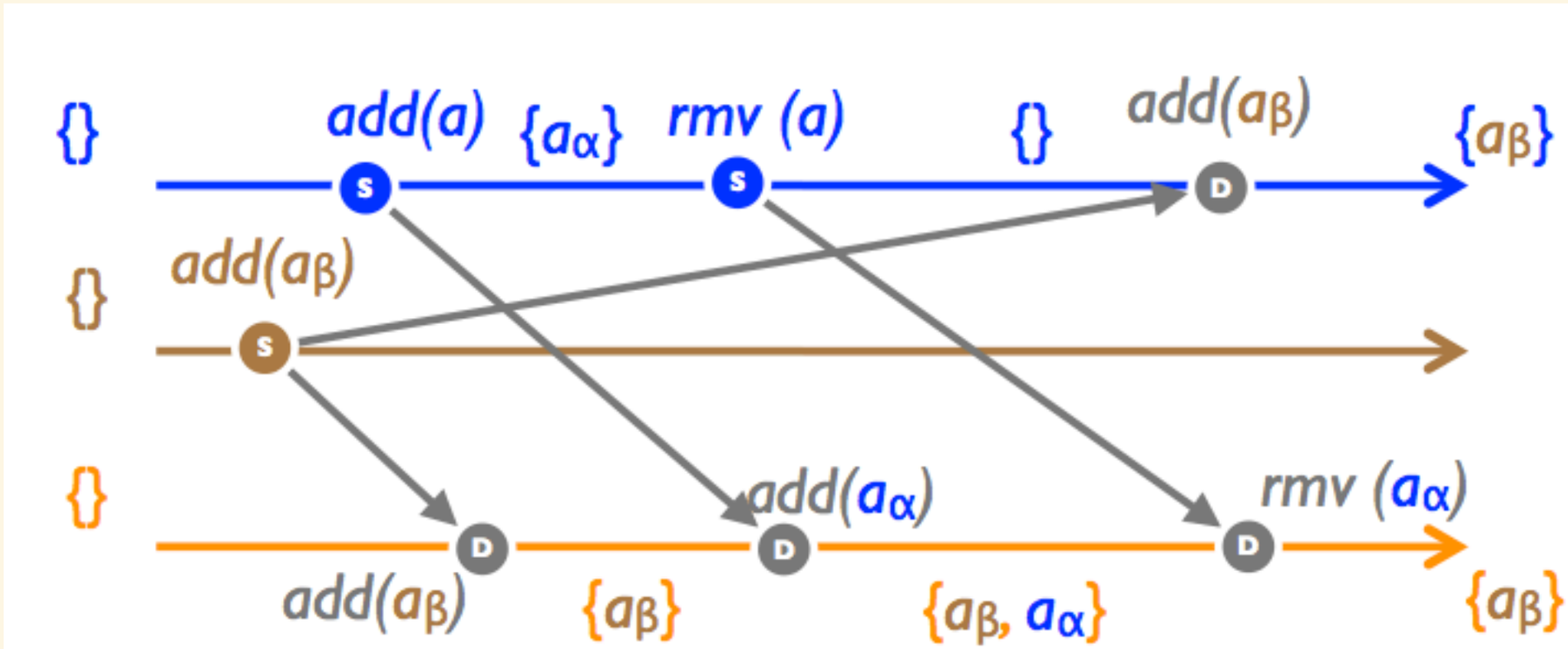
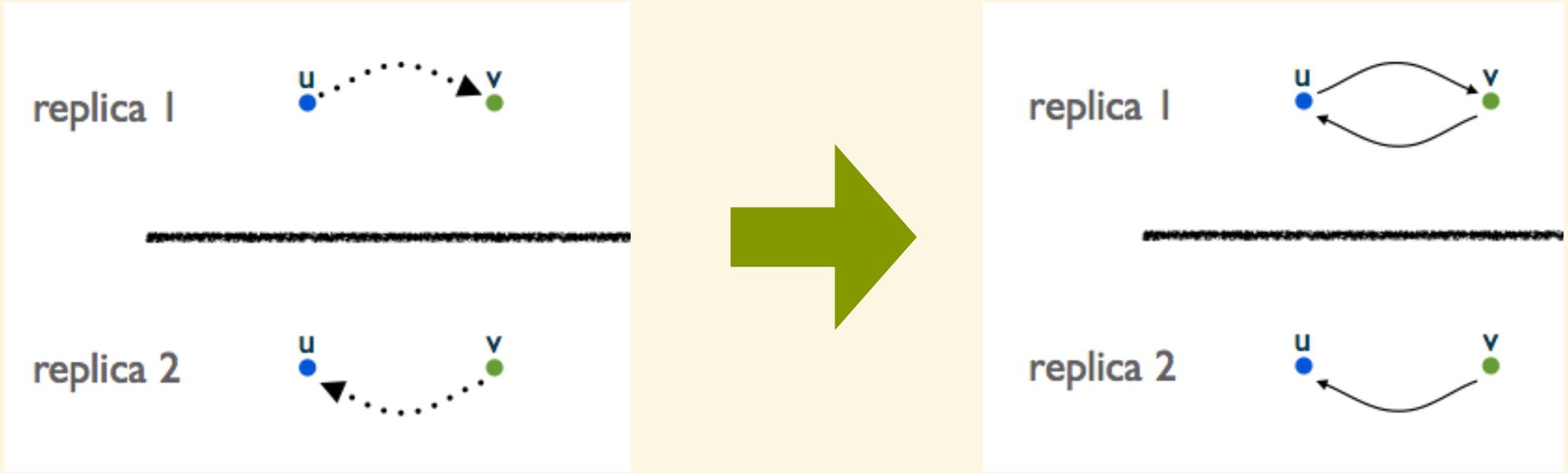


Figure 14: Observed-Remove Set (op-based)

Graphs

$$G = (V,E)$$
$$E \subseteq V \times V$$



Graphs

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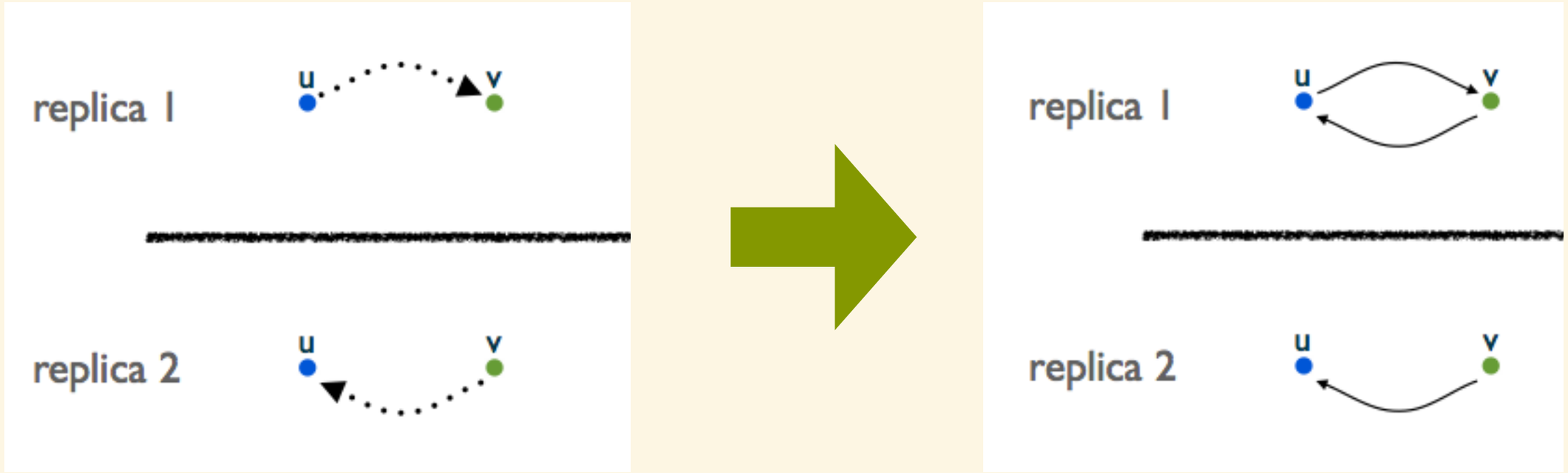

Graphs

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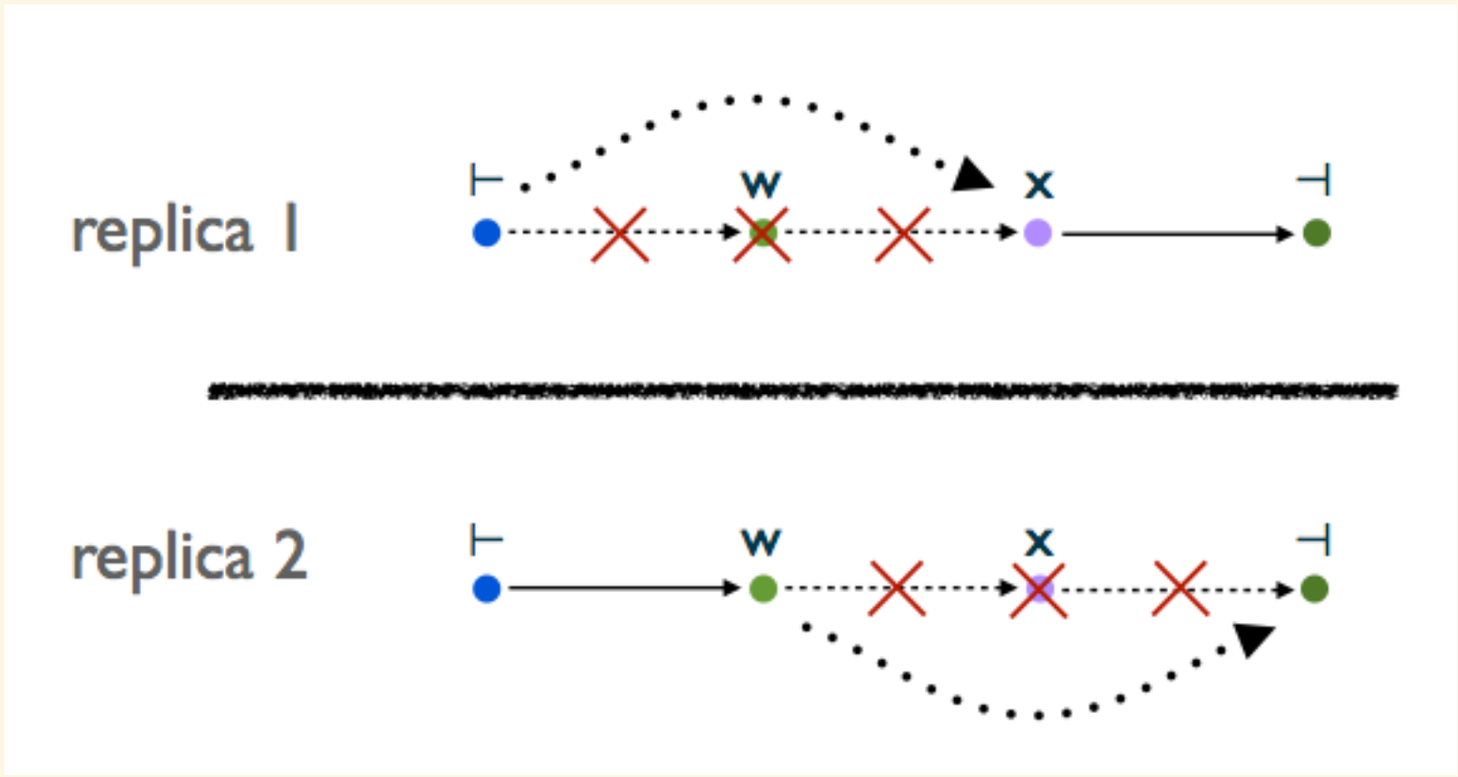

Use-Cases

- Social graph (OR-Set or a Graph)
- Web page visits (G-Counter)
- Shopping Cart (Modified OR-Set)
- “Like” button (U-Set)

Challenges: GC

- CRDTs are inefficient
- Synchronization may be required

Challenges: Responsibility

- Client
  - Erlang: `mochi/statebox`
  - Clojure: `reiddraper/knockbox`
  - Ruby: `aphyr/meangirls`, `bkerley/hanover`
- Server
  - Very few options, Riak soon

Thanks