Designing and Evaluating a Distributed Computing Language Runtime

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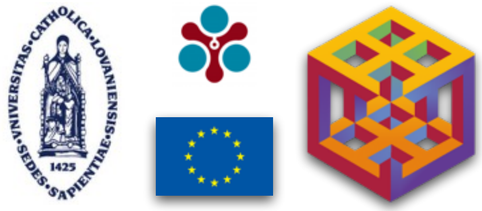
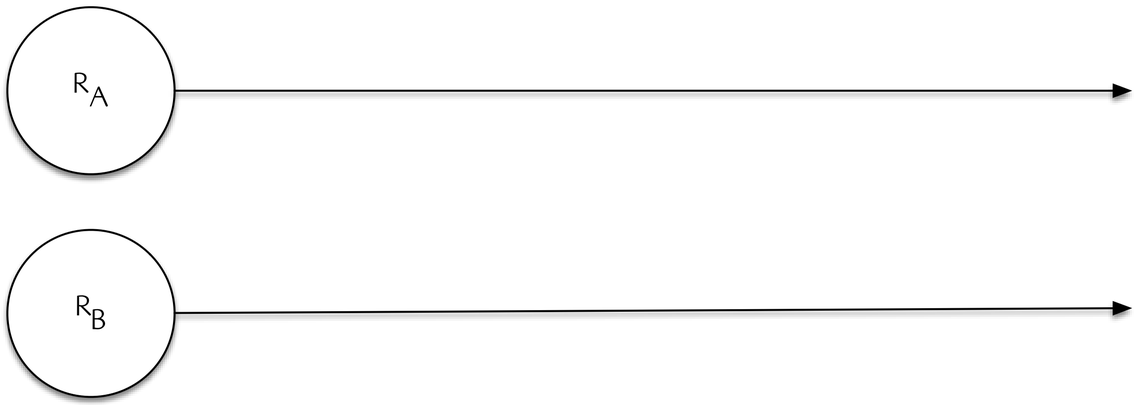
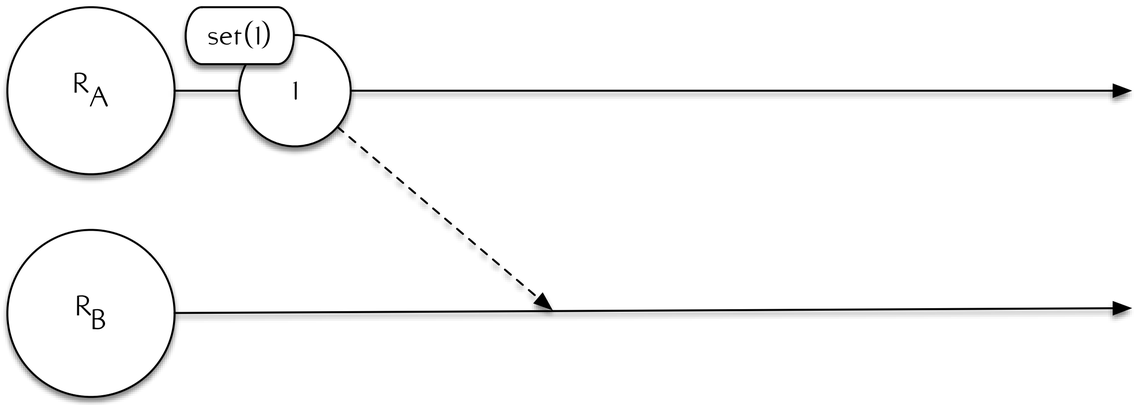
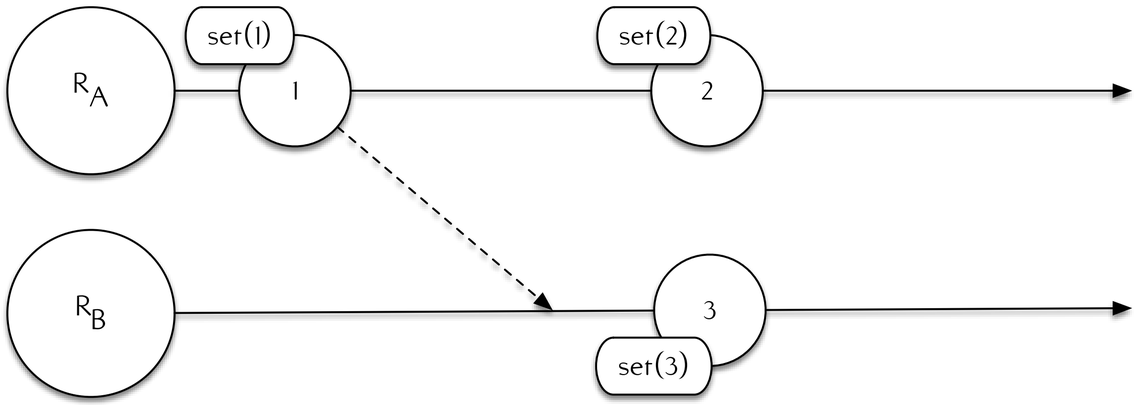
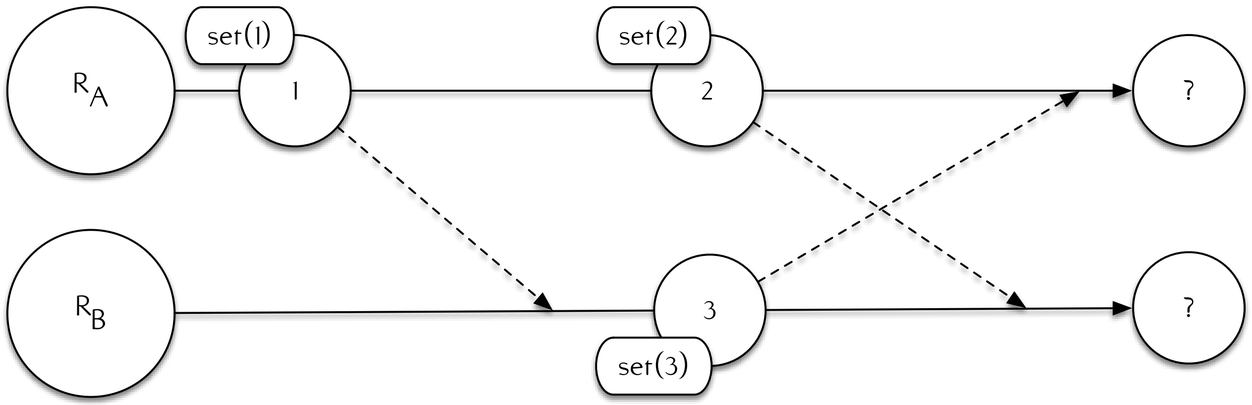
Université catholique de Louvain, Belgium




R_A
R_B


set(1)
R_A
1
R_B


set(1)
set(2)
R_A
1
2
R_B
3
set(3)


R_A
set(1)
1
set(2)
2
?
R_B
3
set(3)
?

Synchronization

- To enforce an order
  Makes programming easier

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  Prevent race conditions
- Techniques
  Locks, mutexes, semaphores, monitors, etc.

Difficult Cases

- “Internet of Things”,
  Low power, limited memory and connectivity

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- Mobile Gaming
  Offline operation with replicated, shared state

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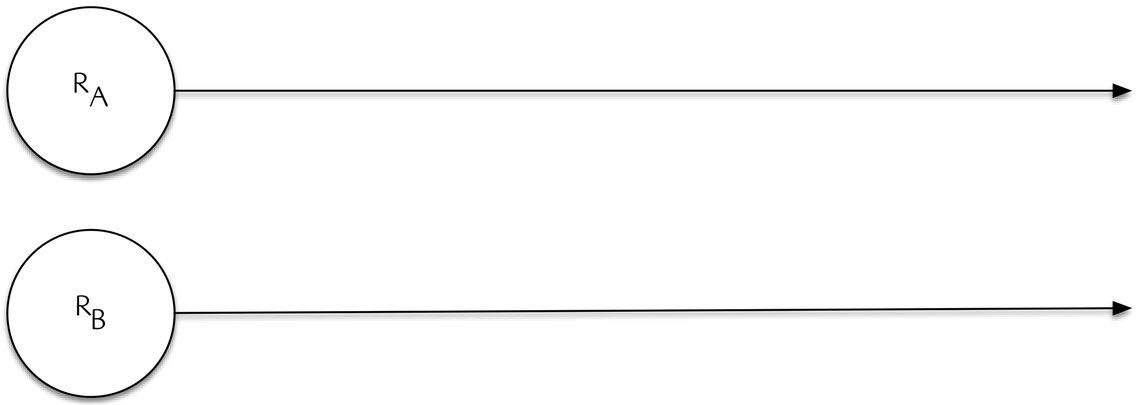
  - **Duplicate insensitive!** (Idempotent)


R_A
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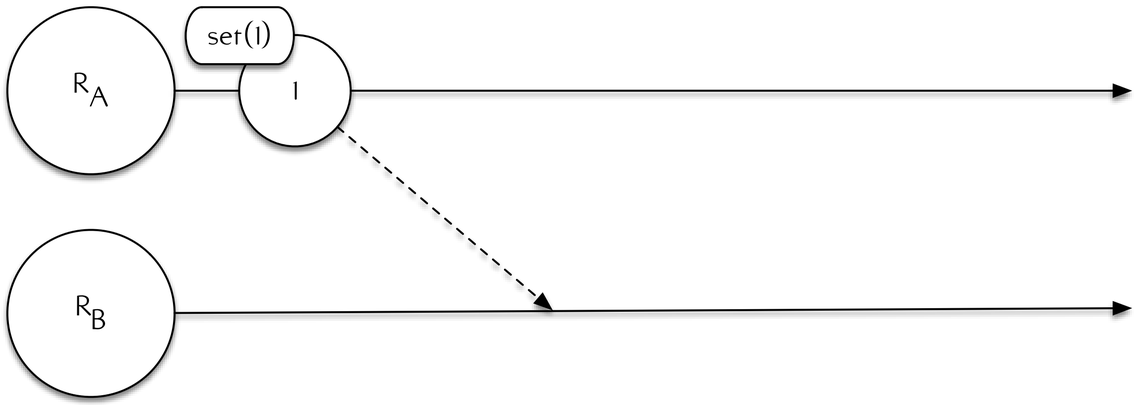
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1
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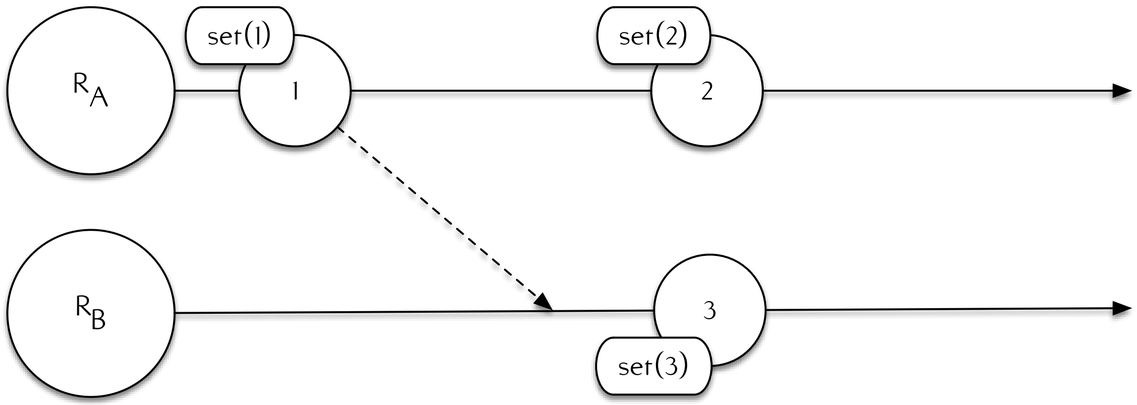
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R_A
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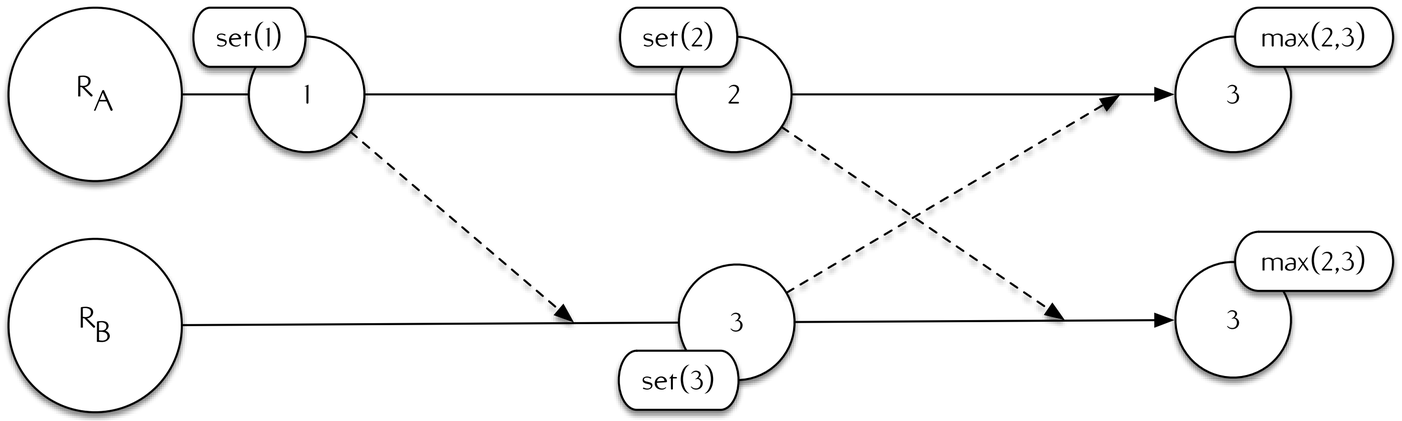
set(3)


R_A
set(1)
1
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2
max(2,3)
3
R_B
3
set(3)
max(2,3)
3

How can we succeed with **Strong Eventual Consistency?**

Programming SEC

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   (ex. deterministic, modeling non-monotonic operations monotonically)

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Convergent Objects
Conflict-Free
Replicated Data Types

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- **Many types exist with different properties**
  Sets, counters, registers, flags, maps, graphs

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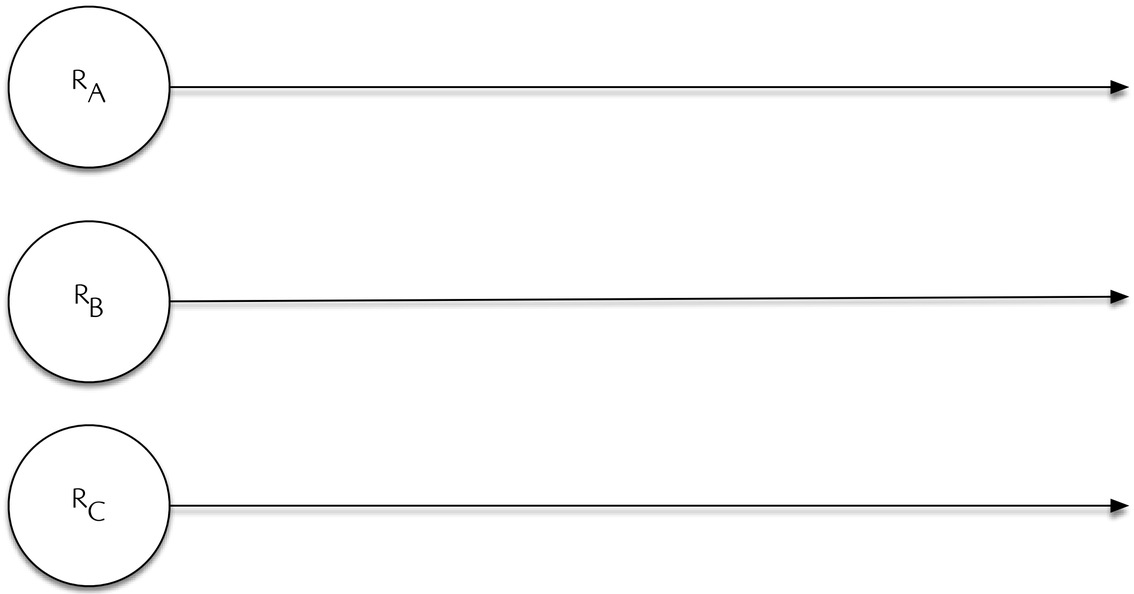
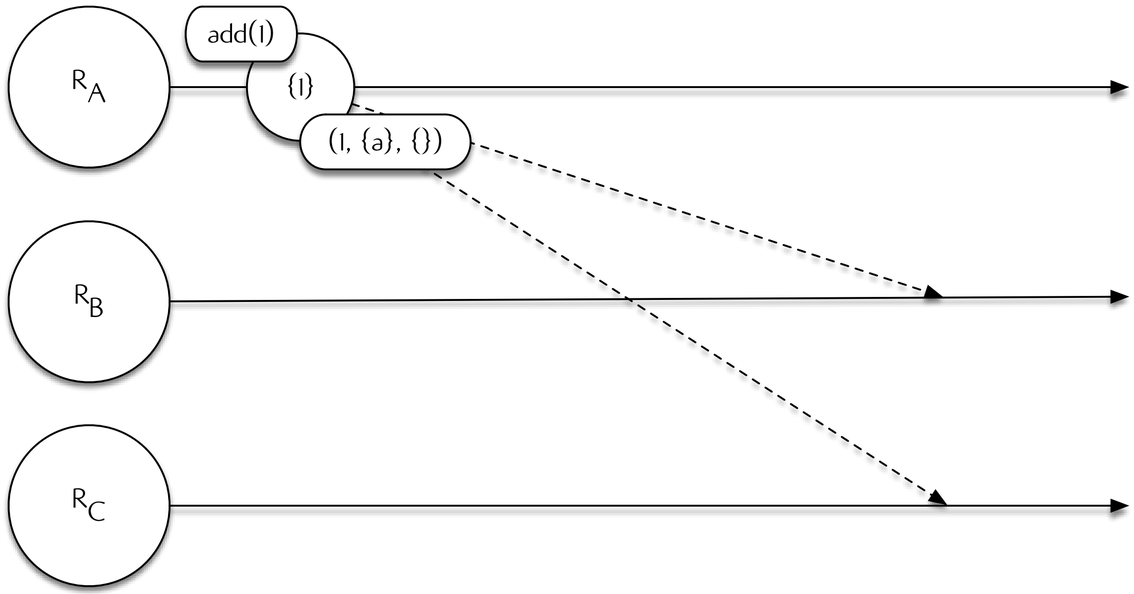
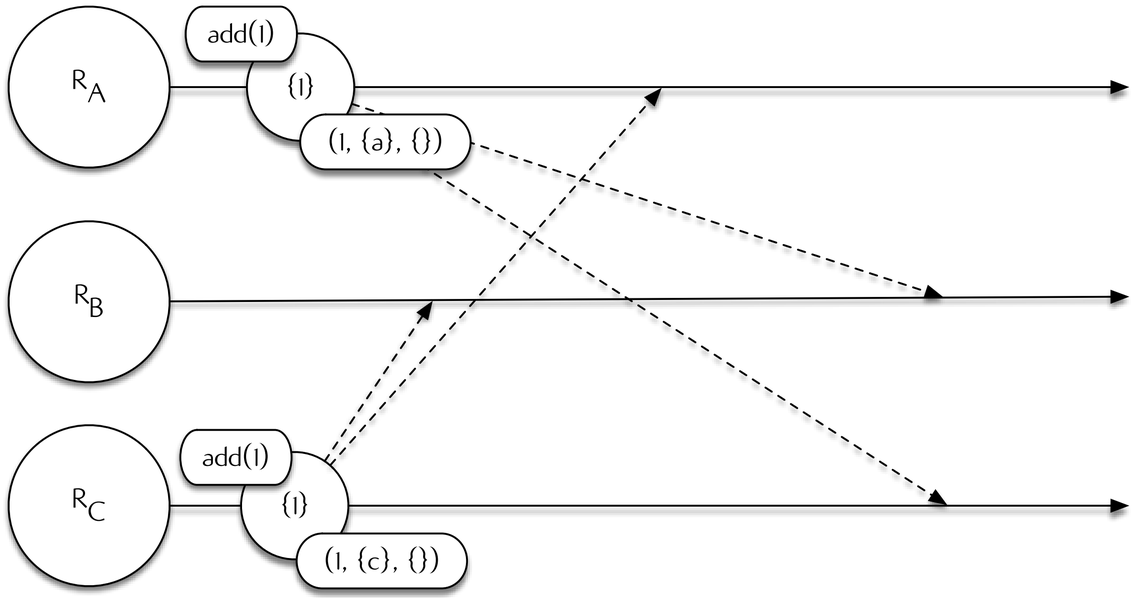
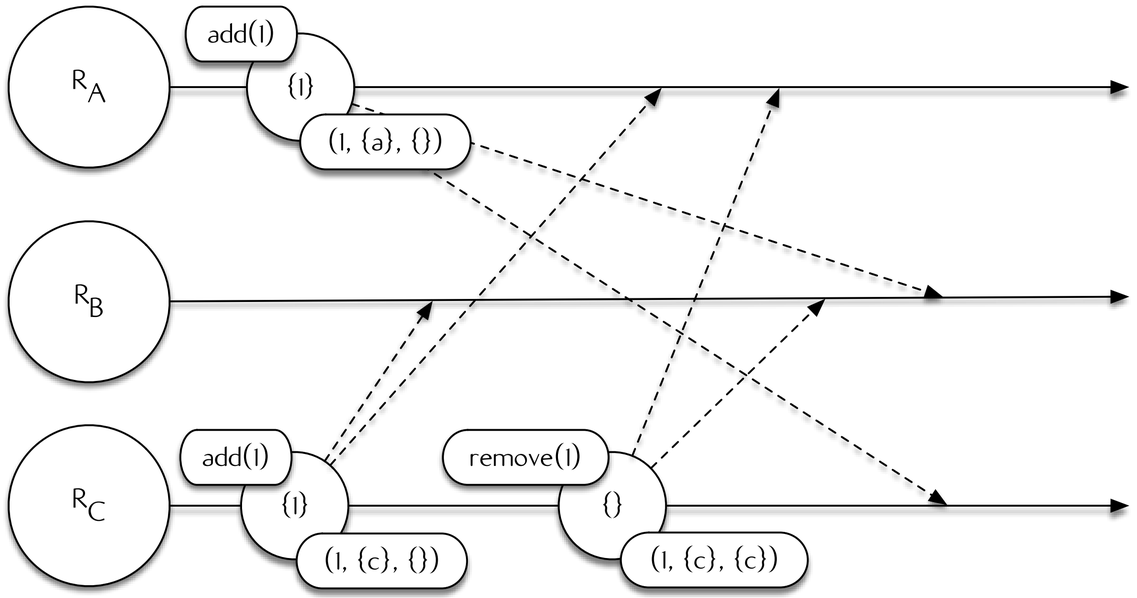
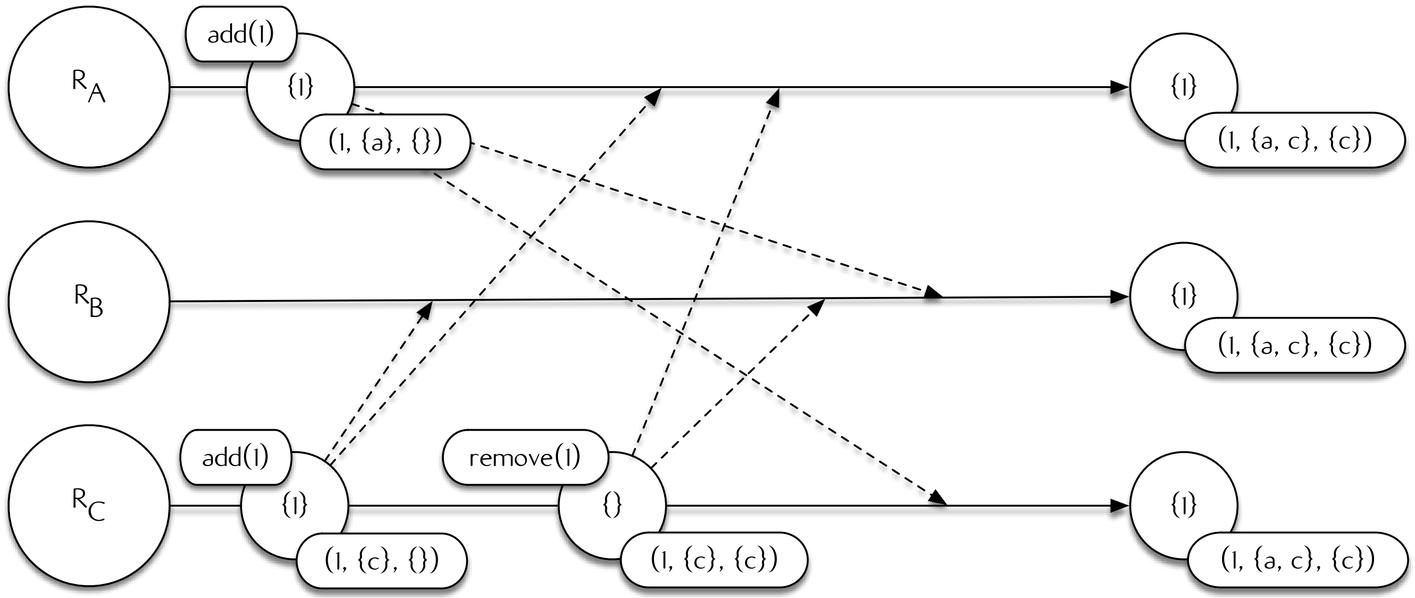
- **Many types exist with different properties**
  Sets, counters, registers, flags, maps, graphs
- **Strong Eventual Consistency**
  Instances satisfy SEC property **per-object**


R_A
R_B
R_C


add(1)
R_A
{1}
(1, {a}, {})
R_B
R_C


add(1)
R_A
{1}
(1, {a}, {})
R_B
add(1)
R_C
{1}
(1, {c}, {})


R_A
R_B
R_C
add(1)
{1}
(1, {a}, {})
add(1)
{1}
(1, {c}, {})
remove(1)
{}
(1, {c}, {c})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R_B
{1}
(1, {a, c}, {c})
R_C
add(1)
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Convergent Programs
Lattice Processing

Lattice Processing (Lasp)

- **Distributed dataflow**
  Declarative, functional programming model

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- **Distributed dataflow**
  Declarative, functional programming model
- **Convergent data structures**
  Primary data abstraction is the CRDT
- **Enables composition**
  Provides functional composition of CRDTs that **preserves the SEC property**

```
%% Create initial set.
S1 = declare(set),

%% Add elements to initial set and update.
update(S1, {add, [1,2,3]}),

%% Create second set.
S2 = declare(set),

%% Apply map operation between S1 and S2.
map(S1, fun(X) -> X * 2 end, S2).
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Distributed Runtime
Selective Hearing

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- Epidemic broadcast based runtime system
  Provide a runtime system that can scale to large numbers of nodes, that is resilient to failures and provides efficient execution

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  - Epidemic broadcast mechanisms provide weak ordering but are resilient and efficient
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- "Selective Receive"
  Nodes selectively receive and process messages based on interest.

Layered Approach

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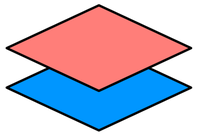
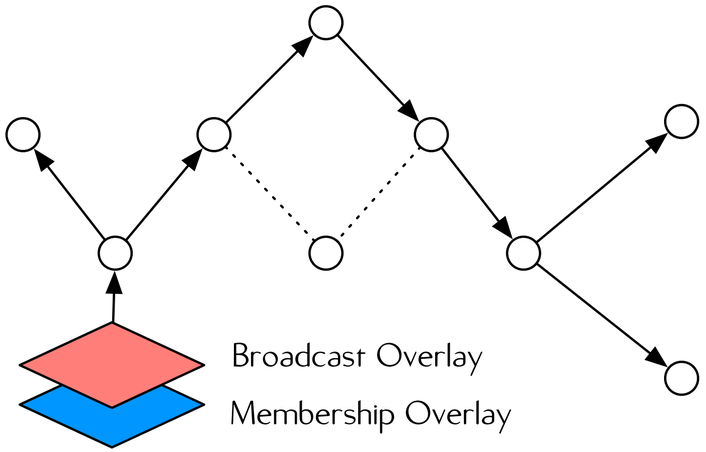
- Auto-discovery
  Integration with Mesos, auto-discovery of Lasp nodes for ease of configurability

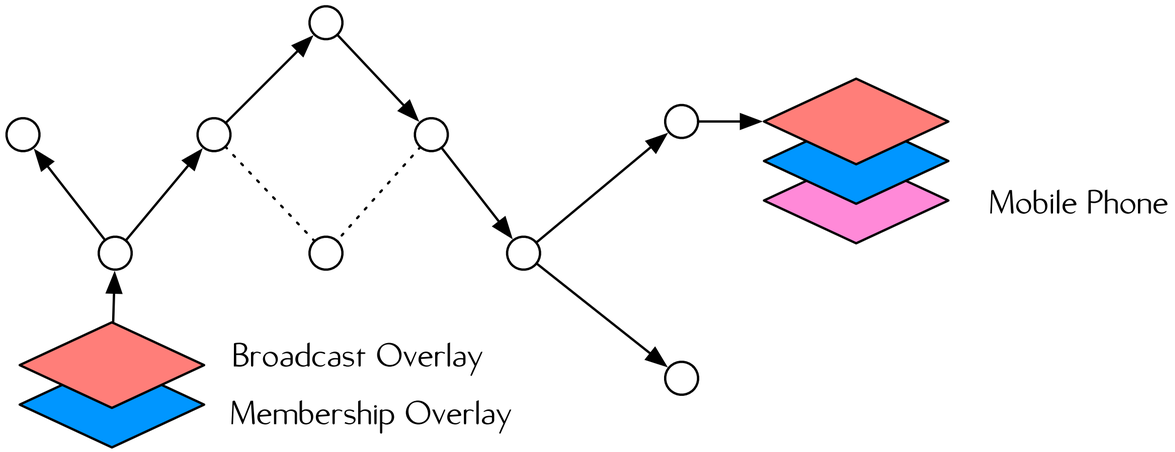

Membership Overlay

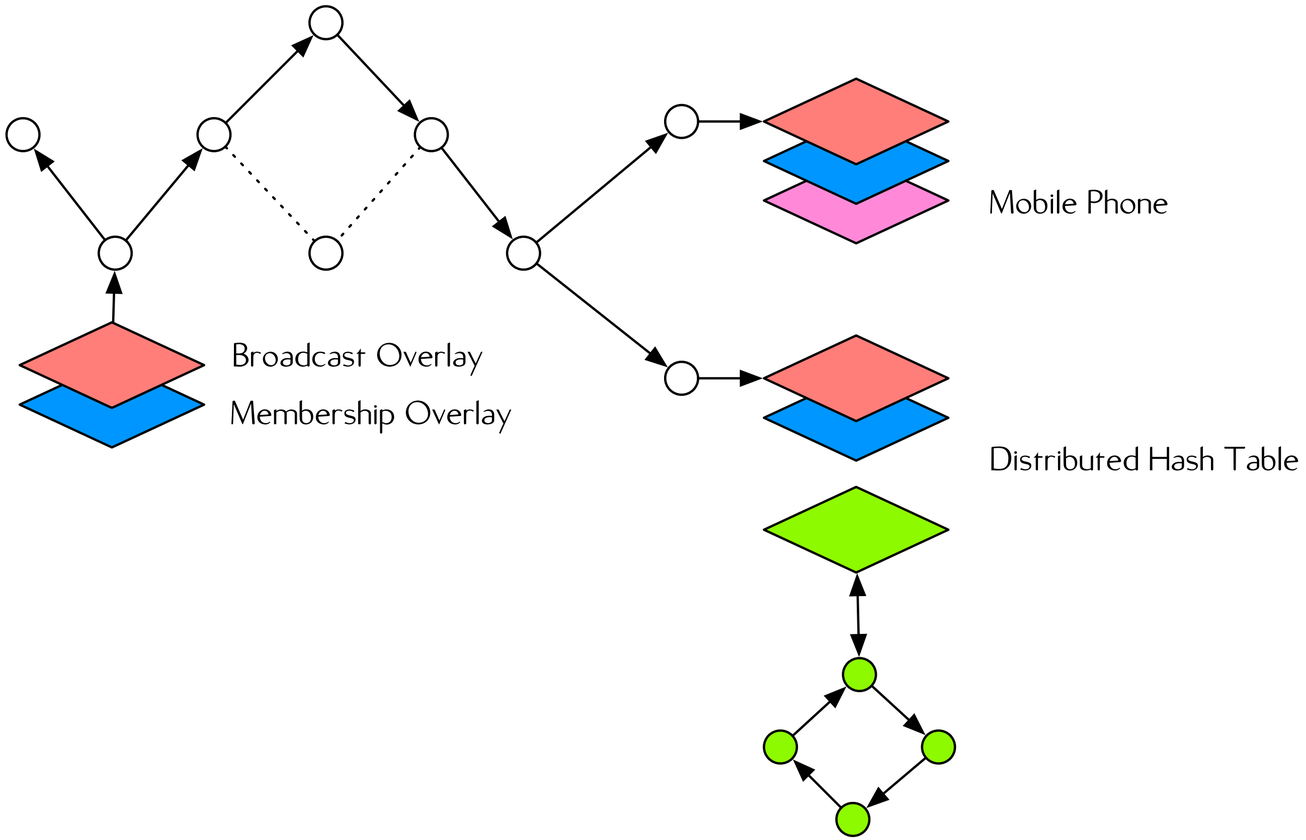


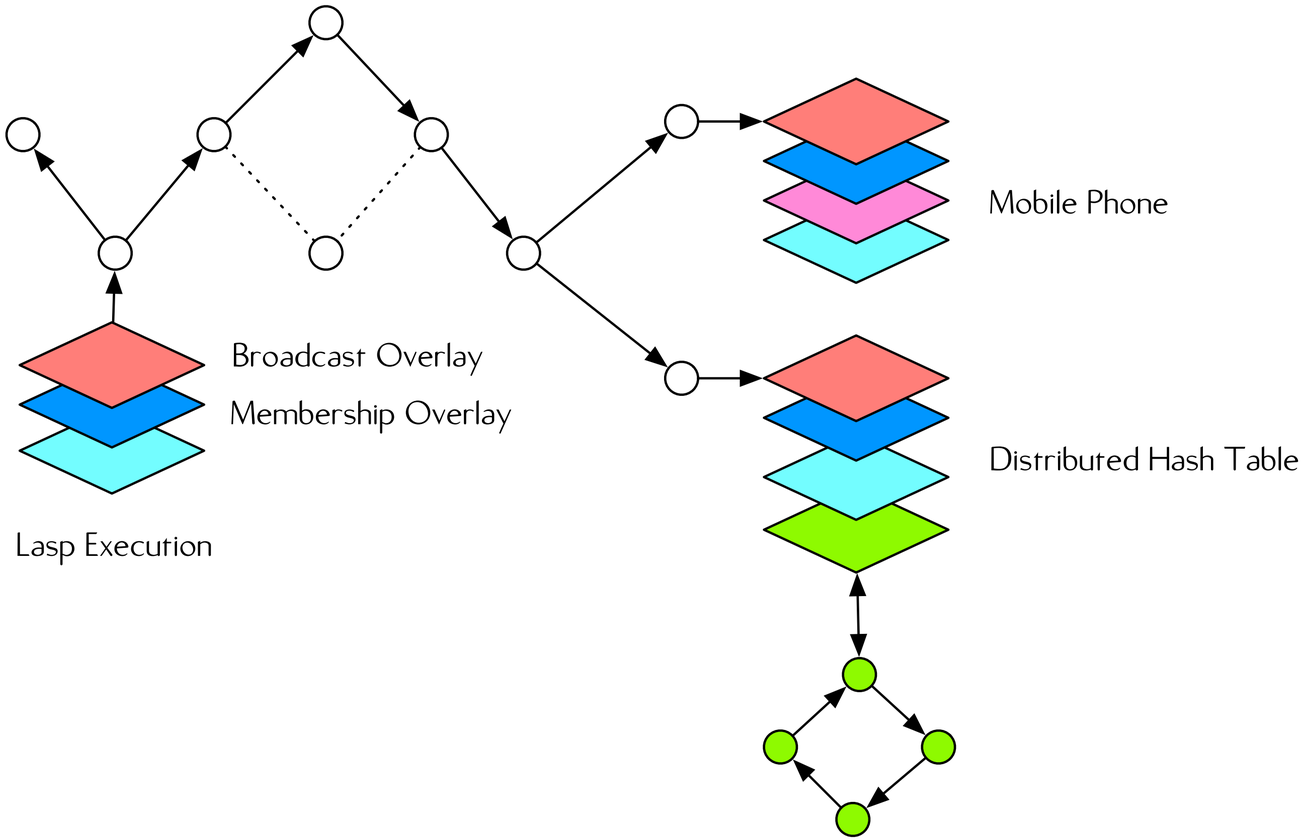
Broadcast Overlay

Membership Overlay


Broadcast Overlay
Membership Overlay


Mobile Phone
Broadcast Overlay
Membership Overlay


Mobile Phone
Broadcast Overlay
Membership Overlay
Distributed Hash Table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Lasp Execution

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What can we build?

Advertisement Counter

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- Mobile game platform selling advertisement space
  Advertisements are paid according to a minimum number of impressions

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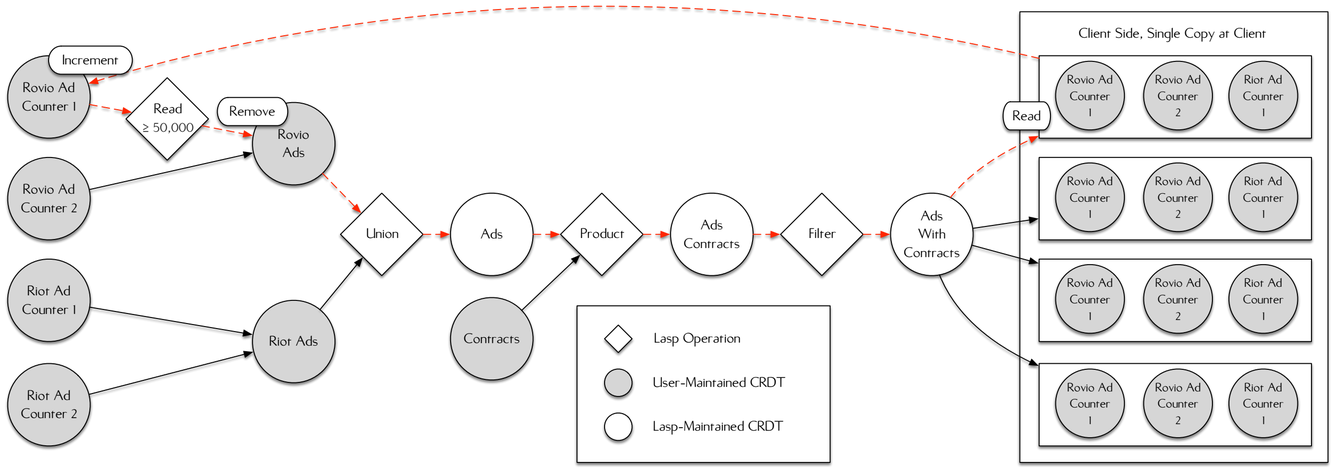
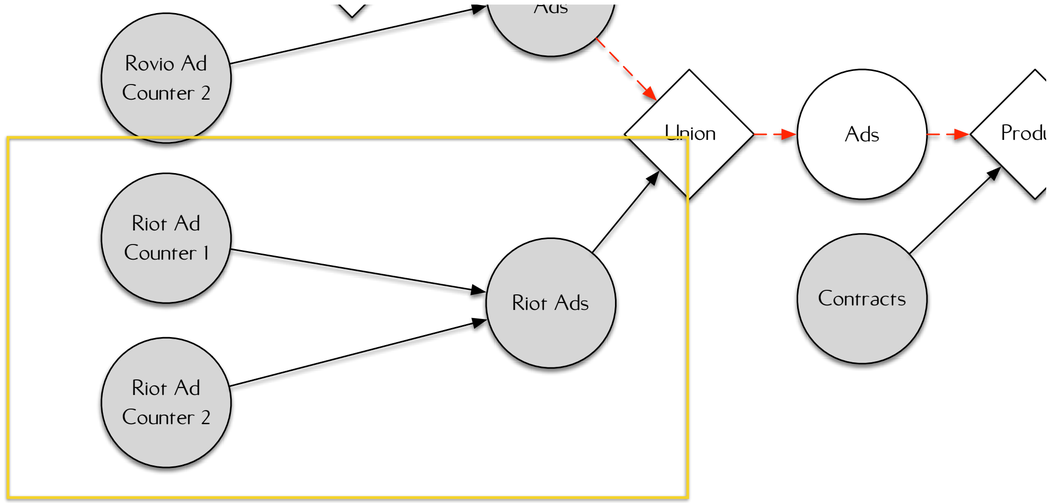
- Clients will go offline
  Clients have limited connectivity and the system still needs to make progress while clients are offline


Increment
Rovio Ad Counter 1
Read ≥ 50,000
Remove
Rovio Ads
Rovio Ad Counter 2
Riot Ad Counter 1
Riot Ads
Riot Ad Counter 2
Union
Ads
Contracts
Product
Ads Contracts
Filter
Ads With Contracts
Read
Client Side, Single Copy at Client
Rovio Ad Counter 1
Rovio Ad Counter 2
Riot Ad Counter 1
Lasp Operation
User-Maintained CRDT
Lasp-Maintained CRDT


Rovio Ad
Counter 2
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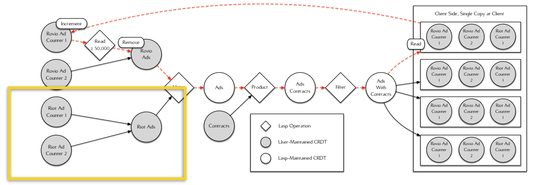

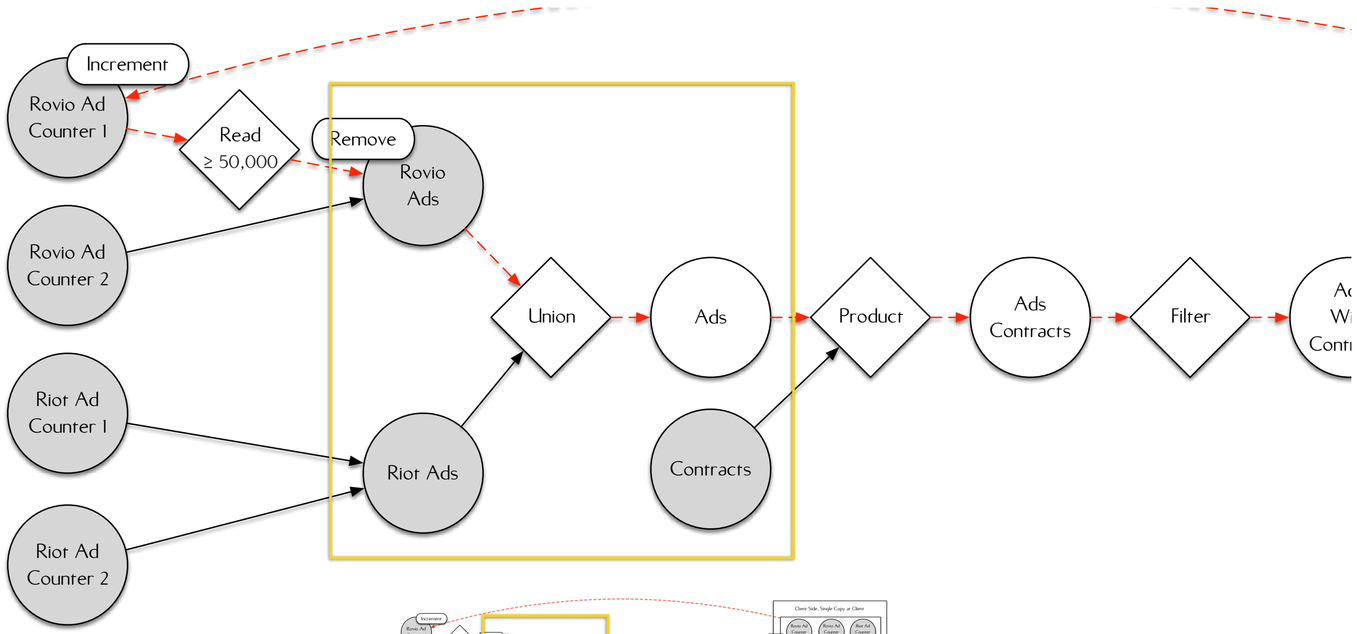
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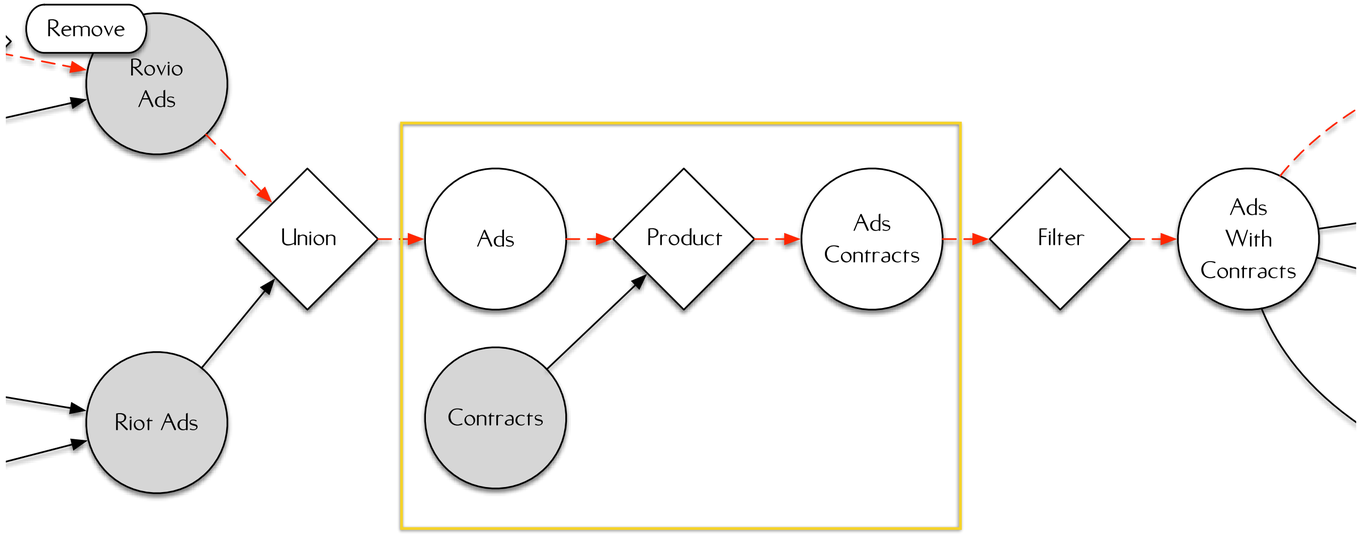
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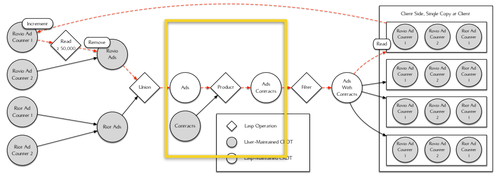

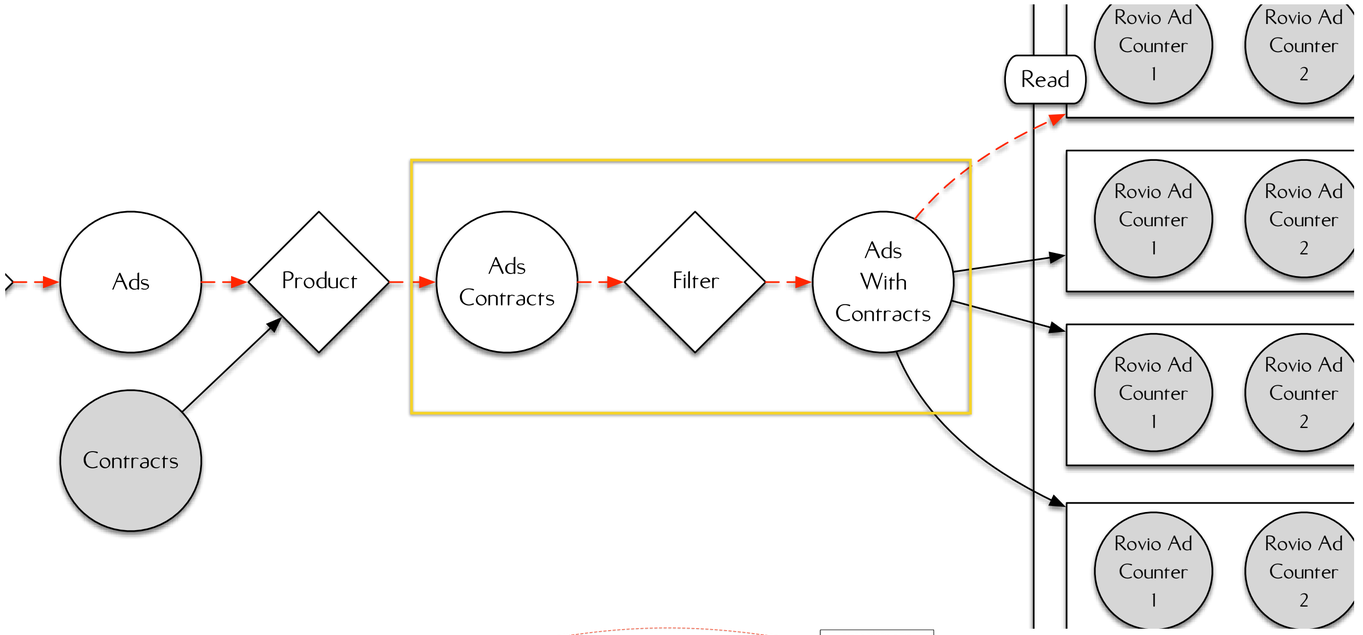
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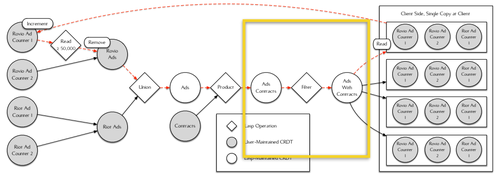

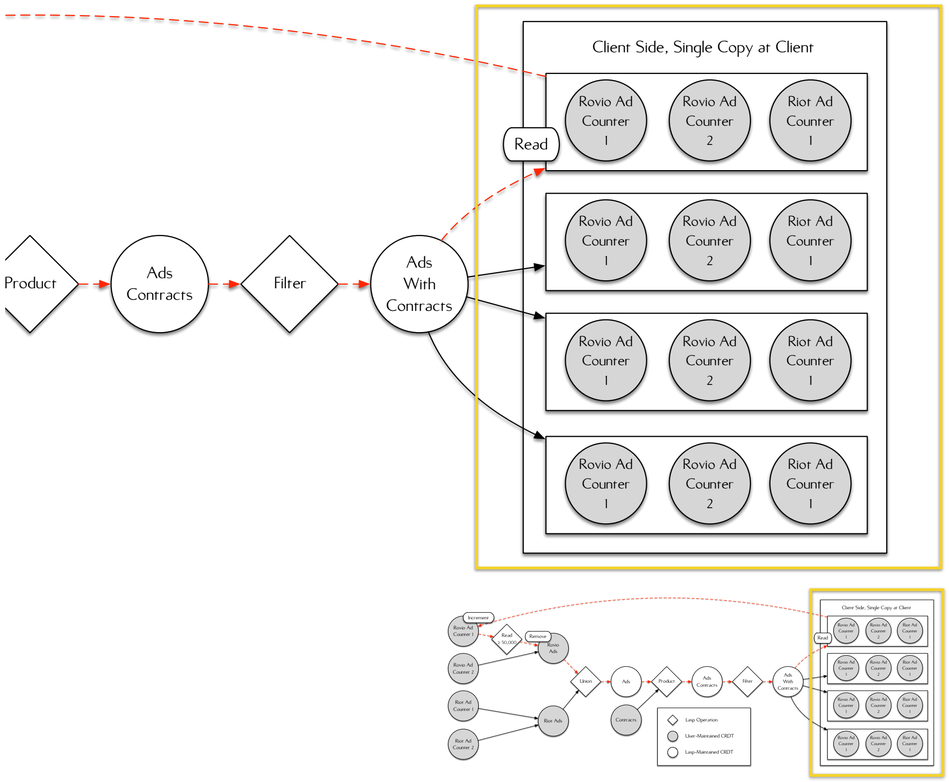
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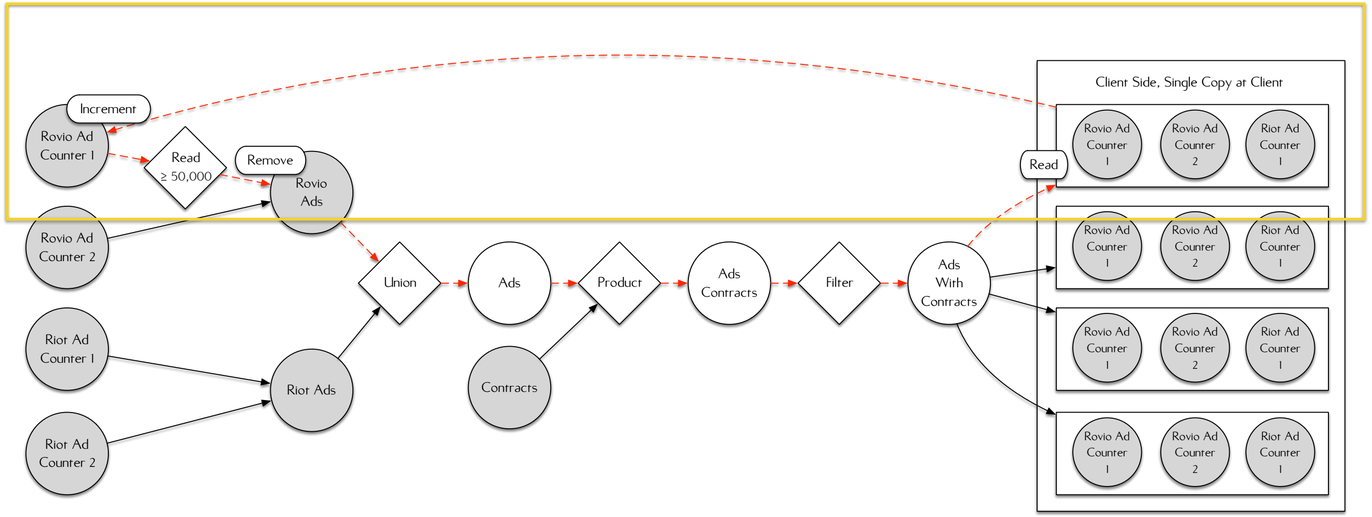
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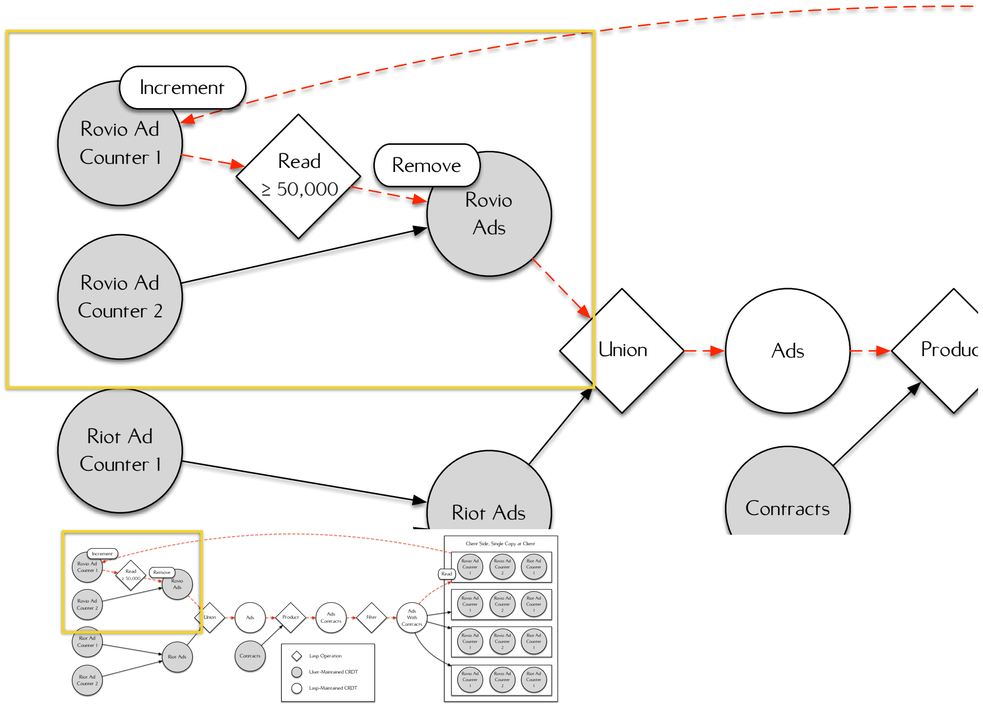
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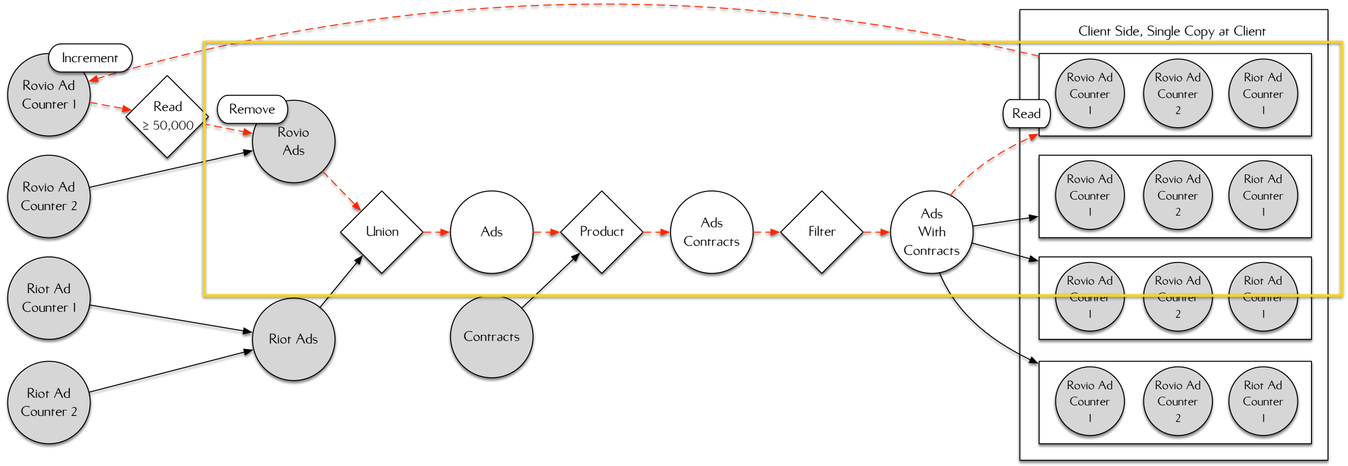
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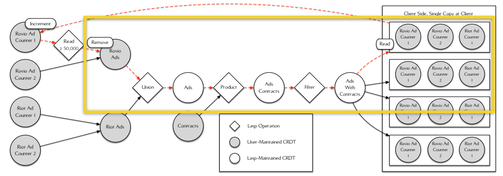

Evaluation
Initial Evaluation

Background
Distributed Erlang

- Transparent distribution
  Built-in, provided by Erlang/BEAM, cross-node message passing.

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Distributed Erlang

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  - Single connection
    Head of line blocking.
  - Full membership
    All-to-all failure detection with heartbeats and timeouts.

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Erlang Port Mapper Daemon

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- Bridged networking
  Problematic for cluster in bridged networking with dynamic port allocation.

Experiment Design

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- Membership
  Full membership with Distributed Erlang via EPMD.
- Dissemination
  State-based object dissemination through anti-entropy protocol (fanout-based, PARC-style.)

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- Docker and Mesos with Marathon
  Used for deployment of both EPMD and Lasp application.

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  Local execution using host networking: connects to local EPMD.

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- **Single EPMD instance per slave**
  Controlled through the use of host networking and HOSTNAME: UNIQUE constraints in Mesos.
- **Lasp**
  Local execution using host networking: connects to local EPMD.
- **Service Discovery**
  Service discovery facilitated through clustering EPMD instances through **Sprinter.**

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- Local Deployment
  High thread concurrency when operating with lower node count.

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- Cloud Deployment
  Low thread concurrency when operating with a higher node count.

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  Environments too different: too much work needed to be adapted for things to work correctly.

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    Events immediately dispatched: would require blocking for processing acknowledgment.

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  - Bottleneck
    Events immediately dispatched: would require blocking for processing acknowledgment.
  - Unrealistic
    Events do not queue up all at once for processing by the client.

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  1000 threads to a single dissemination process (one Mesos task) leads to backed up message queues and memory leaks.
- Unrealistic
  Two different dissemination mechanisms: thread to thread and node to node: one is synthetic.

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- EPMD task restarted by Mesos
  Restarted for an unknown reason, which leads Lasp instances to restart in their own container.

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- Unbounded queues
  Message buffers would lead to VMs crashing because of large memory consumption.

Evaluation

Rearchitecture

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  Integrate pluggable membership service throughout the stack and librate existing libraries from distributed Erlang.

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- Pluggable membership service
  Build pluggable membership service with abstract interface initially on EPMD and later migrate after tested.
- Adapt Lasp and Broadcast layer
  Integrate pluggable membership service throughout the stack and librate existing libraries from distributed Erlang.
- Build service discovery mechanism
  Mechanize node discovery outside of EPMD based on new membership service.

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  Allow runtime configuration of protocols used for cluster membership.

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  - Peer-to-peer membership via TCP (with HyParView)
- Visualization
  Provide a force-directed graph-based visualization engine for cluster debugging in real-time.

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  Heartbeat interval increases when node count increases leading to false or delayed detection.
- Testing
  Used to create the initial test suite for Partisan.

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- Failure detection
  Nodes heartbeat with timeout all peers they are aware of.
- Limited scalability
  Single point of failure: server; with limited scalability on visibility.
- Testing
  Used for baseline evaluations as “reference” architecture.

Partisan
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- Partial view protocol
  Two views: active (fixed) and passive (log n); passive used for failure replacement with active view.

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- Partial view protocol
  Two views: active (fixed) and passive (log n); passive used for failure replacement with active view.

- Failure detection
  Performed by monitoring active TCP connections to peers with keep-alive enabled.

- Very scalable (10k+ nodes during academic evaluation)
  However, probabilistic; potentially leads to isolated nodes during churn.

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- Responsible for clustering tasks
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- Node local
  Operates at each node and is responsible for taking actions to ensure connected graph: required for probabilistic protocols.
- Membership mode specific
  Knows, based on the membership mode, how to properly cluster nodes and enforces proper join behaviour.

Debugging Sprinter

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  - Periodic alerting
    Alerts regarding disconnected graphs so external measures can be taken, if necessary.

Evaluation

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- Deployment and runtime configuration
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    Automatically generate plots for the execution and aggregate the results of multiple executions.
- Minimal coordination
  Work must be performed with minimal coordination, as a single orchestrator is a scalability bottleneck for large applications.

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    Upon log aggregation completion, nodes shutdown.
- External monitoring
  When events complete execution, nodes automatically begin the next experiment.

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- Results
  Reduced Lasp memory footprint to 75MB; larger in practice for debugging.

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- Pluggable protocol helps debugging
  Being able to switch to full membership or client-server assists in debugging protocol vs. application problems.

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- **Mean state reduction per client**
  Around 100x improvement from our PaPoC 2016 initial evaluation results.

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  Graph performance, visualize your cluster: all of these things lead to easier debugging.

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- Automation
  Developers use graphs when they are easy to make: lower the difficulty for generation and understand how changes alter system behaviour.
- Make work easily testable
  When you test locally and deploy globally, you need to make things easy to test, deploy and evaluate (for good science, I say!)

Thanks!

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