<~ bloom

Disorderly programming for a distributed world

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Joint work

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BERKELEY Database Research

BOOM
Berkeley Orders Of Magnitude

Thanks to

- National Science Foundation
- Air Force Office of Scientific Research
- Gifts from IBM, Microsoft and Yahoo! Research

The future is already here

- All systems are (or are becoming) distributed
- Programming distributed systems is hard
- Reasoning about them is harder

Outline

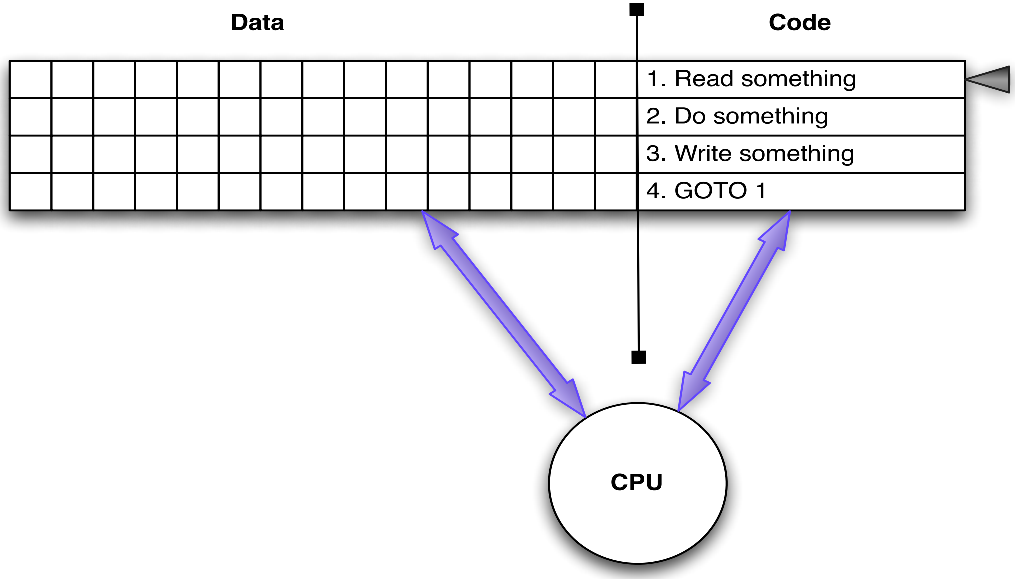
1. Disorderly Programming
2. The Bloom programming language
3. CALM Analysis and visualization
4. Challenge app: replicated shopping carts

Programming distributed systems

The state of the art

Order is pervasive in the Von Neumann model

- Program state is an ordered array
- Program logic is a sequence of instructions



The state of the art

Order is pervasive in the Von Neumann model

Parallelism and concurrency via retrofits:

- Threads
- Event-driven programming

The state of the art

In distributed systems, order is

The state of the art

In distributed systems, order is

- expensive to enforce

The state of the art

In distributed systems, order is

- expensive to enforce
- often unnecessary

The state of the art

In distributed systems, order is

- expensive to enforce
- often unnecessary
- easy to get wrong

The state of the art

art of the state

The art of the state

Disorderly programming

The art of the state

Disorderly programming:

Computation as transformation

The art of the state

Disorderly programming:

- Program state is unordered collections
- Program logic is an unordered ``bag'' of rules

The art of the state

Disorderly programming:

- Independence and concurrency are assumed
- Ordering is *explicit*

The art of the state

Disorderly programming

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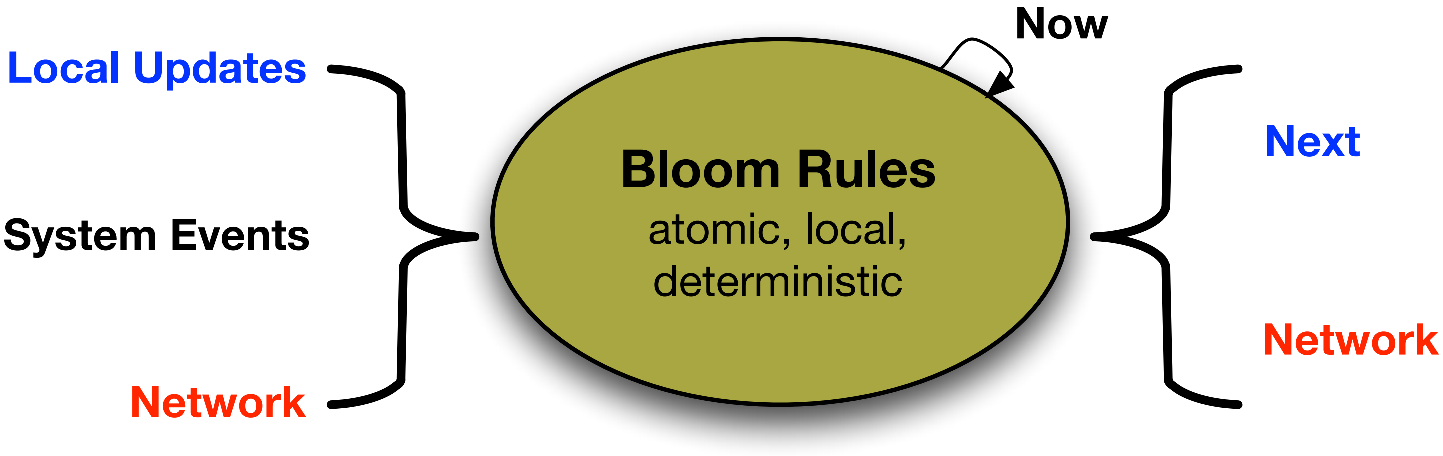
BUD: Bloom Under Development

- Ruby internal DSL
- Set comprehension style of programming
- Declarative semantics

Operational model

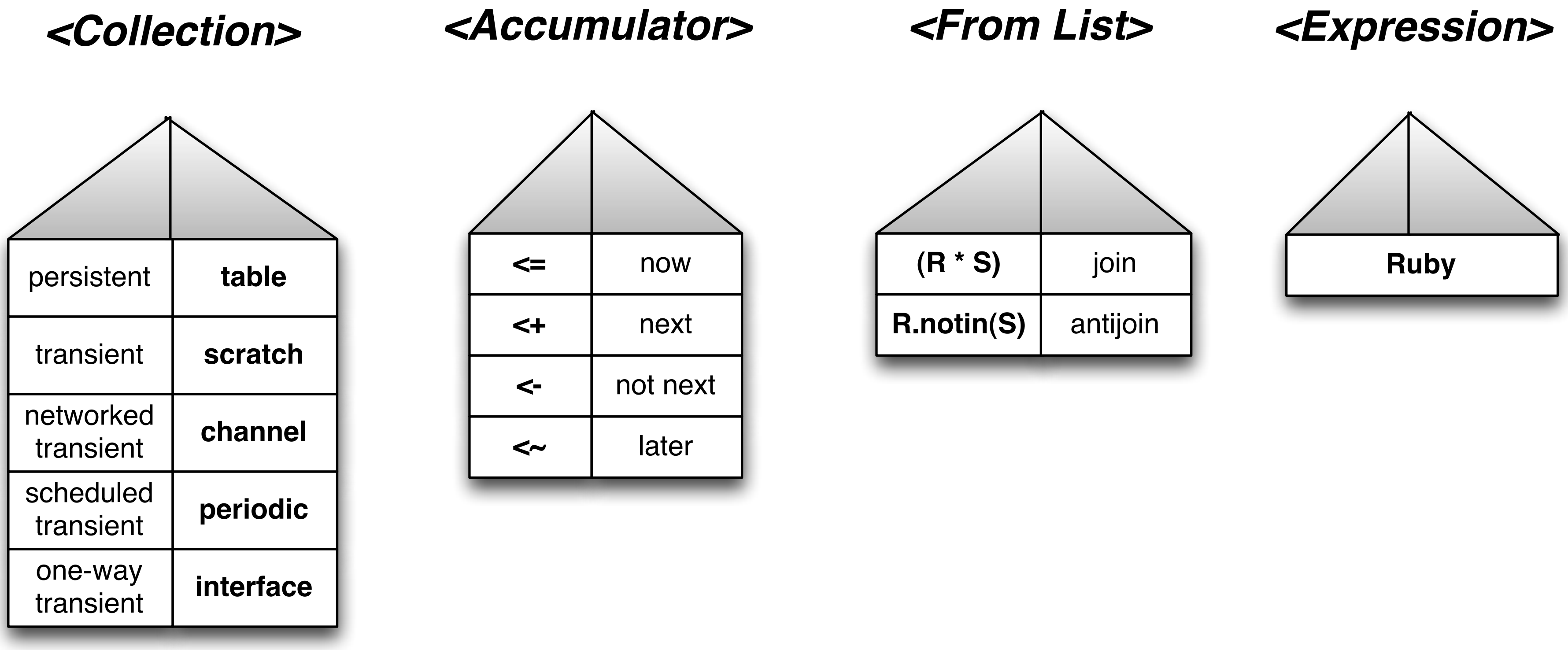


Bloom Rules

```
multicast <~ (message * members)   do |mes, mem|
  [mem.address, mes.id, mes.payload]
end
```

Bloom Rules

```
multicast <~ (message * members)   do |mes, mem|
  [mem.address, mes.id, mes.payload]
end
```



<Collection>

persistent	**table**
transient	**scratch**
networked transient	**channel**
scheduled transient	**periodic**
one-way transient	**interface**

<Accumulator>

<=	now
<+	next
<-	not next
<~	later

<From List>

(R * S)	join
R.notin(S)	antijoin

<Expression>

Ruby

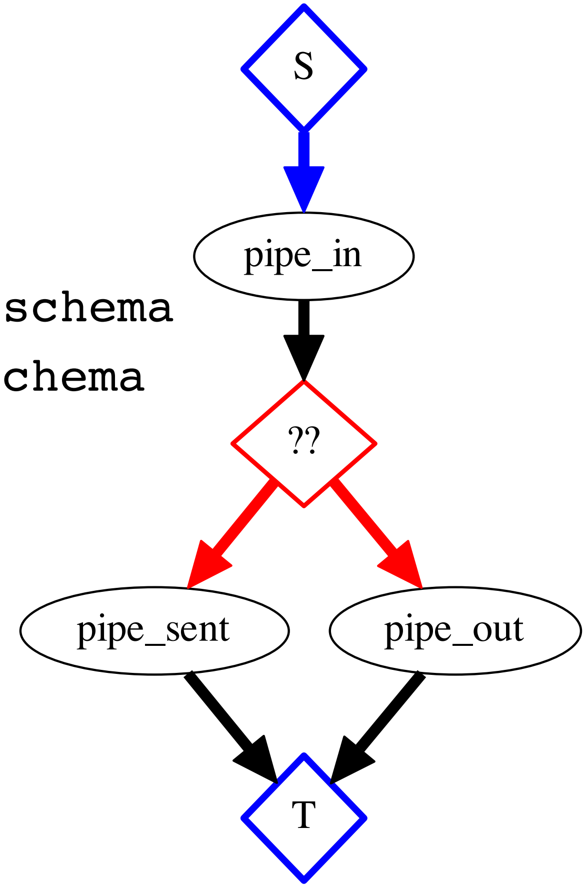
Bud language features

- Module system
  - Encapsulation and composition via mixins
  - Abstract interfaces, concrete implementations
- Metaprogramming and reflection
  - The program is data
- Pay-as-you-code schemas
  - Default is key => value
- CALM Analysis

Writing distributed programs in Bloom

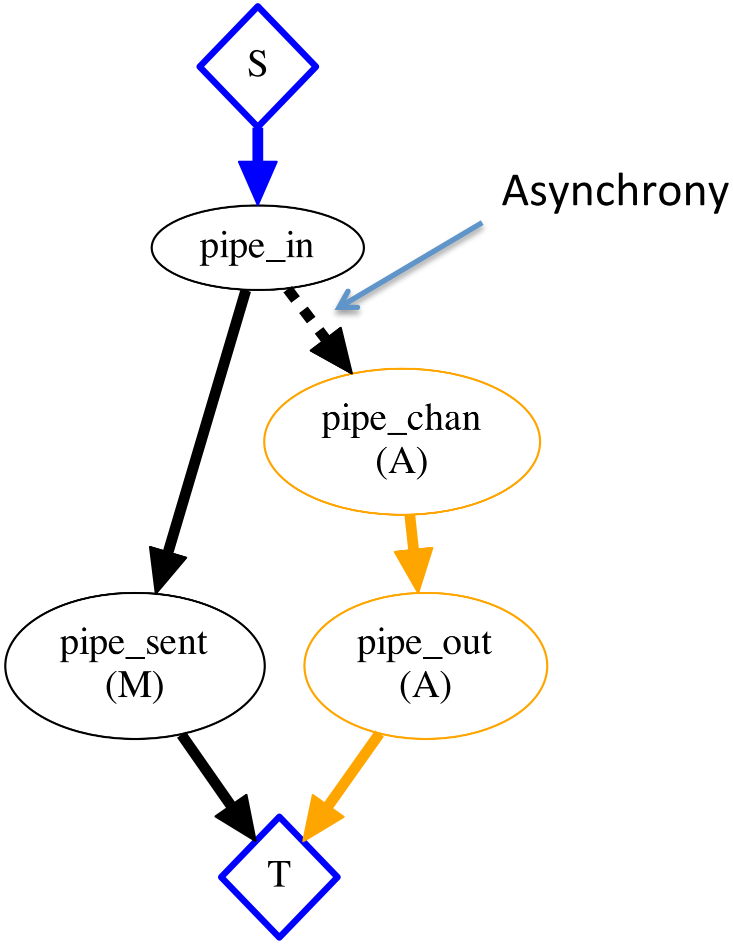
Abstract Interfaces and Declarations

```
module DeliveryProtocol
  state do
    interface input, :pipe_in,
      [:dst, :src, :ident] => [:payload]
    interface output, :pipe_sent, pipe_in.schema
    interface output, :pipe_out, pipe_in.schema
  end
end
```



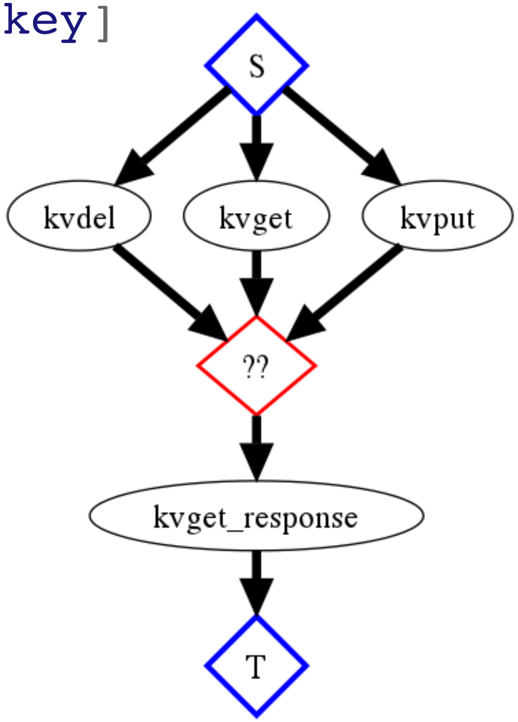
Concrete Implementations

```
module BestEffortDelivery
  include DeliveryProtocol

  state do
    channel :pipe_chan, pipe_in.schema
  end

  bloom :snd do
    pipe_chan <~ pipe_in
  end

  bloom :done do
    pipe_sent <= pipe_in
    pipe_out <= pipe_chan
  end
end
```



A simple key/value store

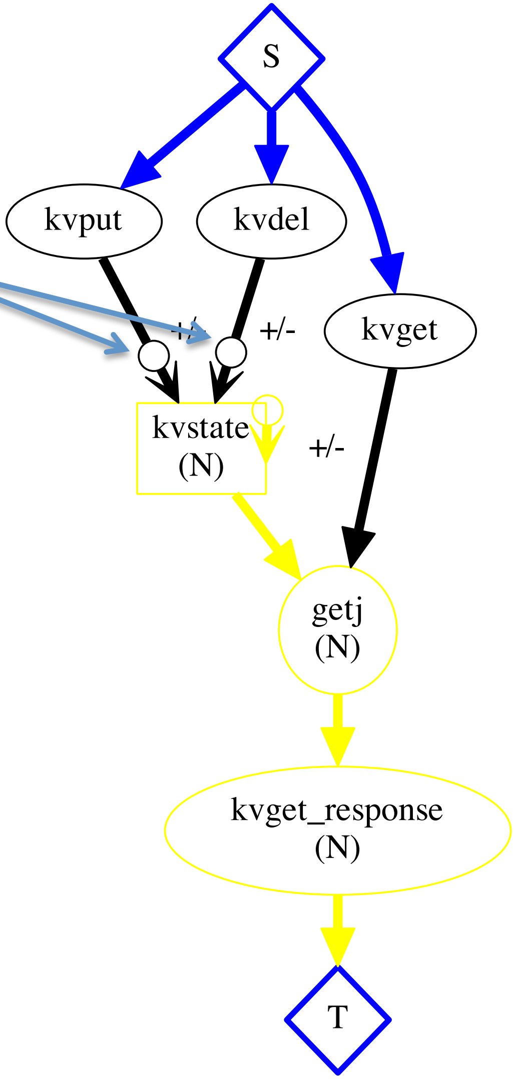
```
module KVSProtocol
  state do
    interface input, :kvput, [:key] => [:reqid, :value]
    interface input, :kvdel, [:key] => [:reqid]
    interface input, :kvget, [:reqid] => [:key]
    interface output, :kvget_response,
      [:reqid] => [:key, :value]
  end
end
```



A simple key/value store

```
module BasicKVS
  include KVSProtocol

  state do
    table :kvstate, [:key] => [:value]
  end

  bloom :mutate do
    kvstate <+ kvput {|s| [s.key, s.value]}
    kvstate <- (kvstate * kvput).lefts(:key => :key)
  end

  bloom :get do
    temp :getj <= (kvget * kvstate).pairs(:key => :key)
    kvget_response <= getj do |g, t|
      [g.reqid, t.key, t.value]
    end
  end

  bloom :delete do
    kvstate <- (kvstate * kvdel).lefts(:key => :key)
  end
end
```

Nonmonotonic operation

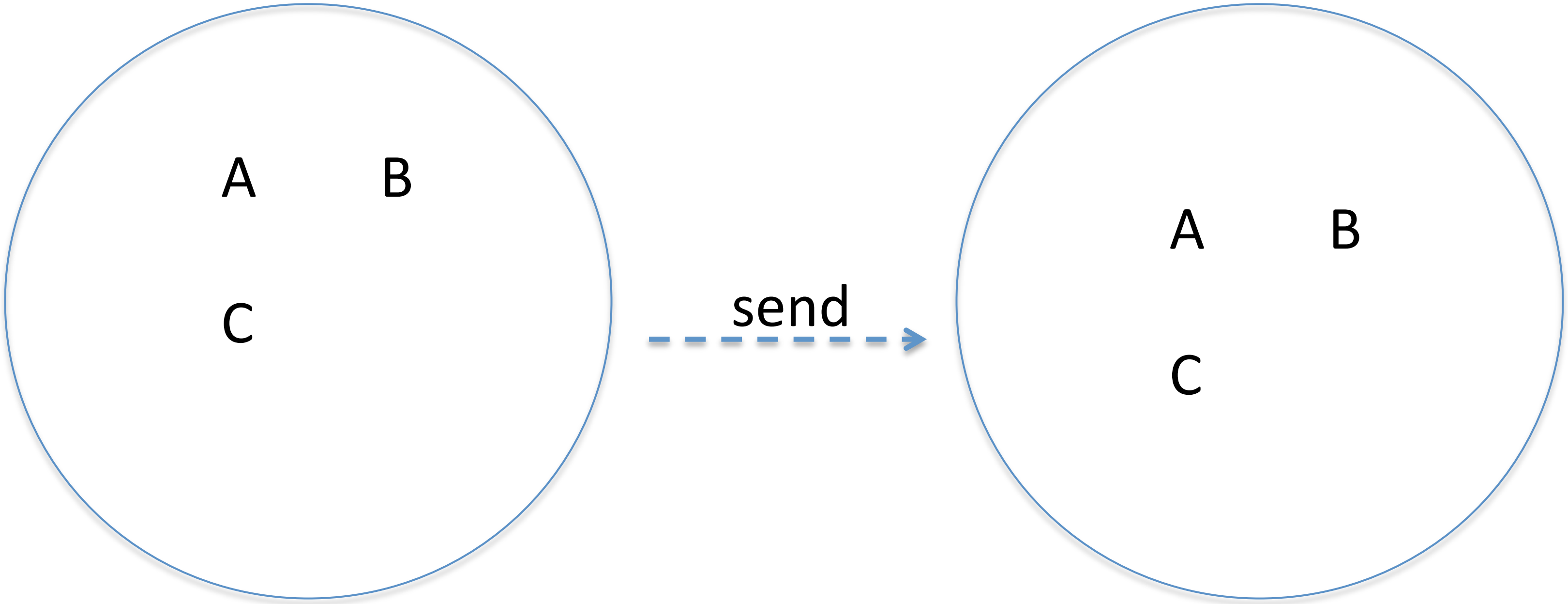


CALM Analysis

Asynchronous messaging

You never really know

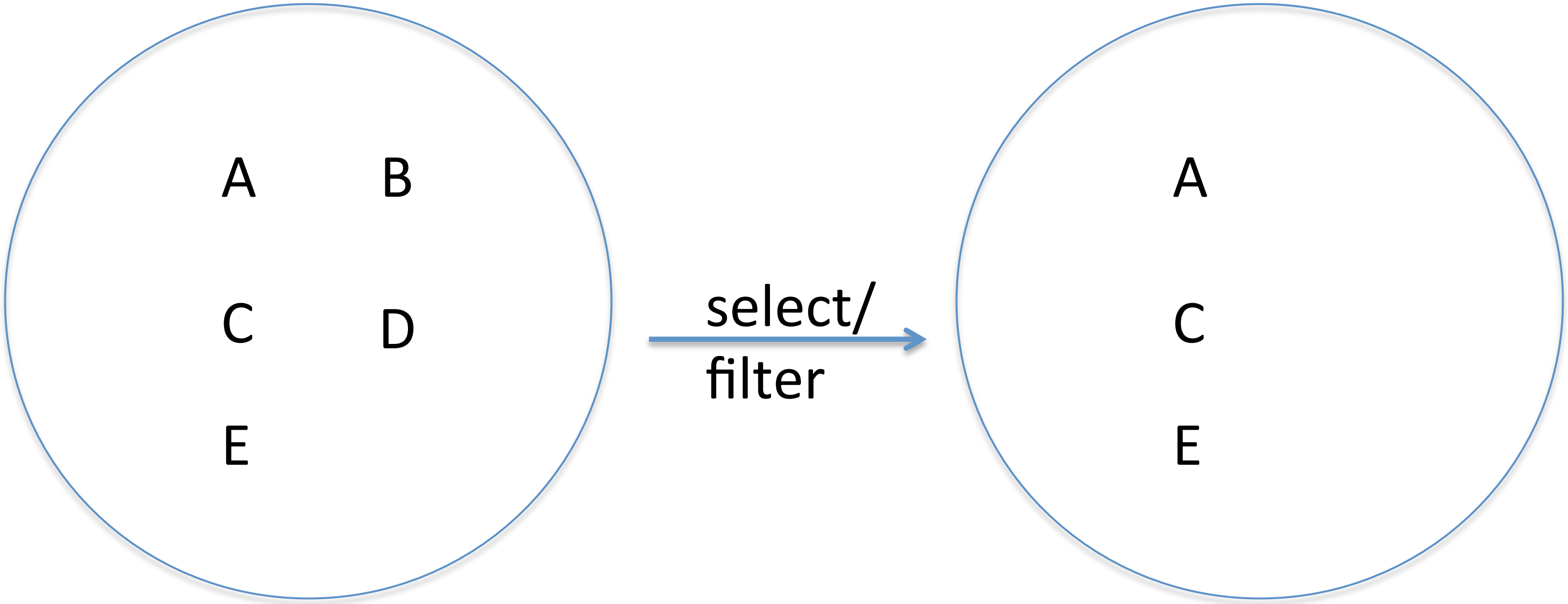
Asynchronous messaging



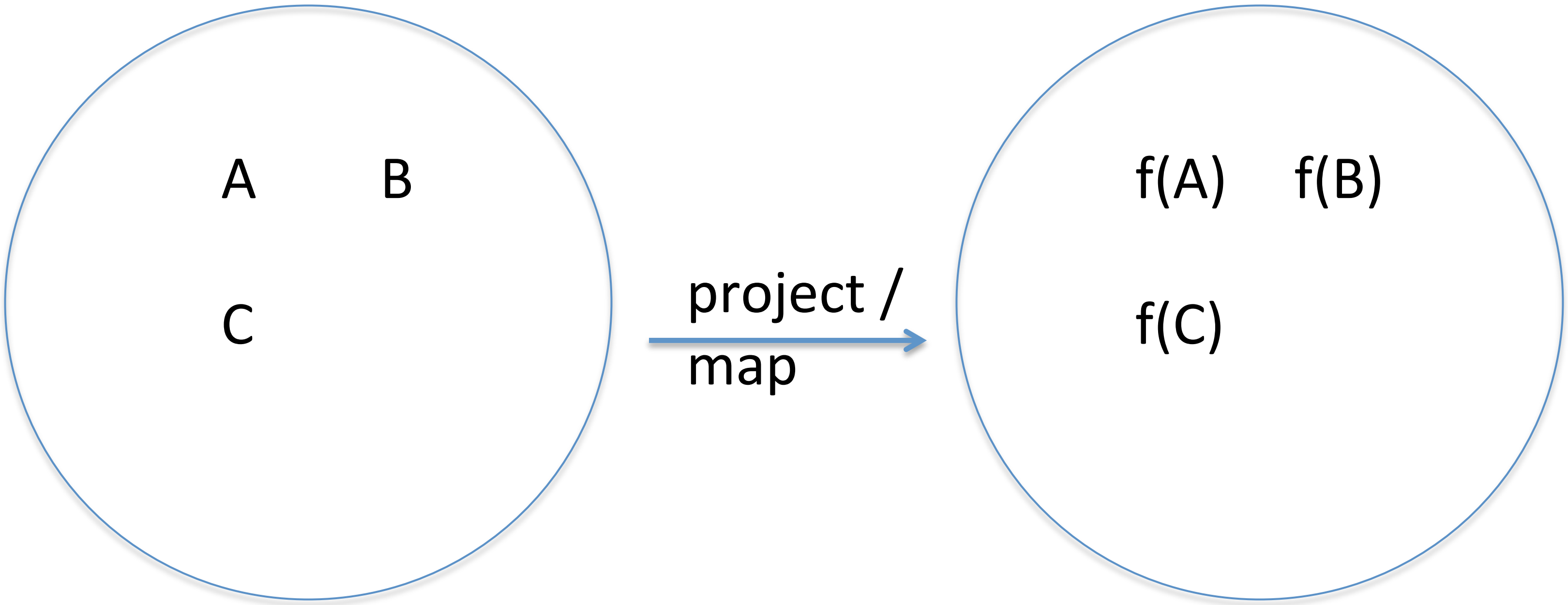
Monotonic Logic

The more you know, the more you know.

Monotonic Logic



Monotonic Logic



A

B

C

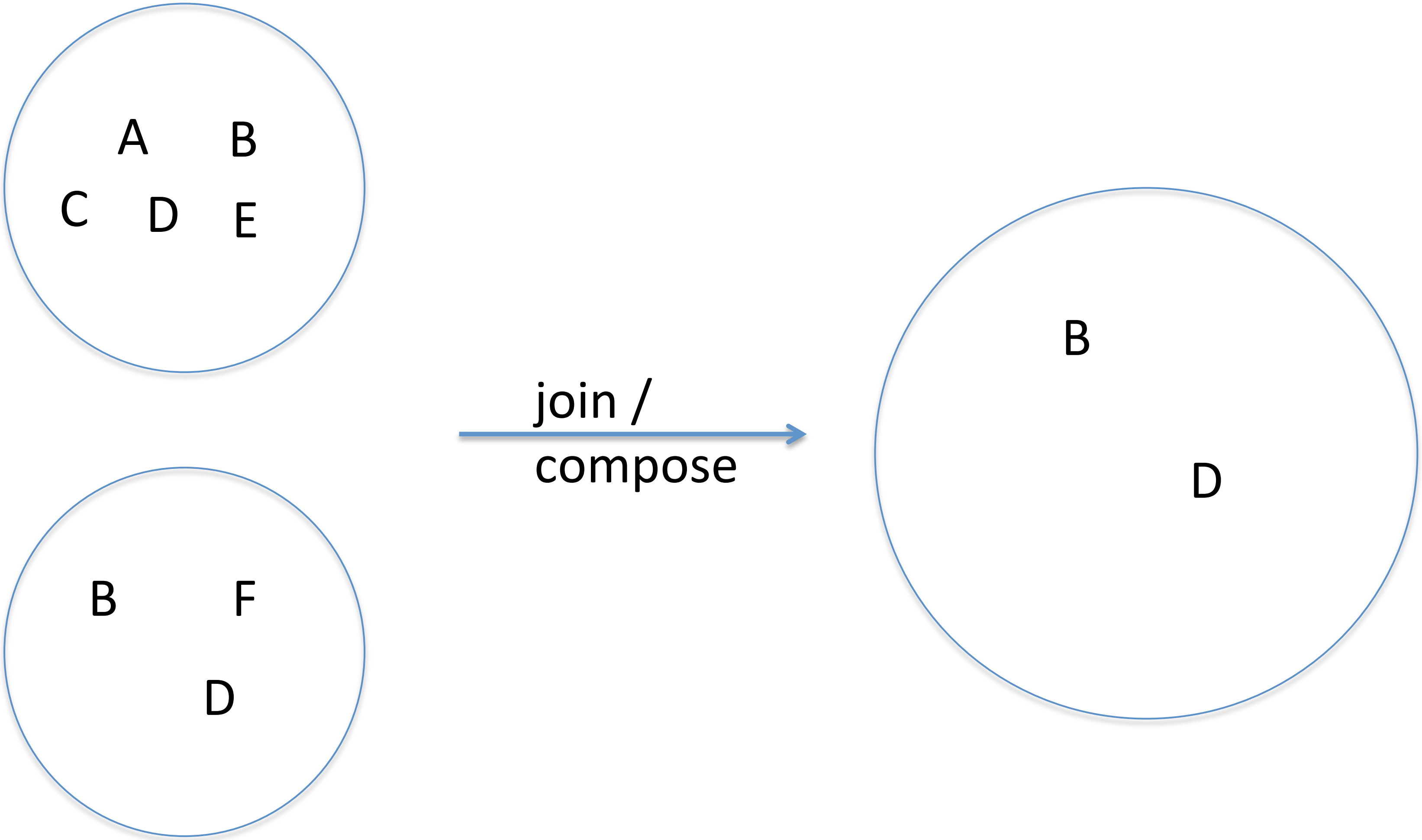
project / map

f(A)

f(B)

f(C)

Monotonic Logic



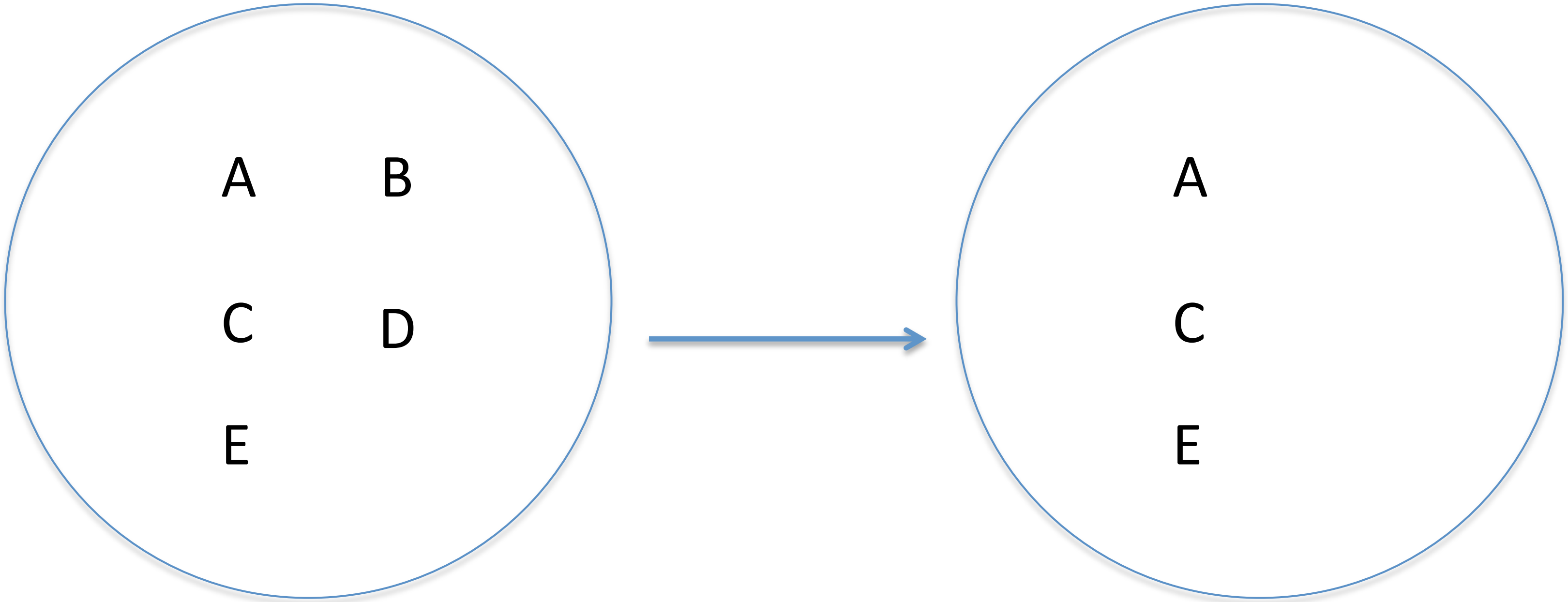
A B
C D E

B F
D

join / compose

B
D

Monotonic Logic is order-insensitive



A B

C D

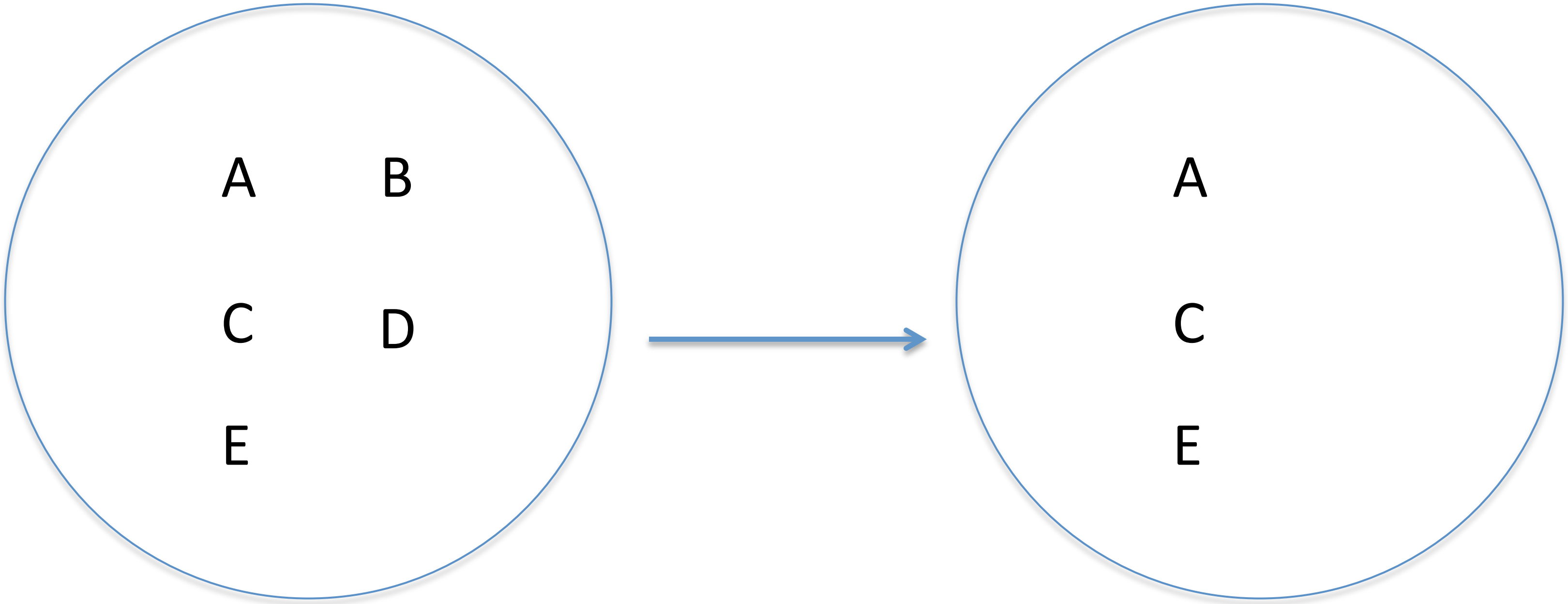
E

A

C

E

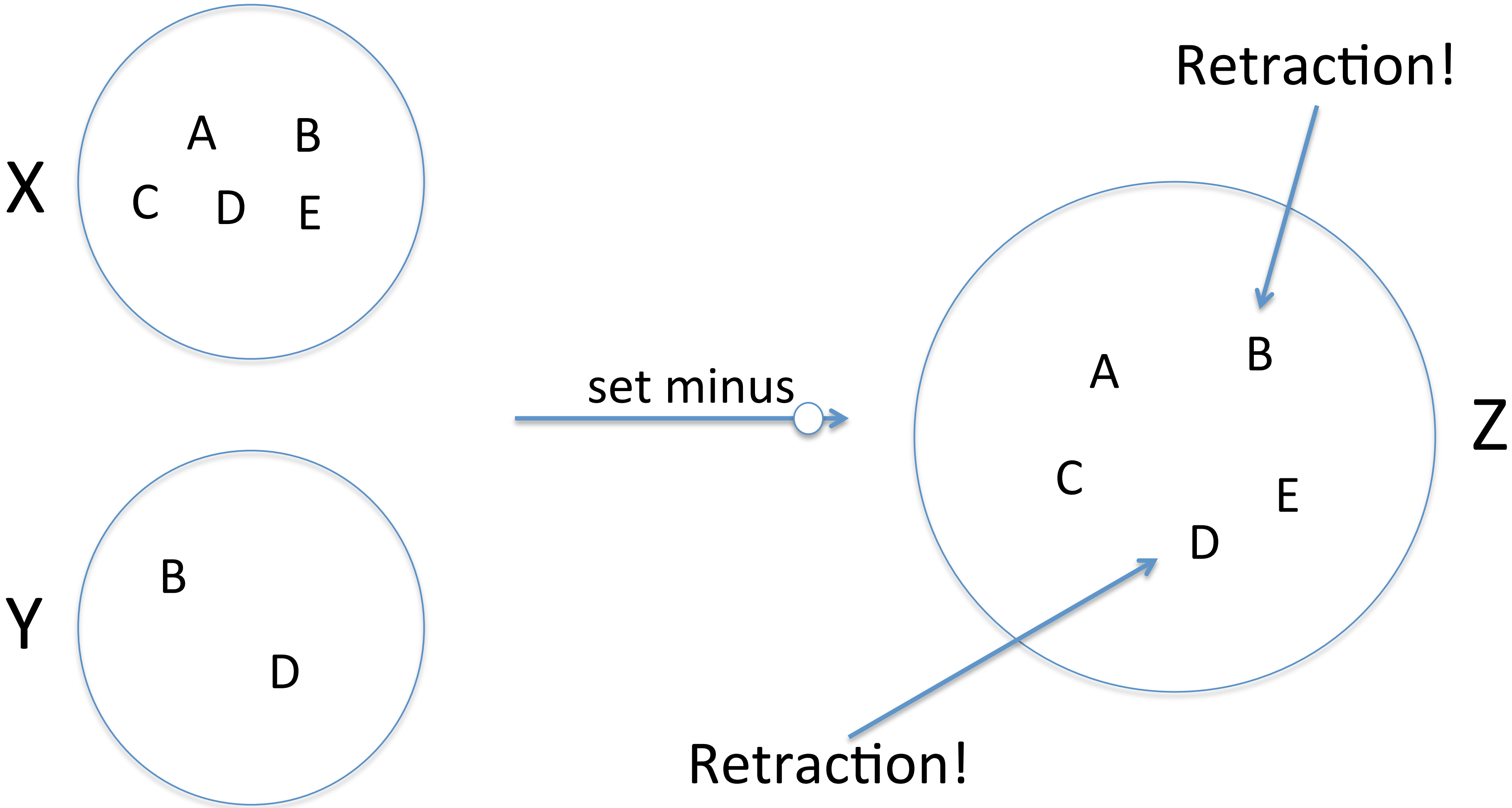
Monotonic Logic is *pipelineable*



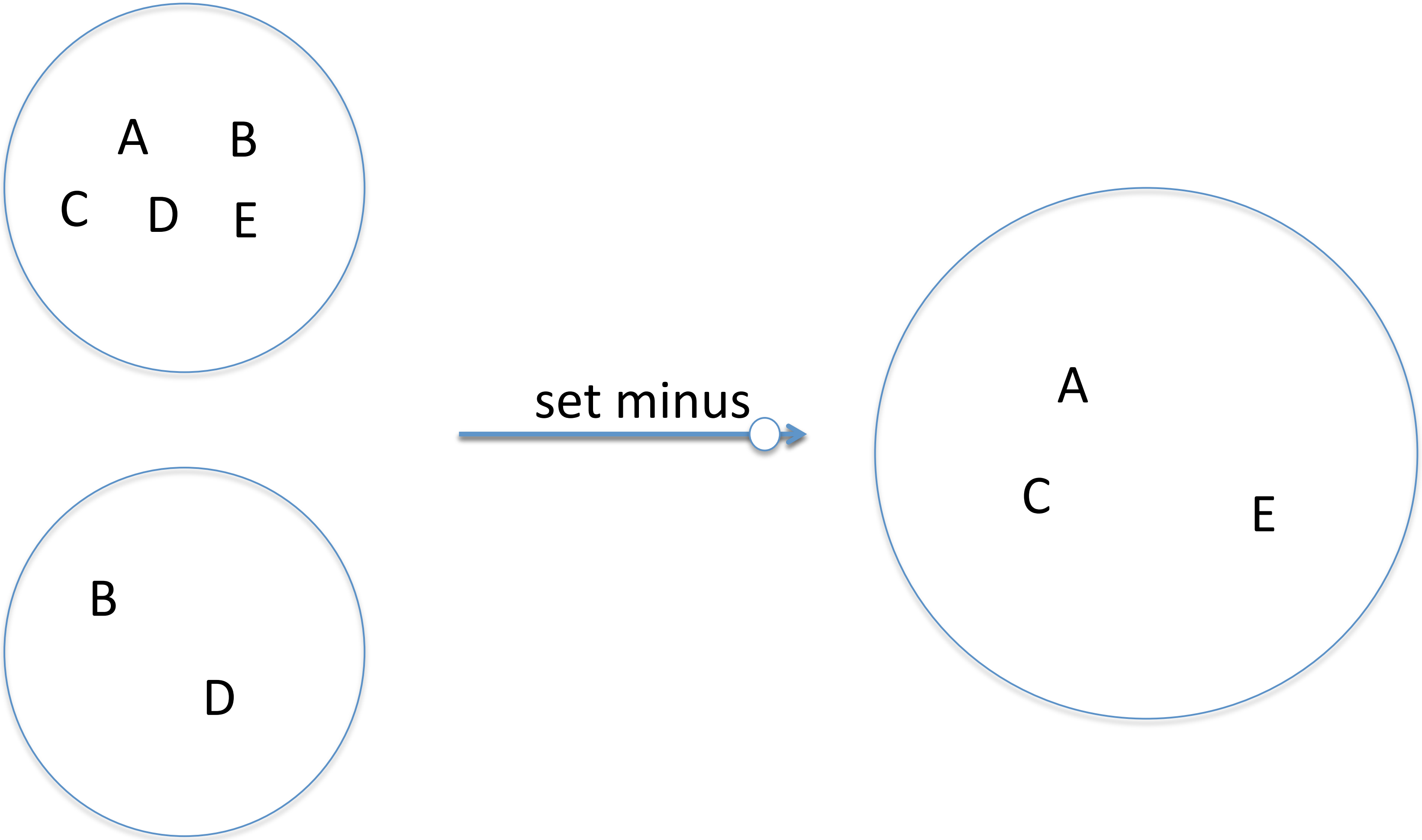
Nonmonotonic Logic

When do you know for sure?

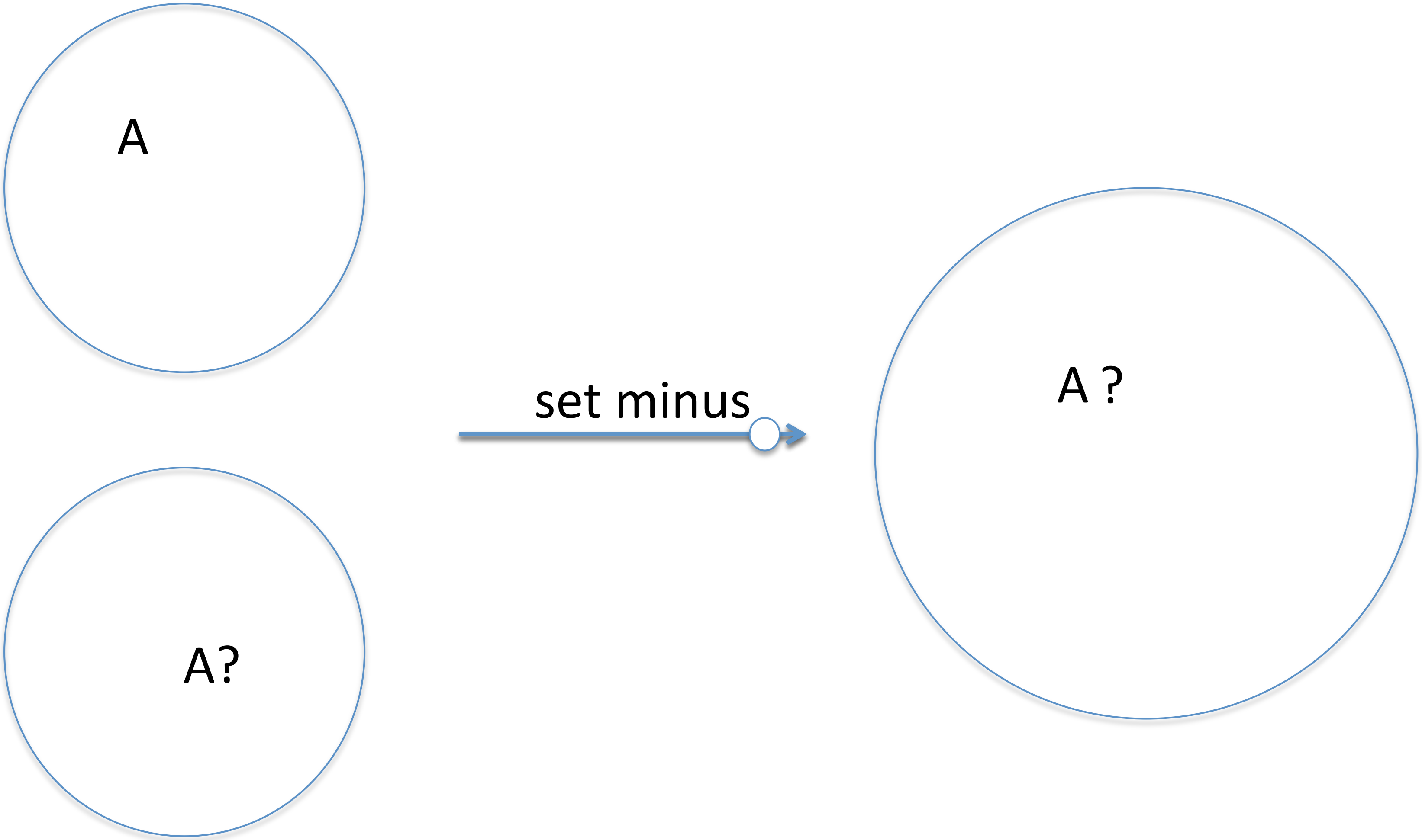
Nonmonotonic Logic



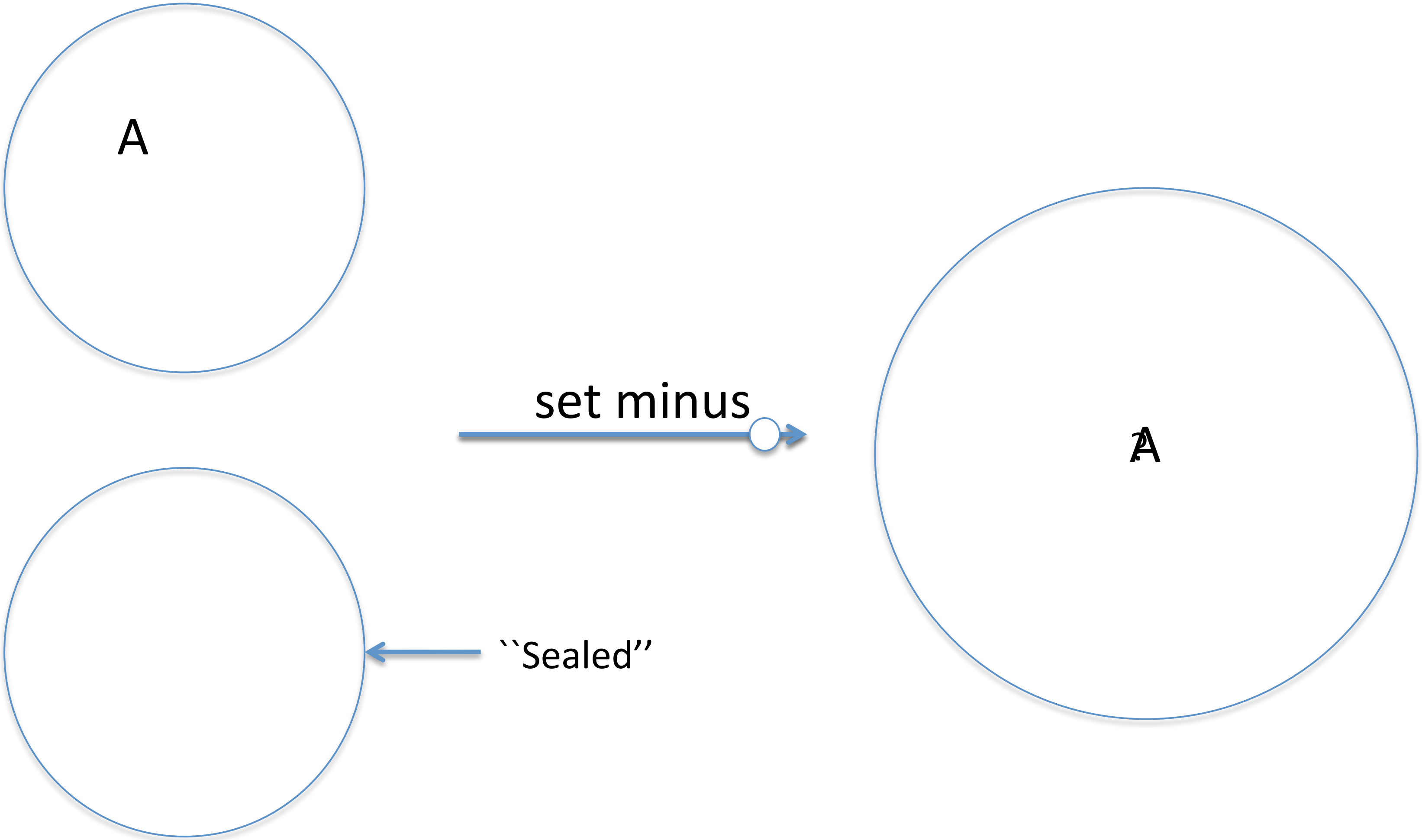
Nonmonotonic logic is order-sensitive



Nonmonotonic logic is *blocking*

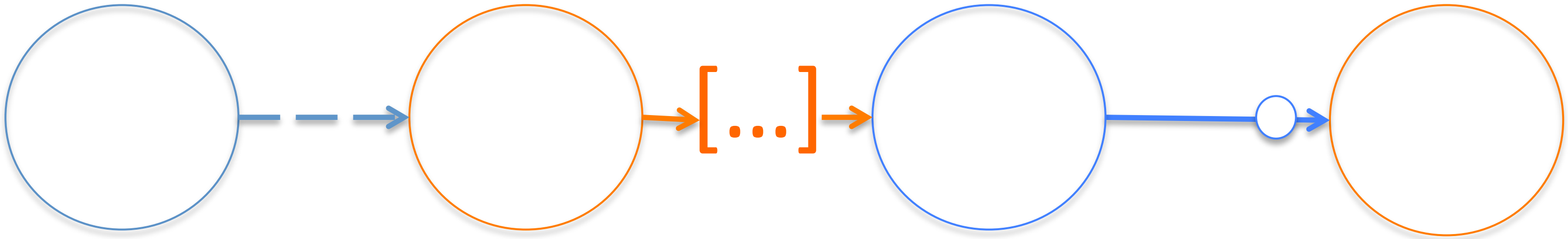


Nonmonotonic logic is *blocking*



CALM Analysis

- Asynchrony => loss of order
- Nonmonotonicity => order-sensitivity
- Asynchrony ; Nonmonotonicity =>
  Inconsistency



CALM Analysis

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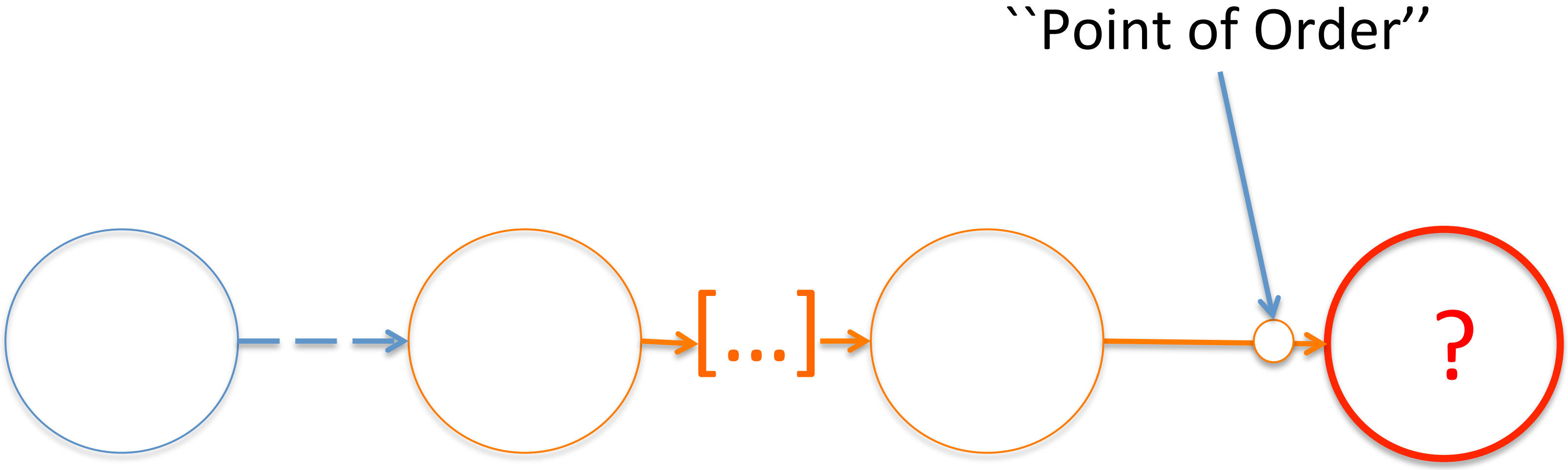

Resolving points of order

Resolving points of order

1. Ask for permission

Resolving points of order

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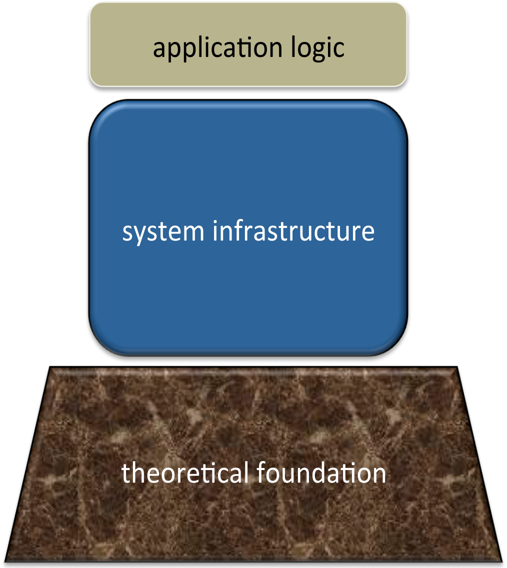


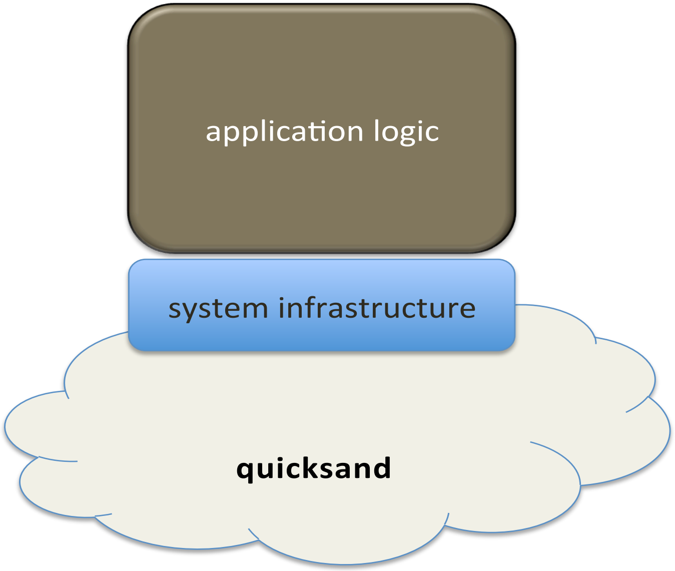
Coordination => strong consistency

Resolving points of order

1. Ask for permission
2. Ask for forgiveness

Resolving points of order

1. Ask for permission
2. Ask for forgiveness



Compensation, weak consistency

Resolving points of order

1. Ask for permission
2. Ask for forgiveness
3. Ask differently?

Rewrite to reduce consistency cost…

Shopping Carts

Replicated Shopping Carts

Replicated for high availability and low latency

Challenge:

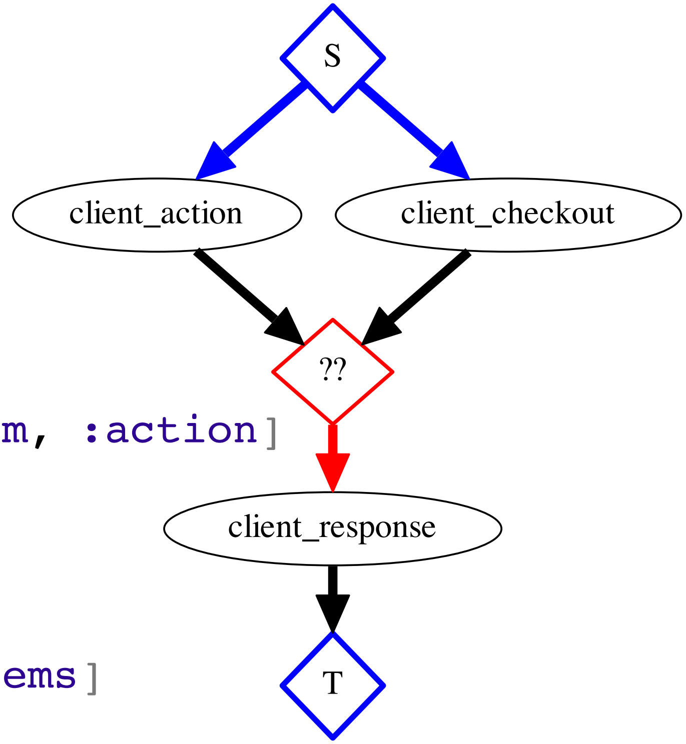
Ensure that replicas are ``eventually consistent’’

Replicated Shopping Carts

```
module CartClientProtocol
  state do
    interface input, :client_action,
        [:server, :session, :reqid] => [:item, :action]
    interface input, :client_checkout,
        [:server, :session, :reqid]
    interface output, :client_response,
        [:client, :server, :session] => [:items]
  end
end
```

Replicated Shopping Carts

```
module CartClientProtocol
  state do
    interface input, :client_action,
        [:server, :session, :reqid] => [:item, :action]
    interface input, :client_checkout,
        [:server, :session, :reqid]
    interface output, :client_response,
        [:client, :server, :session] => [:items]
  end
end
```



Carts done two ways

1. A “destructive” cart
2. A “disorderly” cart

``Destructive’’ Cart

```
module DestructiveCart
  include CartProtocol
  include KVSProtocol

  bloom :on_action do
    kvget <= action_msg {|a| [a.reqid, a.session] }
    kvput <= (action_msg * kvget_response).outer(:reqid => :reqid) do |a,r|
      val = (r.value || {})
      [a.client, a.session, a.reqid, val.merge({a.item => a.action}) do
          |k,old,new| old + new
       end]
    end
  end

  bloom :on_checkout do
    kvget <= checkout_msg {|c| [c.reqid, c.session] }
    response_msg <~ (kvget_response * checkout_msg).pairs
          (:reqid => :reqid) do |r,c|
      [c.client, c.server, r.key, r.value.select {|k,v| v > 0}.to_a.sort]
    end
  end
end
```

``Destructive'' Cart

```
module DestructiveCart
  include CartProtocol
  include KVSProtocol
```

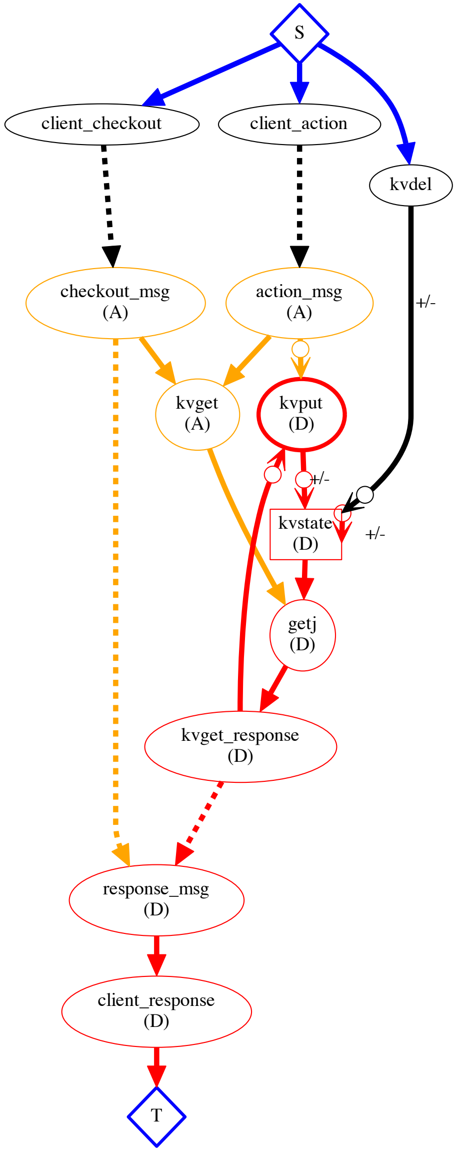
React to client updates

```
  bloom :on_action do
    kvget <= action_msg {|a| [a.reqid, a.session] }
    kvput <= (action_msg * kvget_response).outer(:reqid => :reqid) do |a,r|
      val = (r.value || {})
      [a.client, a.session, a.reqid, val.merge({a.item => a.action}) do
          |k,old,new| old + new
       end]
    end
  end
```

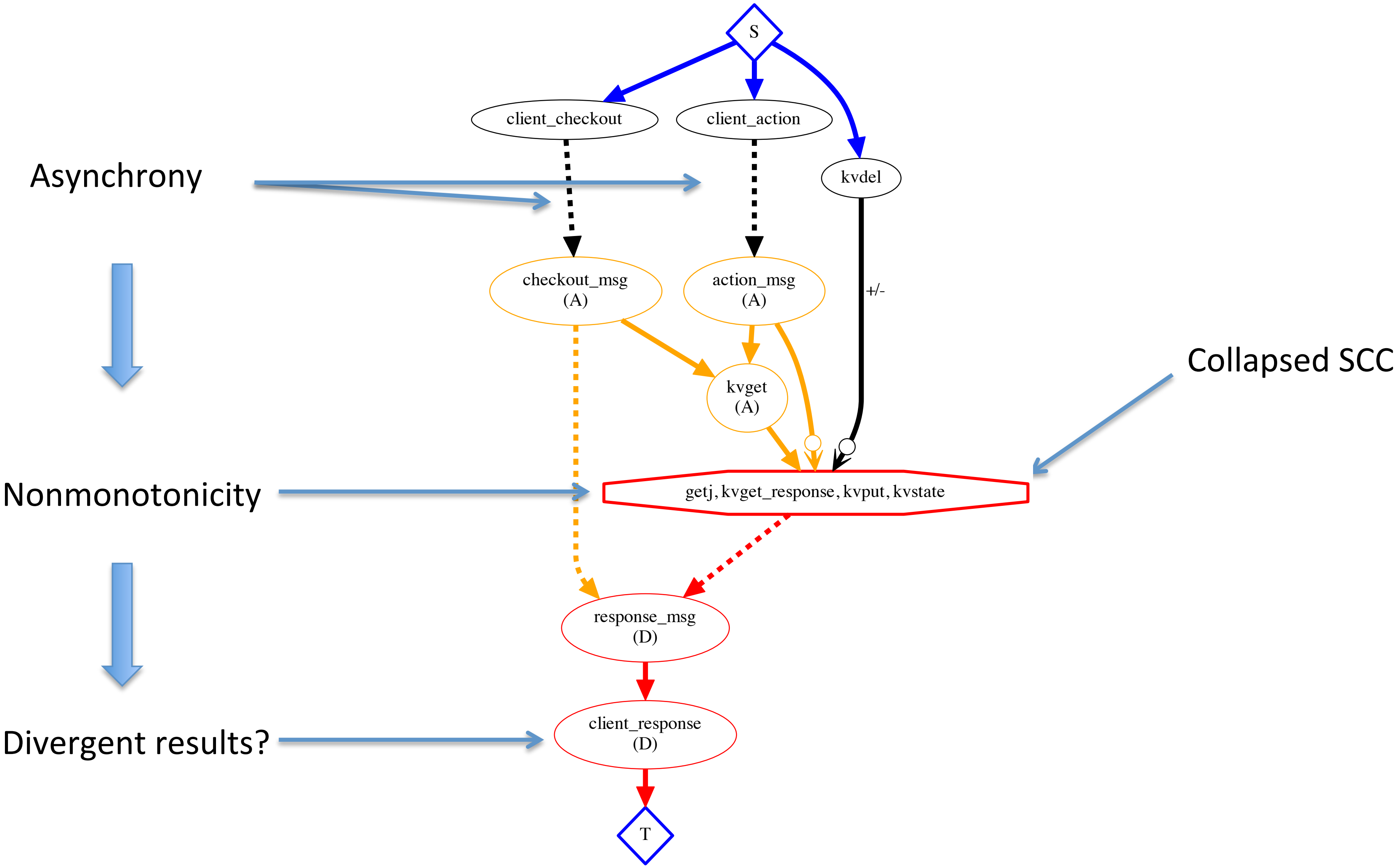
React to client checkout

```
  bloom :on_checkout do
    kvget <= checkout_msg {|c| [c.reqid, c.session] }
    response_msg <~ (kvget_response * checkout_msg).pairs
          (:reqid => :reqid) do |r,c|
      [c.client, c.server, r.key, r.value.select {|k,v| v > 0}.to_a.sort]
    end
  end
end
```

Destructive Cart Analysis



Destructive Cart Analysis



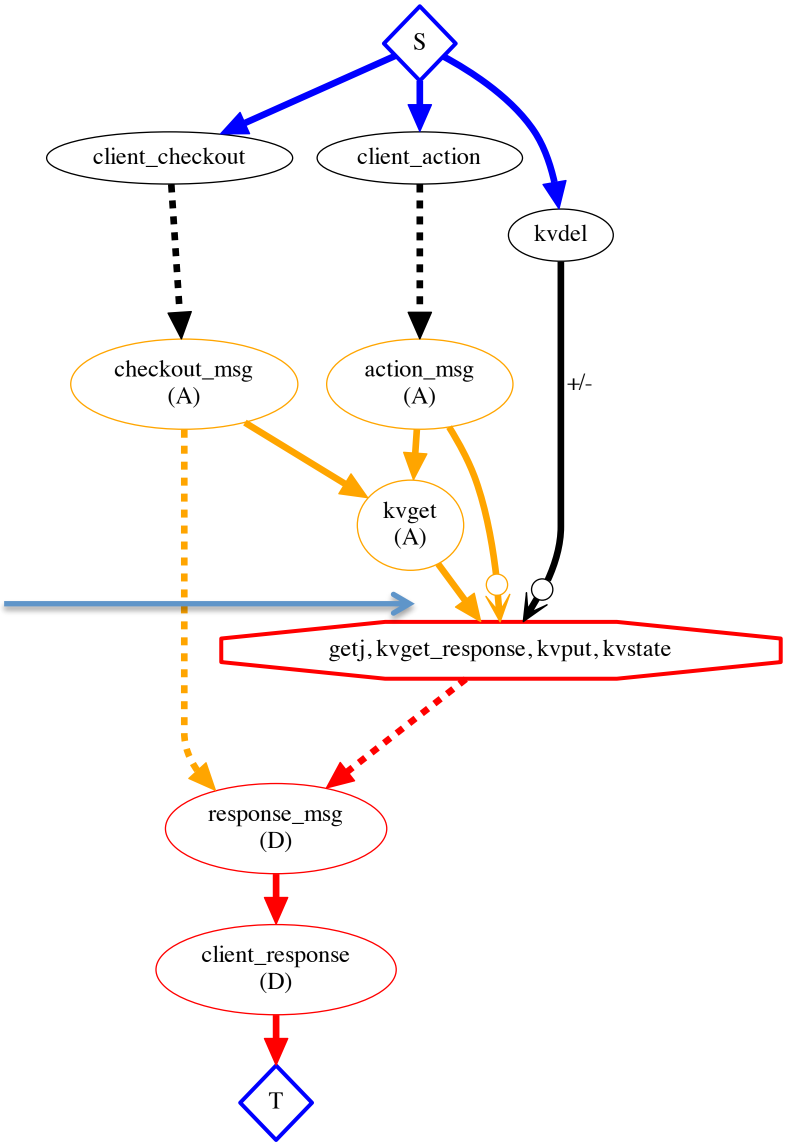
Asynchrony

Nonmonotonicity

Divergent results?

Collapsed SCC

Destructive Cart Analysis



Add coordination? E.g.,

- Synchronous replication
- Paxos

n = |client_action|

m = |client_checkout| = 1

***n* rounds of coordination**

``Disorderly Cart’’

```
module DisorderlyCart
  include CartProtocol

  state do
    table :action_log, [:session, :reqid] => [:item, :action]
    scratch :item_sum, [:session, :item] => [:num]
    scratch :session_final, [:session] => [:items, :counts]
  end

  bloom :on_action do
    action_log <= action_msg { |c| [c.session, c.reqid, c.item, c.action] }
  end

  bloom :on_checkout do
    temp :checkout_log <= (checkout_msg * action_log).rights(:session => :session)
    item_sum <= checkout_log.group([action_log.session, action_log.item],
                                   sum(action_log.action)) do |s|
     s if s.last > 0
    end
    session_final <= item_sum.group([:session], accum(:item), accum(:num))
    response_msg <~ (session_final * checkout_msg).pairs(:session => :session) do |c,m|
      [m.client, m.server, m.session, c.items.zip(c.counts).sort]
    end
  end
end
```

``Disorderly Cart’’

```
module DisorderlyCart
  include CartProtocol

  state do
    table :action_log, [:session, :reqid] => [:item, :action]
    scratch :item_sum, [:session, :item] => [:num]
    scratch :session_final, [:session] => [:items, :counts]
  end
```

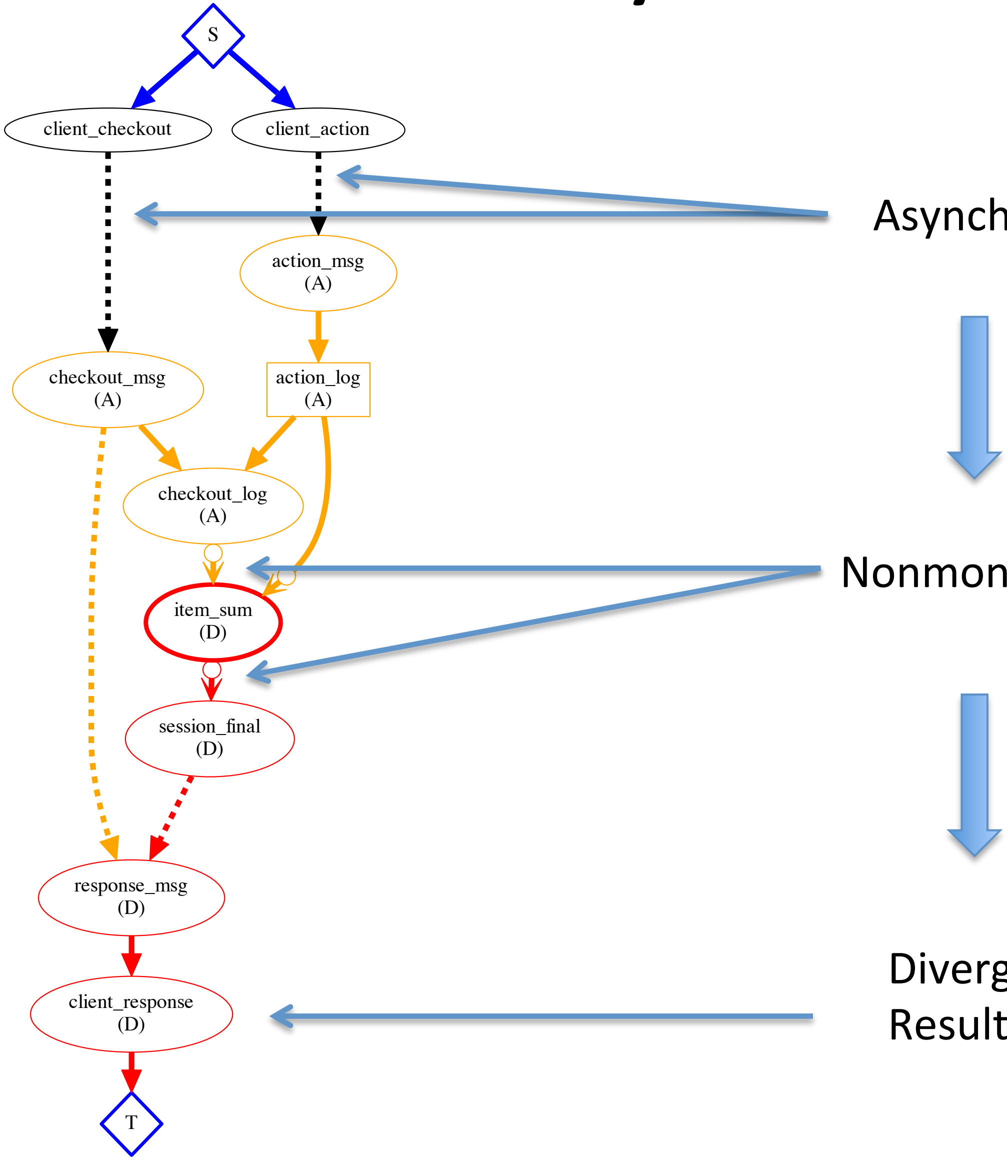
Actions

```
  bloom :on_action do
    action_log <= action_msg { |c| [c.session, c.reqid, c.item, c.action] }
  end
```

Checkout

```
  bloom :on_checkout do
    temp :checkout_log <= (checkout_msg * action_log).rights(:session => :session)
    item_sum <= checkout_log.group([action_log.session, action_log.item],
                                   sum(action_log.action)) do |s|
     s if s.last > 0
    end
    session_final <= item_sum.group([:session], accum(:item), accum(:num))
    response_msg <~ (session_final * checkout_msg).pairs(:session => :session) do |c,m|
      [m.client, m.server, m.session, c.items.zip(c.counts).sort]
    end
  end
end
```

Disorderly Cart Analysis

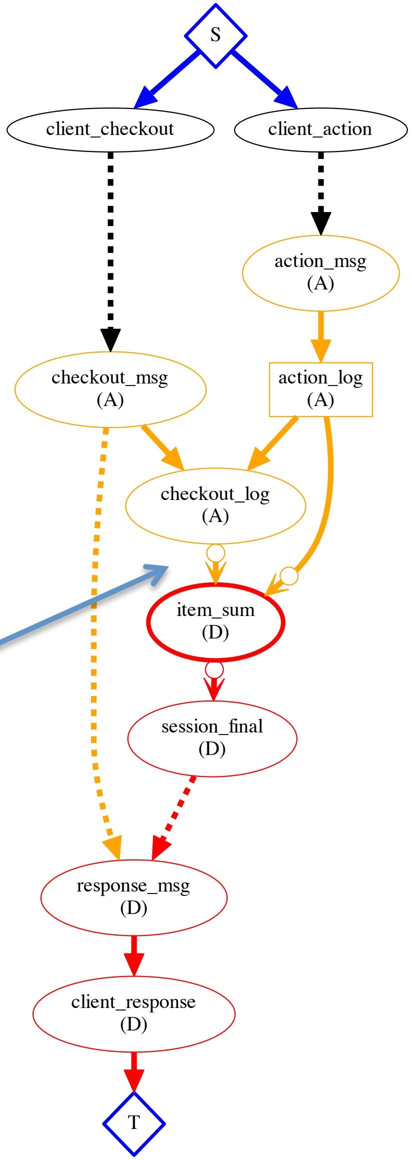


Asynchrony

Nonmontonicity

Divergent Results?

Disorderly Cart Analysis

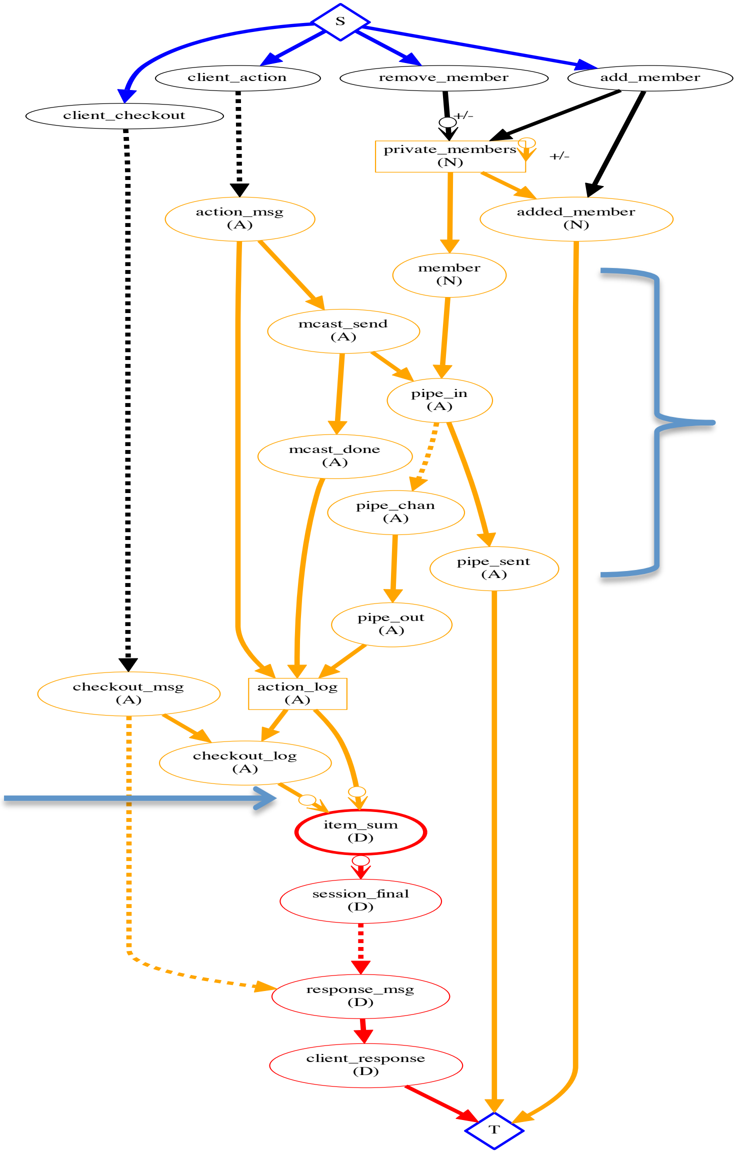


n = |client_action|

m = |client_checkout| = 1

***1* round of coordination**

Replicated Disorderly Cart



Asynchronous (uncoordinated) replication

Still just 1 round of coordination

Teaching `<~ bloom`

Summary

- Why *dis*orderly?
  - Order is a scarce (and distracting!) resource
- When is order really *needed*?
  - To resolve nonmonotonicity
- What is coordination *for*?
  - Re-establishing order, to guarantee consistency.
- CALM `<~ bloom`
  - A disorderly programming language
  - Tools to identify points of order

More

Resources:

http://boom.cs.berkeley.edu

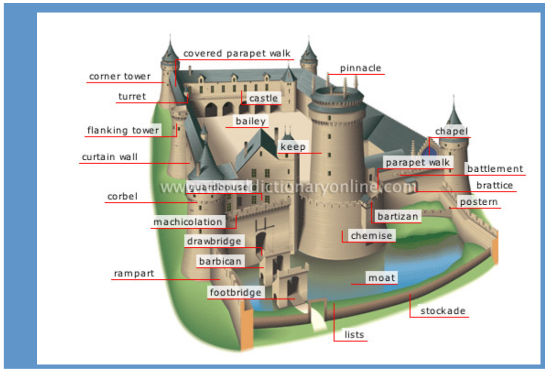
http://bloom-lang.org

Writeups:

- Consistency Analysis in Bloom: A CALM and Collected Approach (CIDR'11)
- Dedalus: Datalog in Time and Space (Datalog2.0)
- The Declarative Imperative (PODS'10 Keynote address)
- Model-theoretic Correctness Criteria for Distributed Systems (in submission)

Queries?

Languages regarding languages

	Other Languages	Bloom
Other Languages		
Bloom		