Reagents:

expressing and composing fine-grained concurrency

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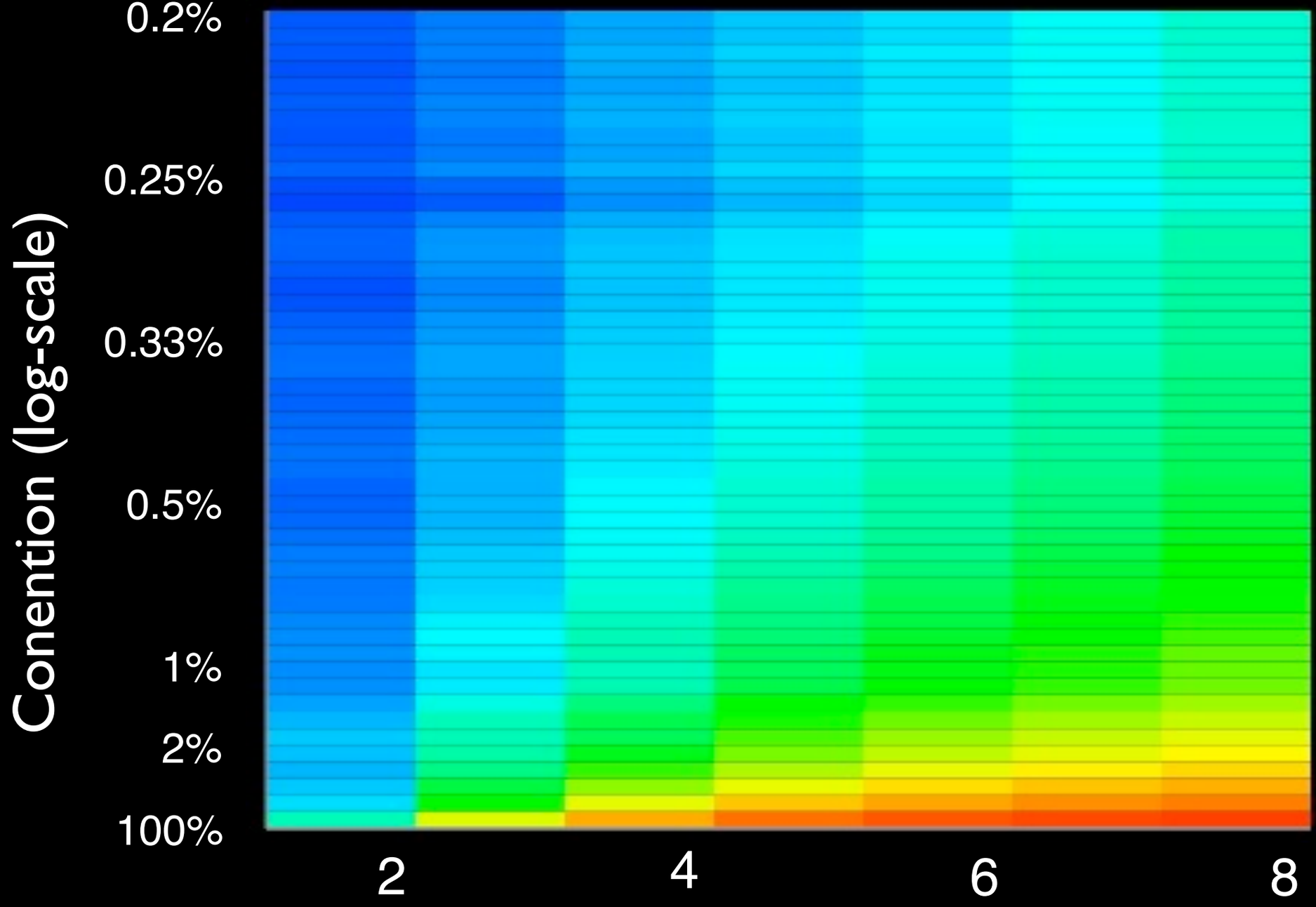
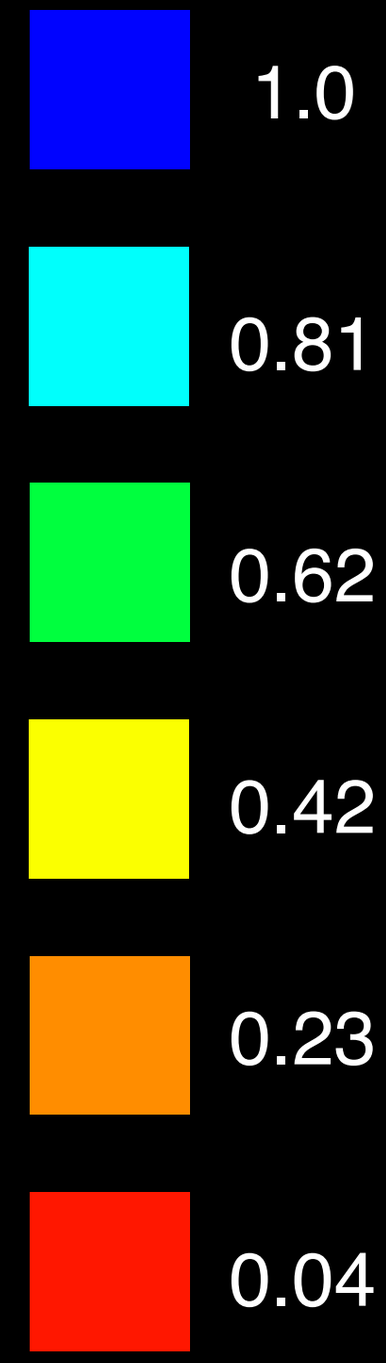
CAS: cost versus contention





Throughput / Sequential

java.util.concurrent

Synchronization

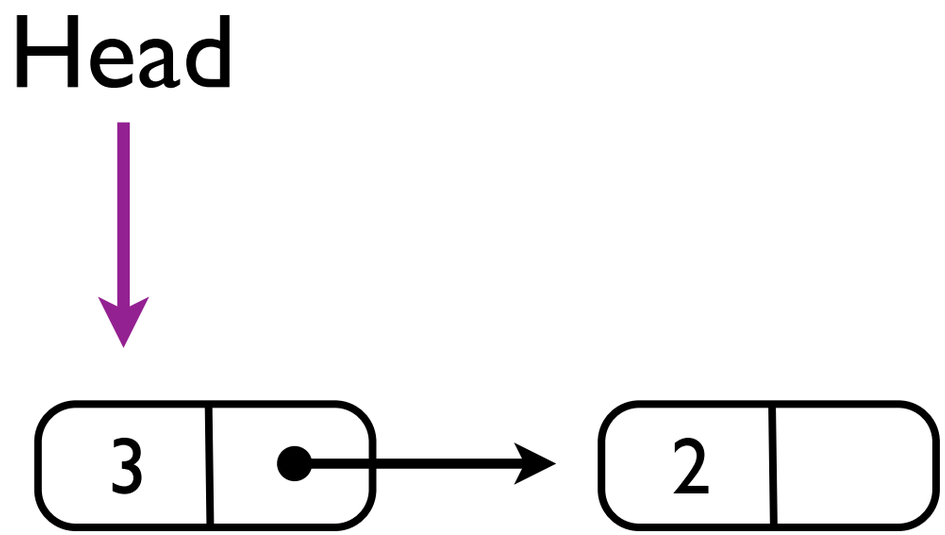
Reentrant locks
Semaphores
R/W locks
Reentrant R/W locks
Condition variables
Countdown latches
Cyclic barriers
Phasers
Exchangers

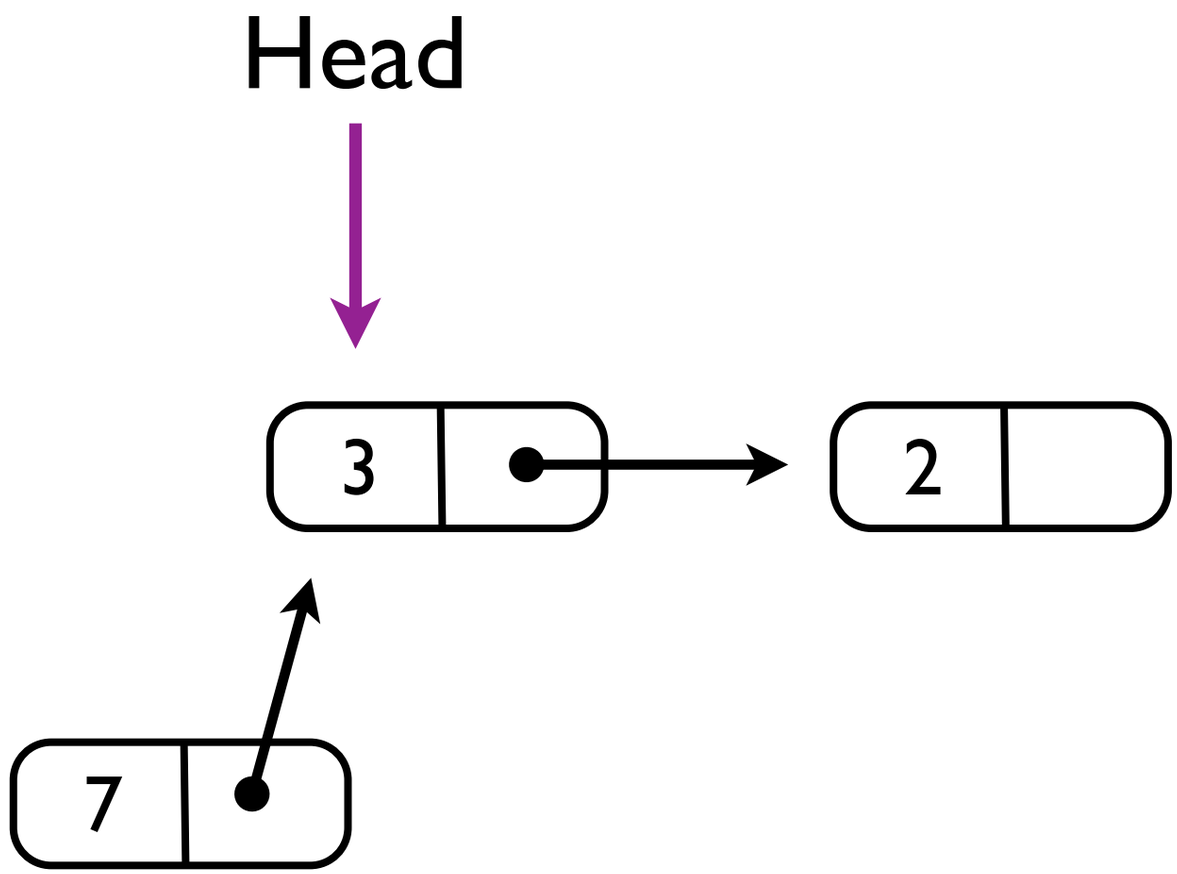
Data structures

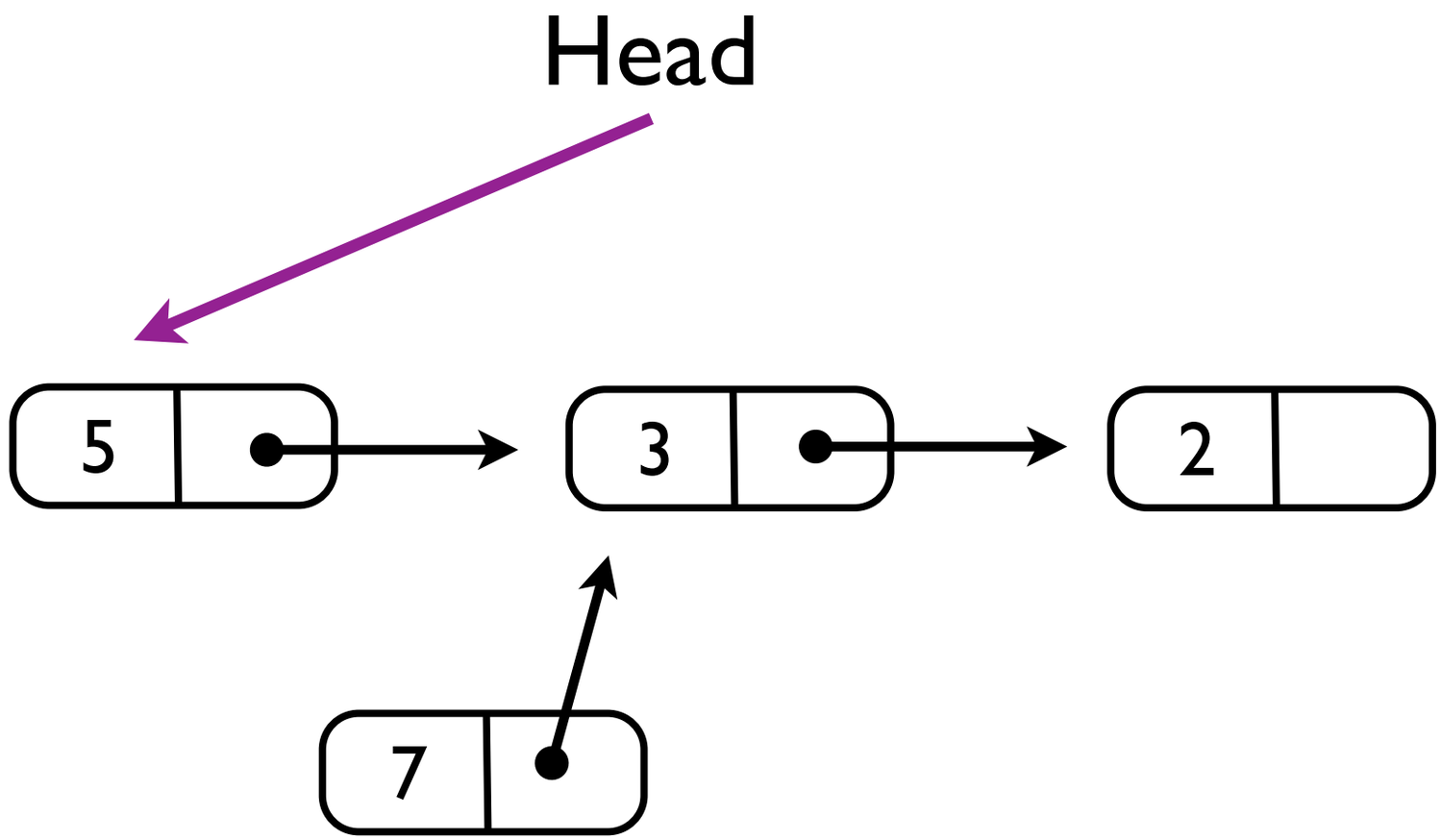
Queues
- Nonblocking
- Blocking (array & list)
- Synchronous
- Priority, nonblocking
- Priority, blocking

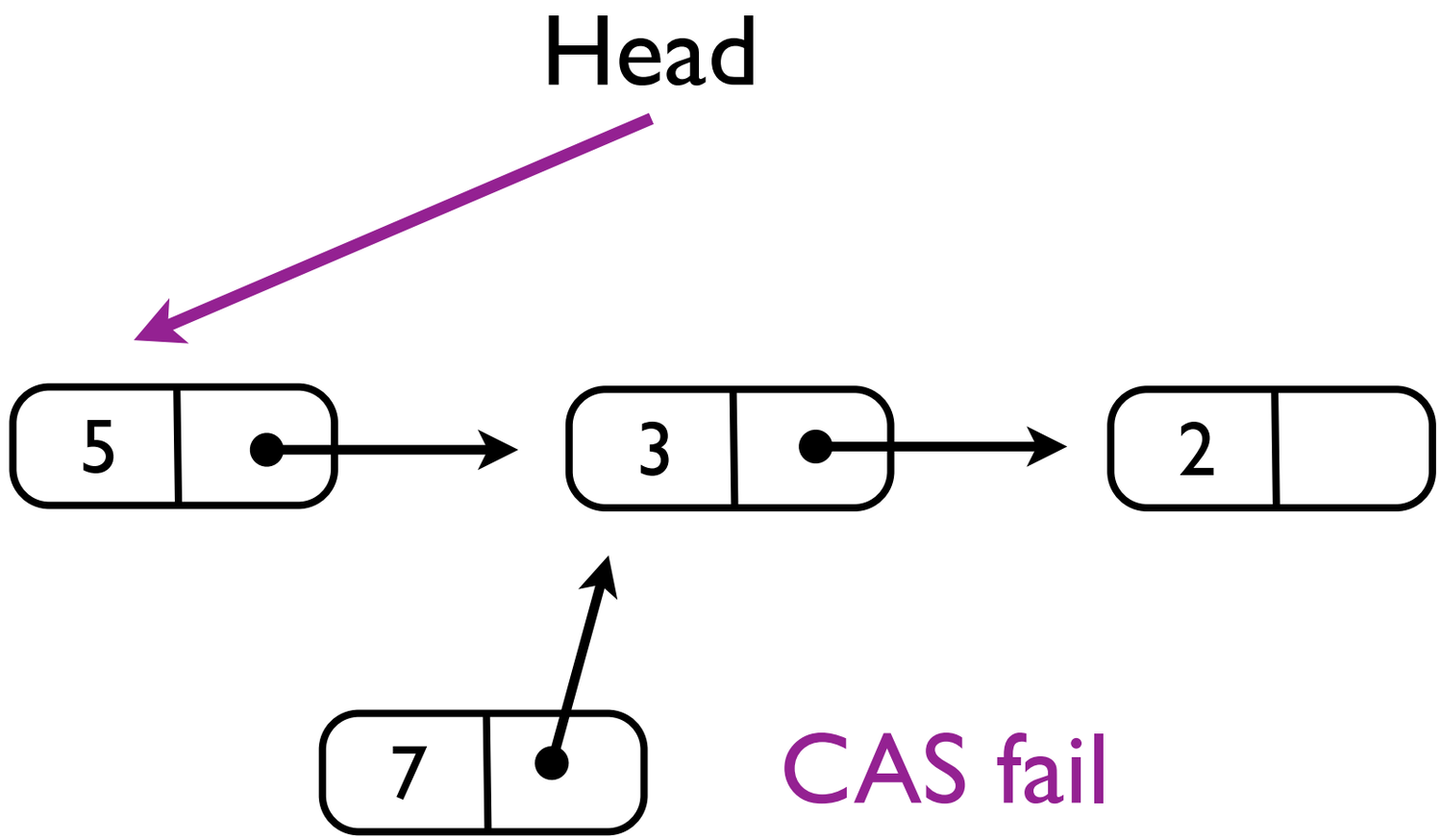
Deques
Sets
Maps (hash & skiplist)

```
class TreiberStack[A] {
  private val head =
    new AtomicRef[List[A]](Nil)

  def push(a: A) {
    val backoff = new Backoff
    while (true) {
      val cur = head.get()
      if (head.cas(cur, a :: cur)) return
      backoff.once()
    }
  }

...
```

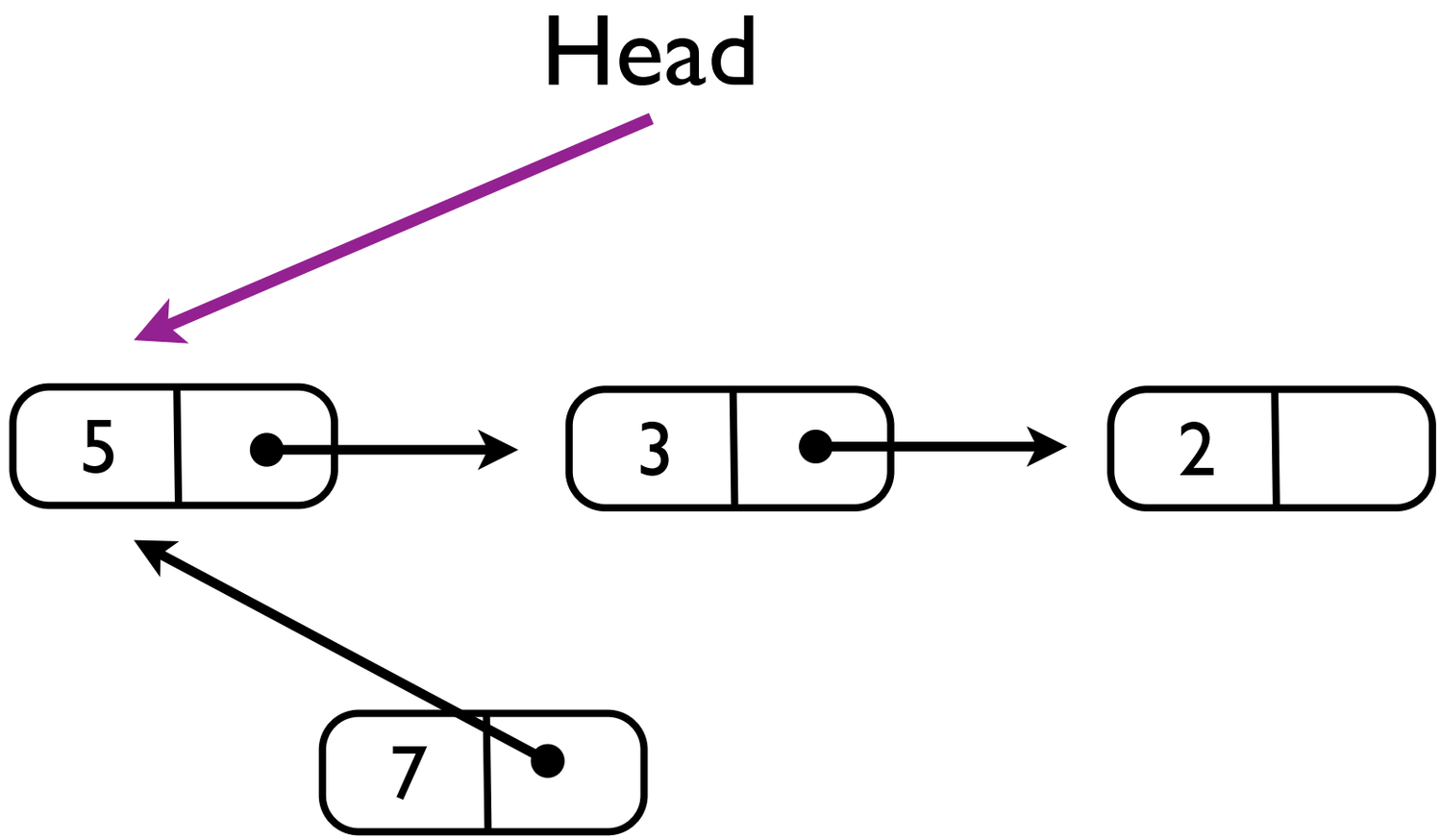

Head
3
2

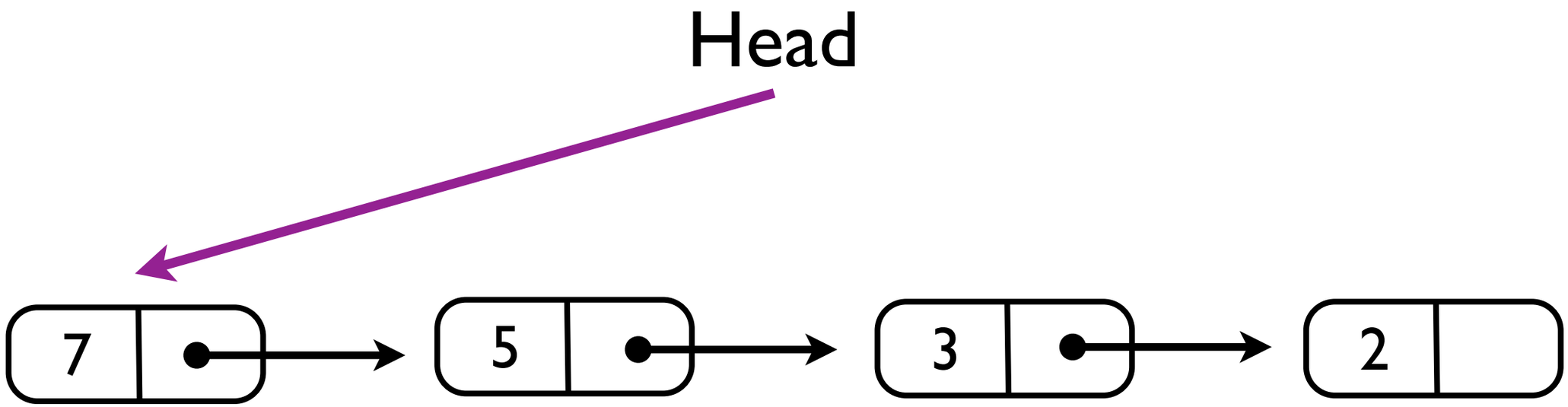

Head
3
2
7


Head
5
3
2
7



CAS fail


Head
5
3
2
7


Head
7
5
3
2

```
def tryPop(): Option[A] = {
  val backoff = new Backoff
  while (true) {
    val cur = head.get()
    cur match {
      case Nil      => return None
      case a::tail =>
        if (head.cas(cur, tail))
          return Some(a)
    }
    backoff.once()
  }
}
```

The Problem:

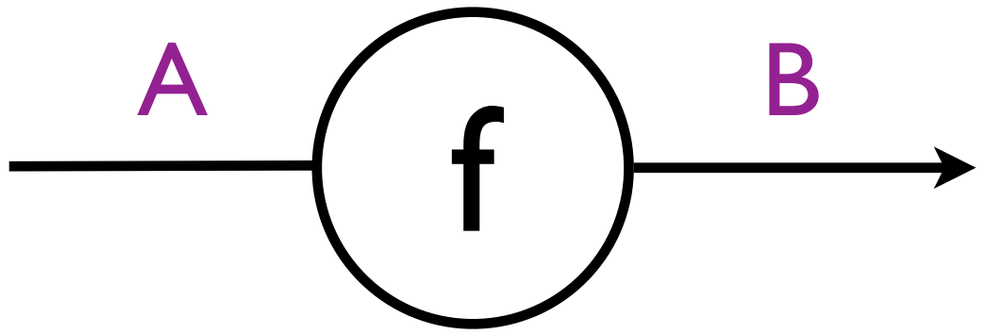
Concurrency libraries are indispensable, but hard to build and extend

The Proposal:

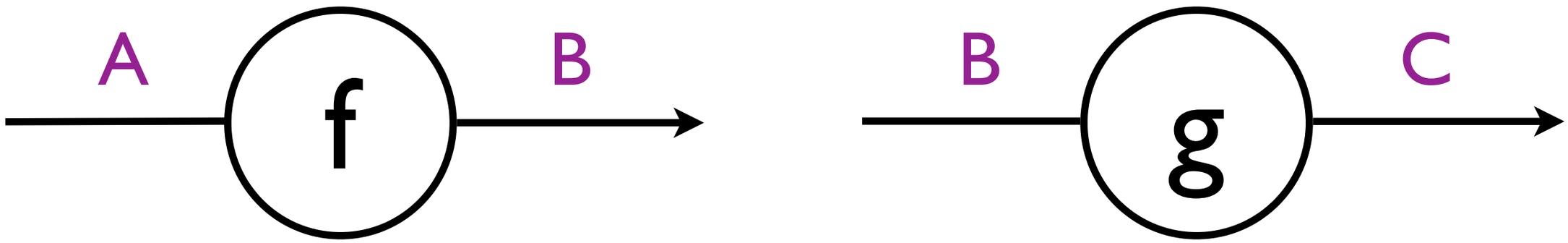
Scalable concurrent algorithms can be built and extended using abstraction and composition

Design

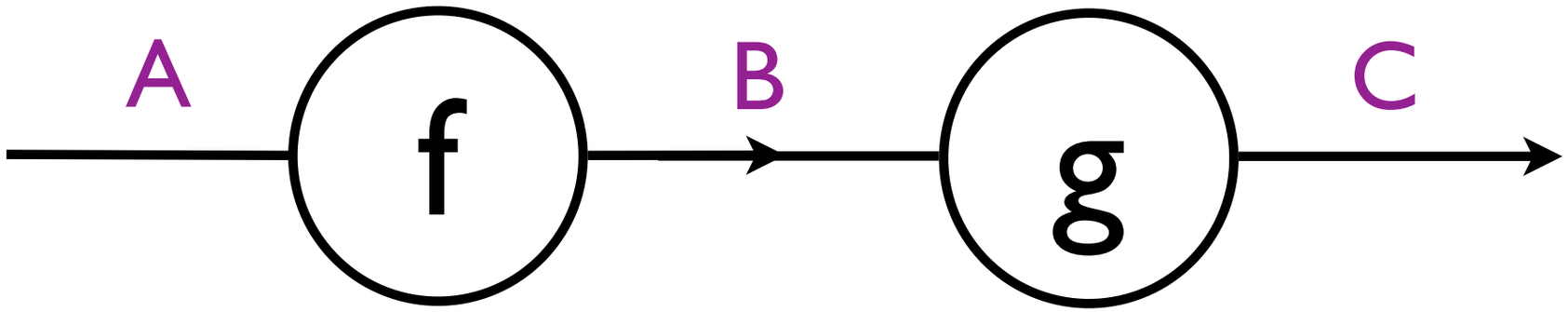
Lambda: the ultimate abstraction



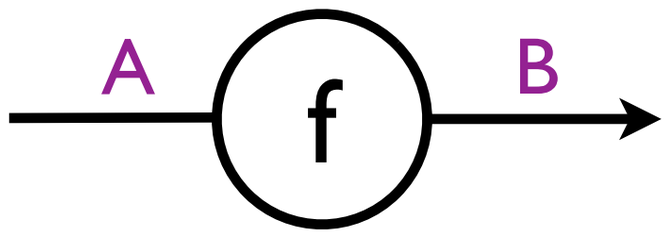
Lambda: the ultimate abstraction



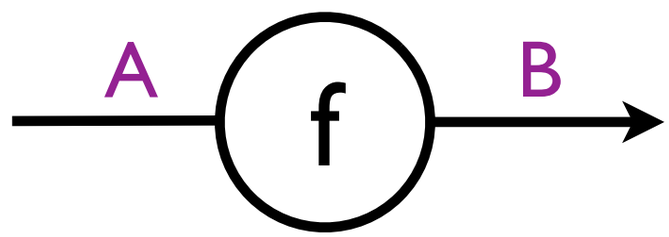
Lambda: the ultimate abstraction



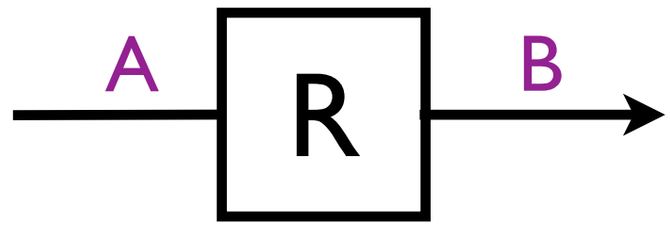
Lambda abstraction:



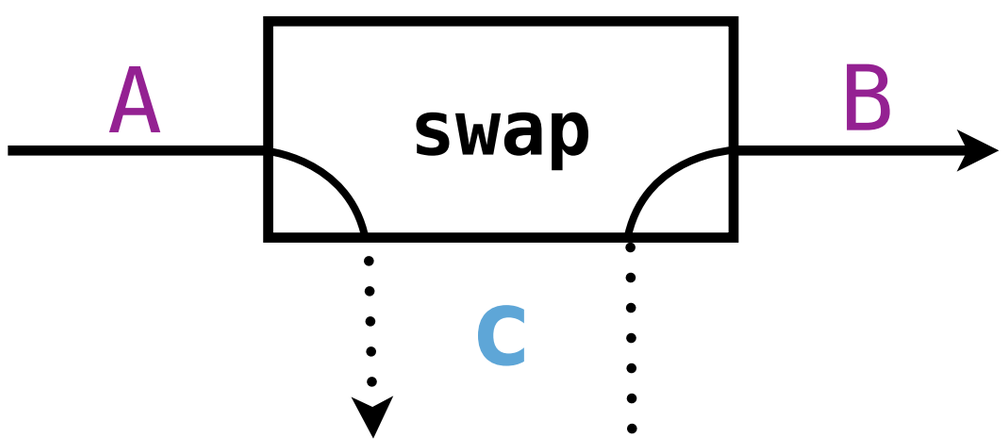
Lambda abstraction:



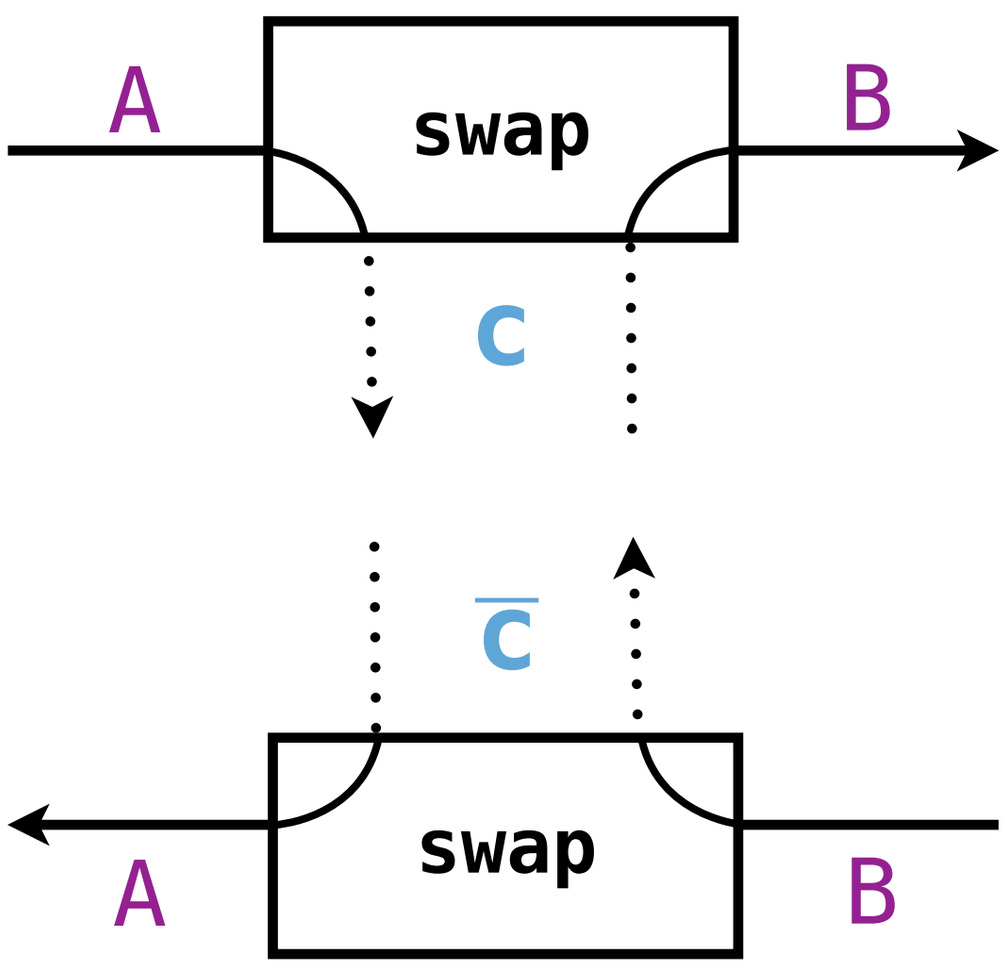
Reagent abstraction:



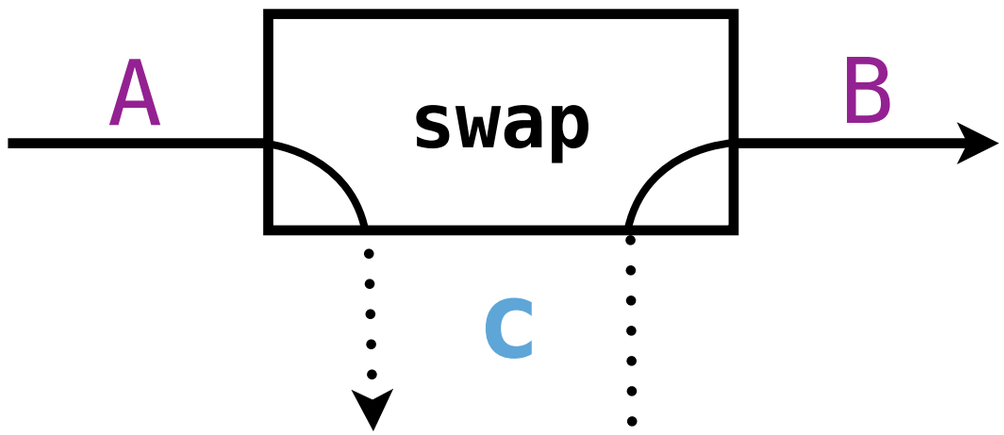
c: Chan[A,B]



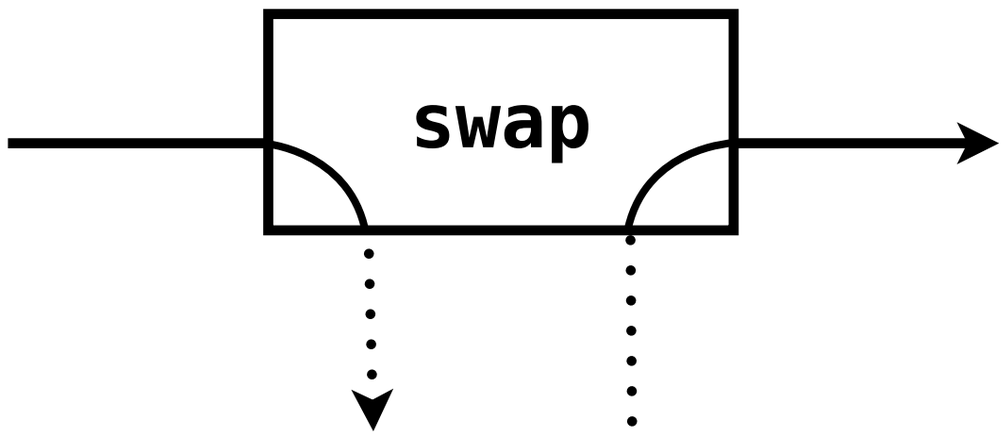
c: Chan[A,B]



```
c: Chan[A,B]
```



Message passing



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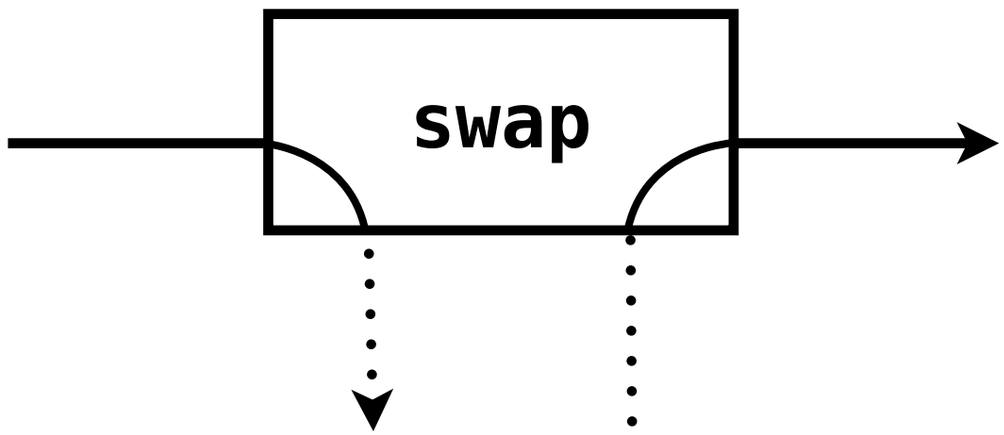
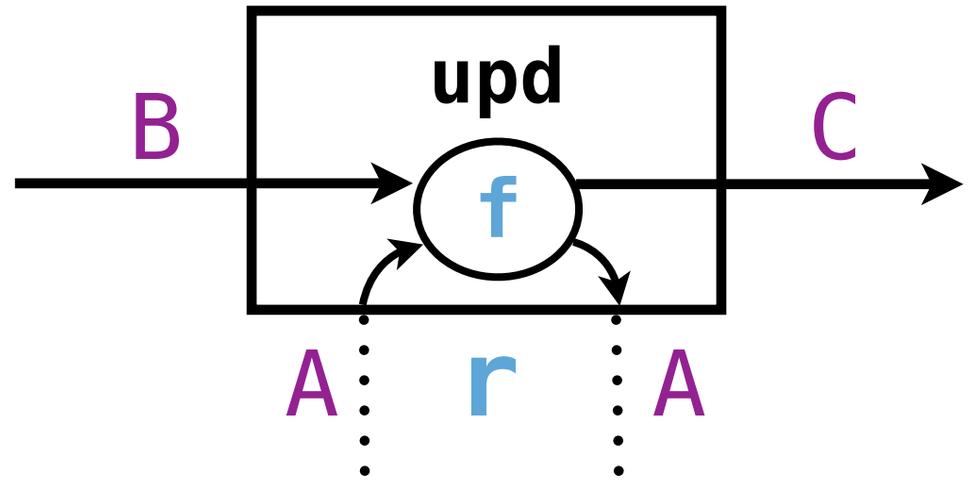



```
r: Ref[A]
f: (A,B)→(A,C)
```



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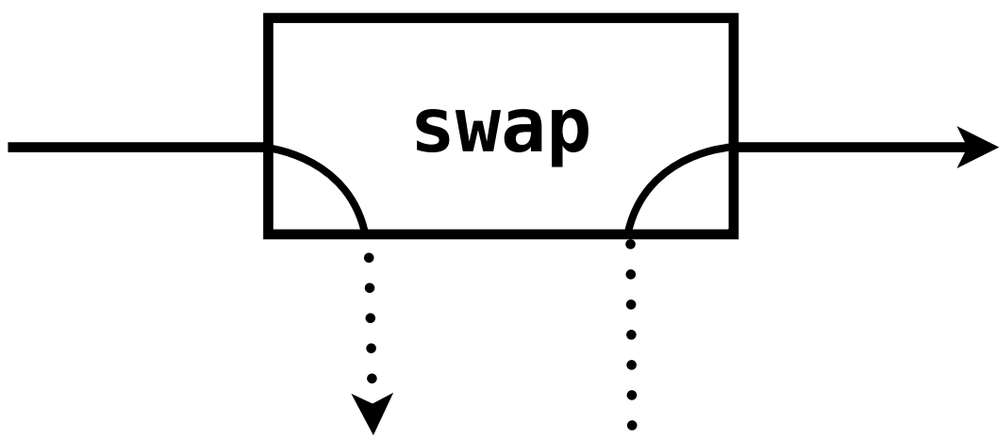
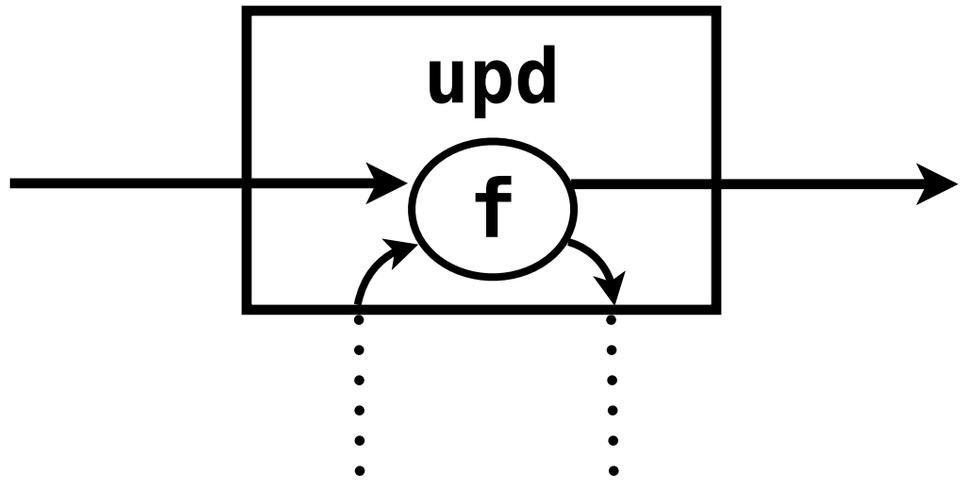


Shared state



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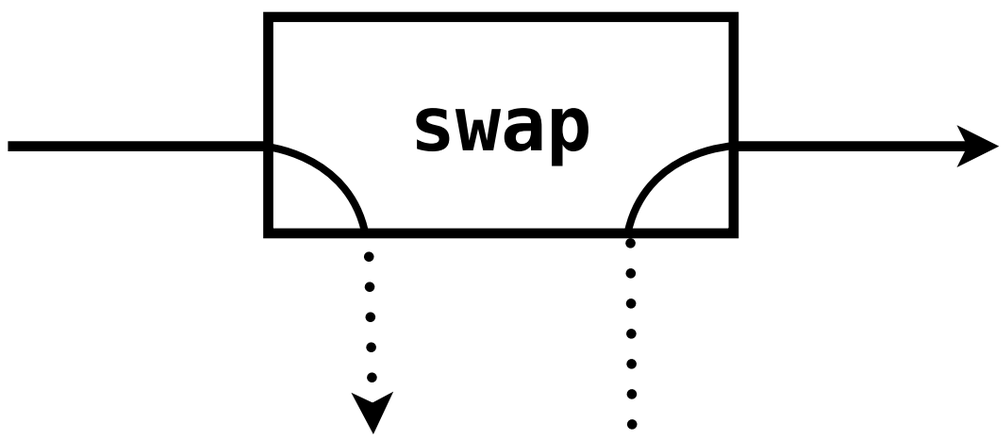

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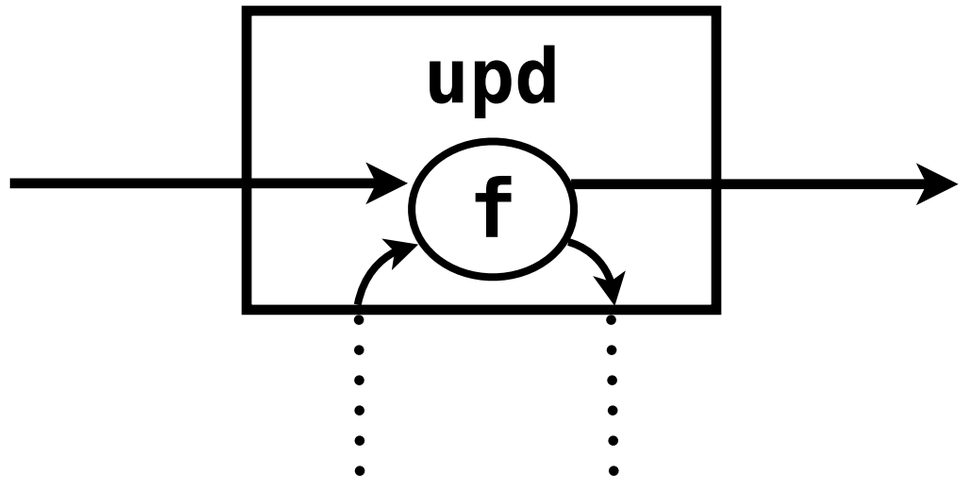

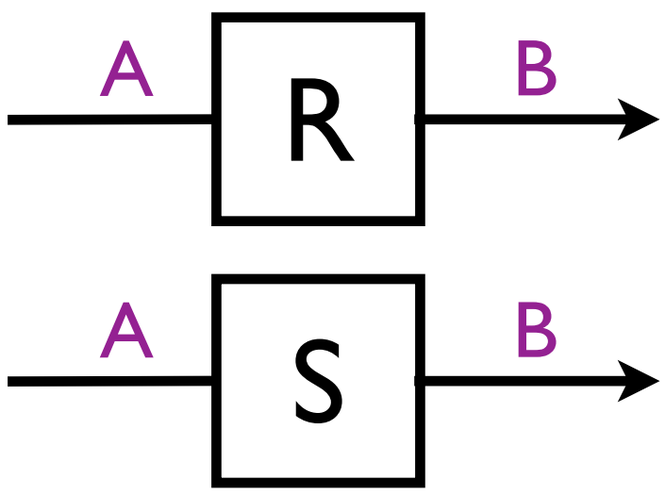

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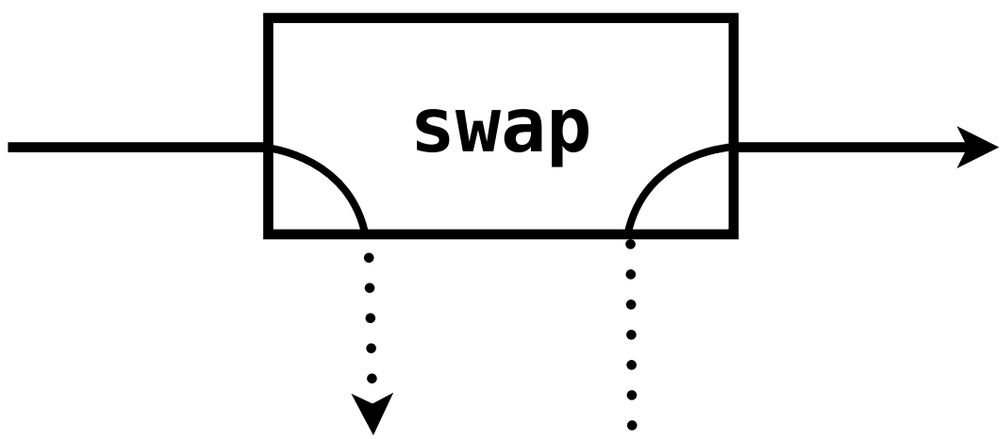

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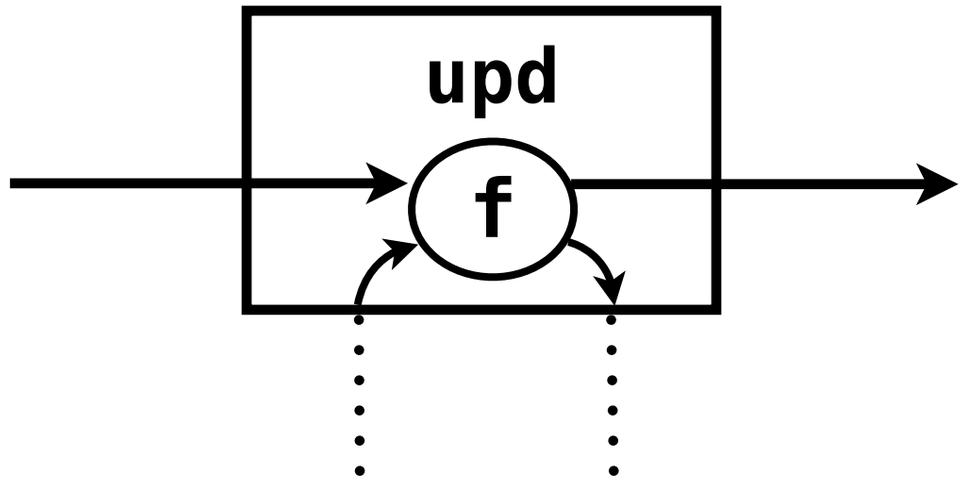

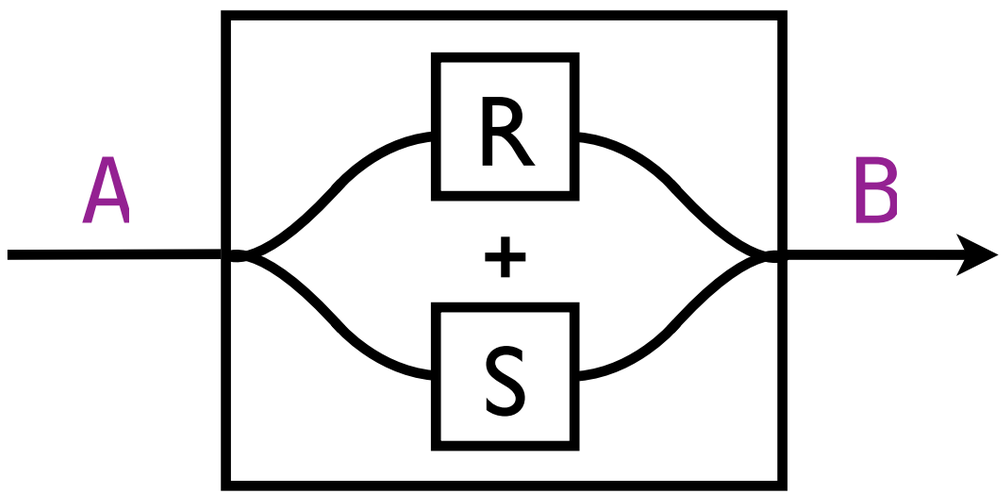

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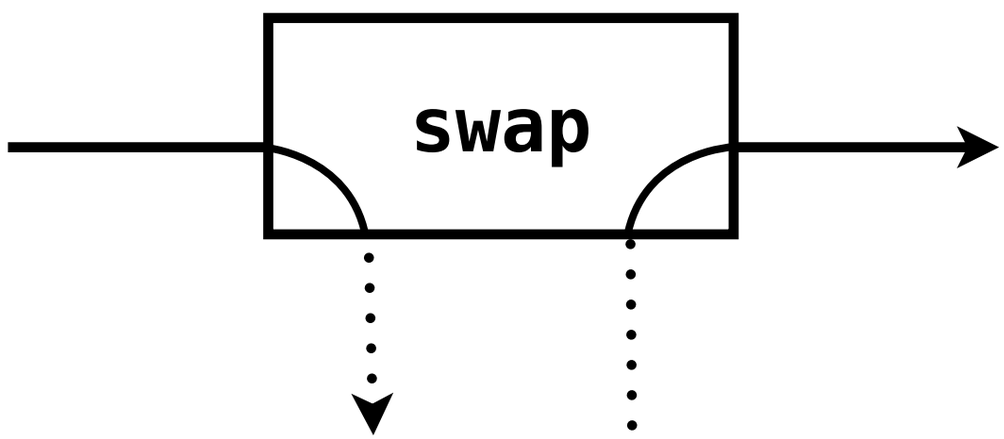

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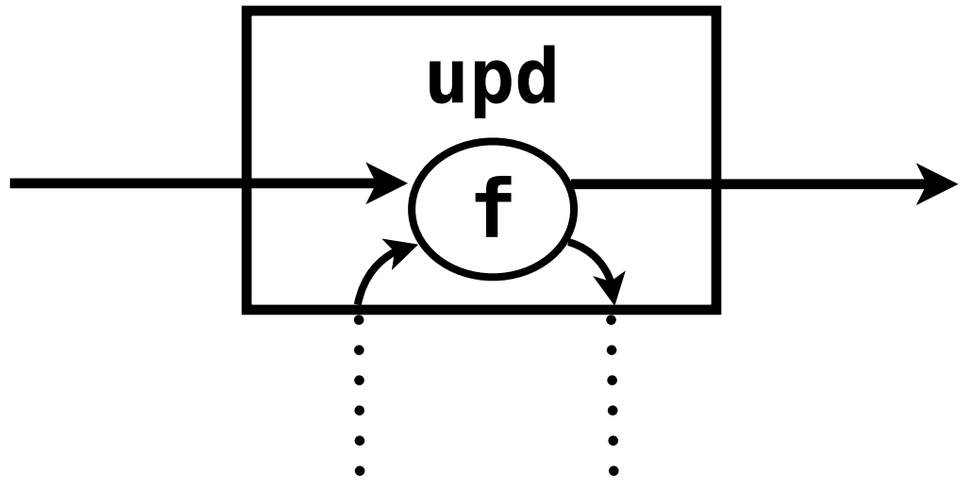
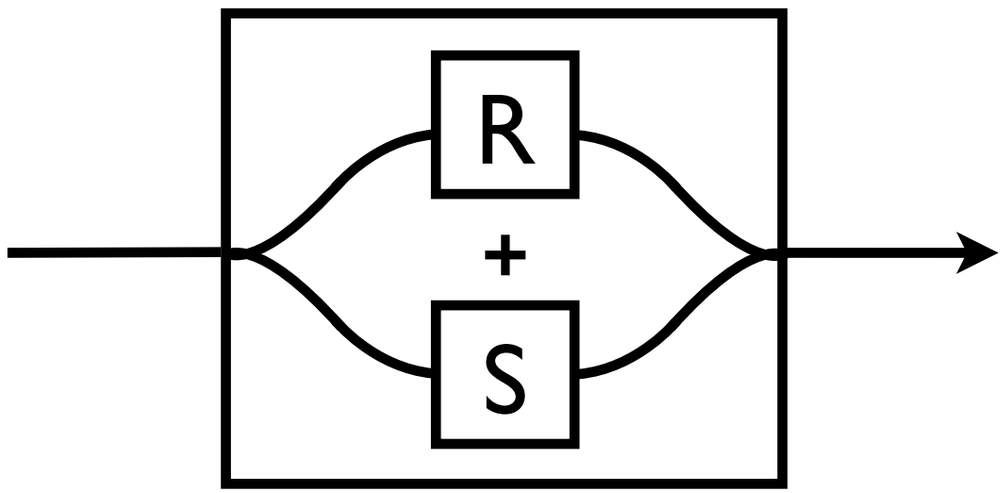


Disjunction



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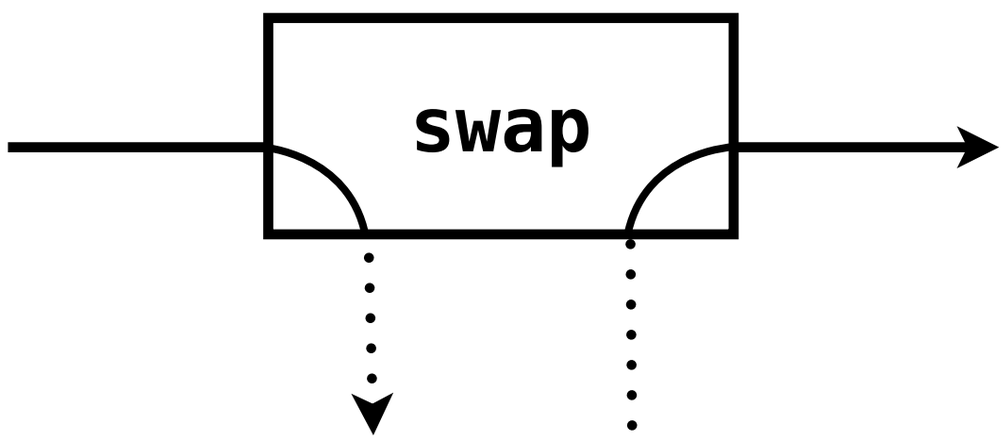
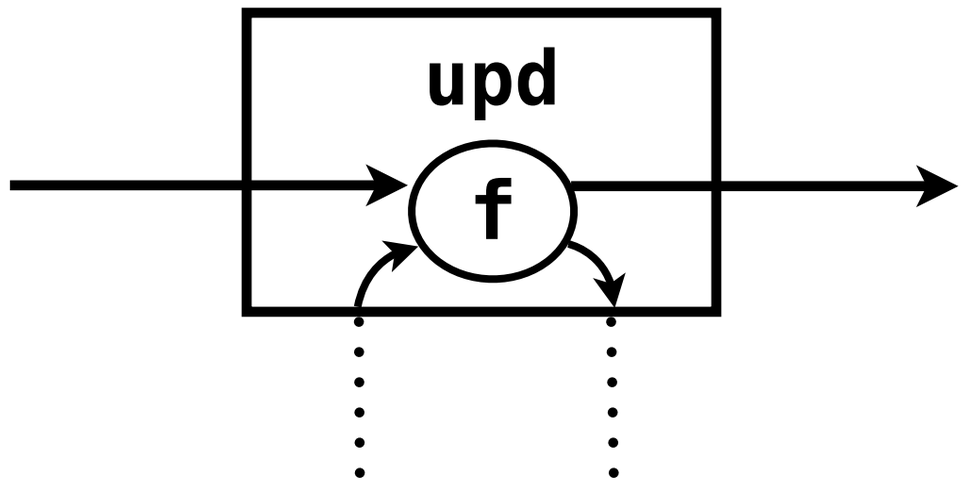
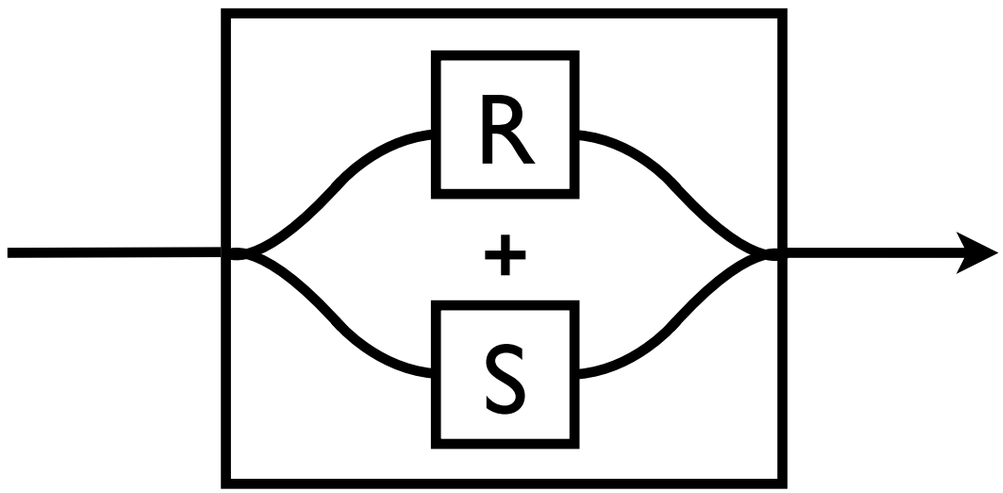
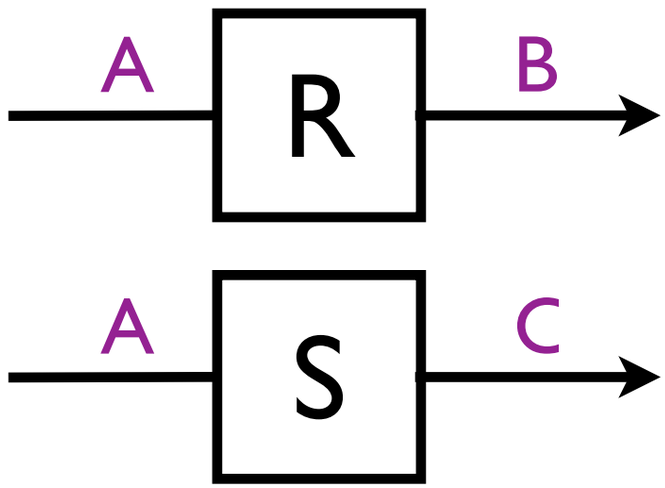


Shared state



Disjunction





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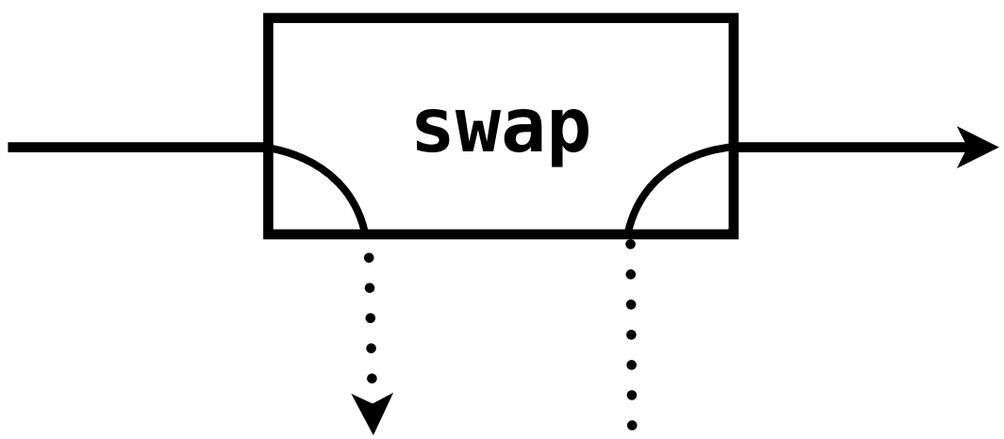

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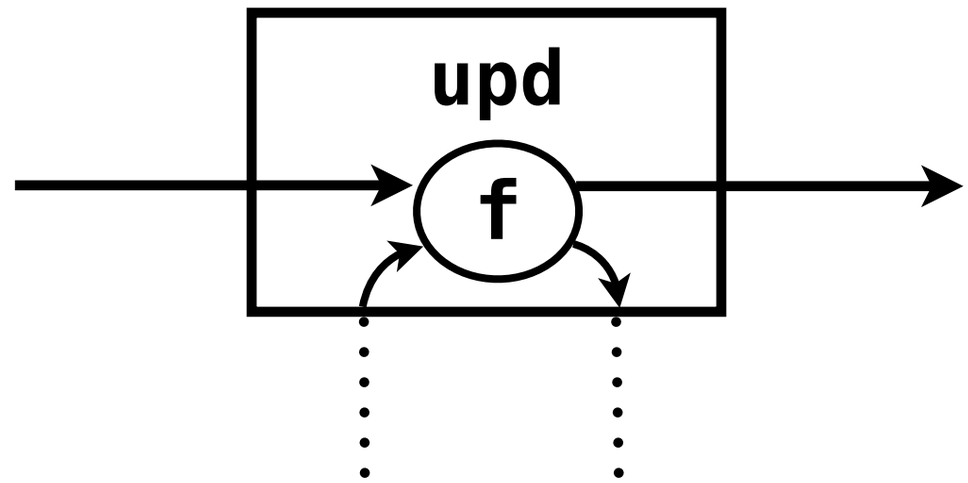

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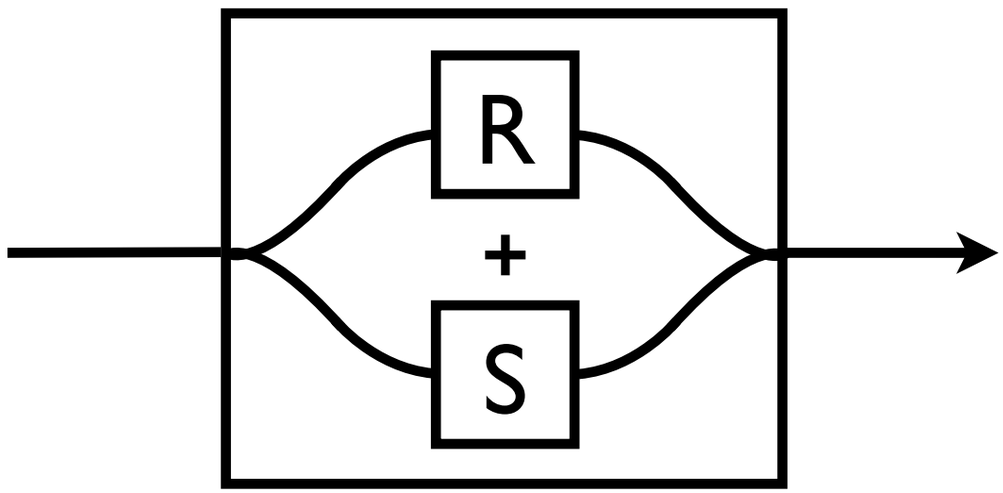

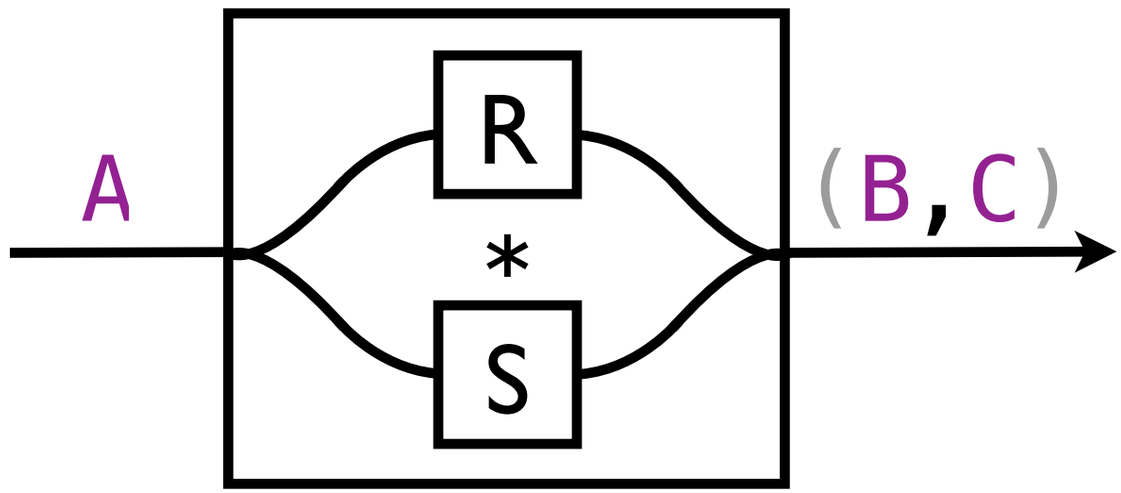

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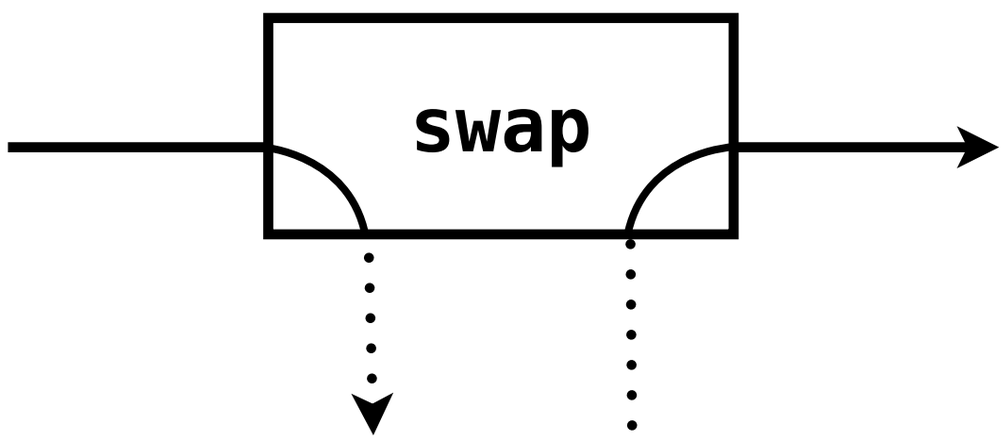

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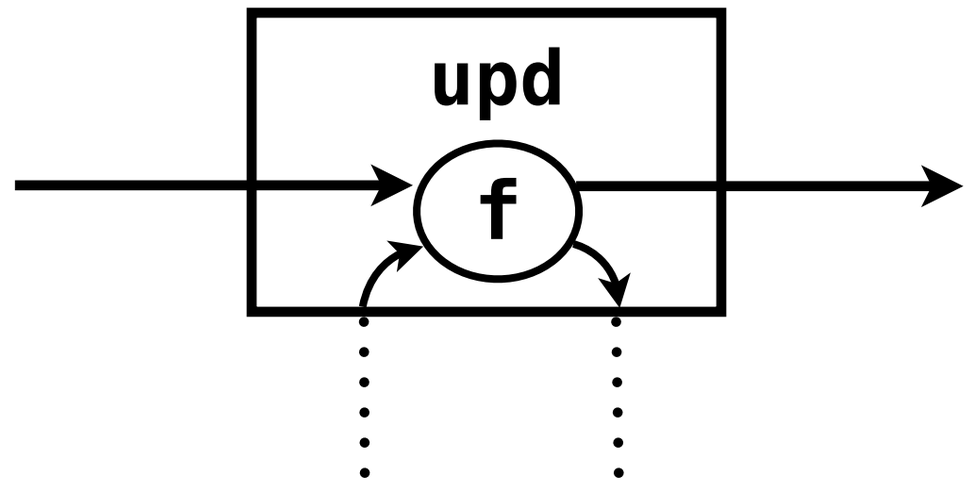

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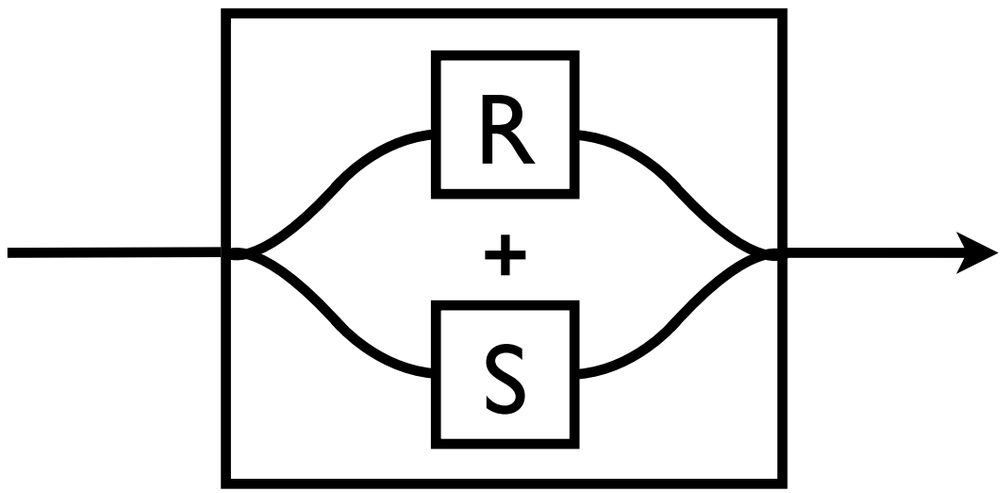
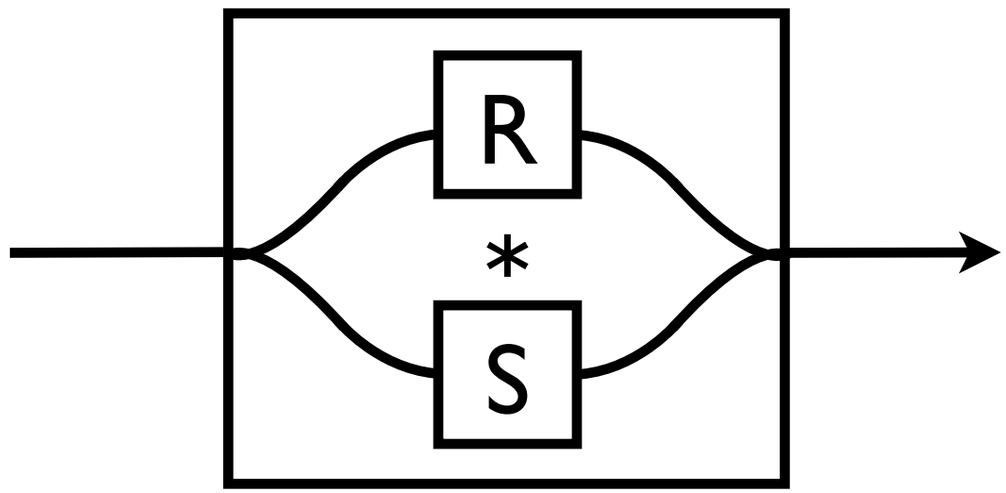
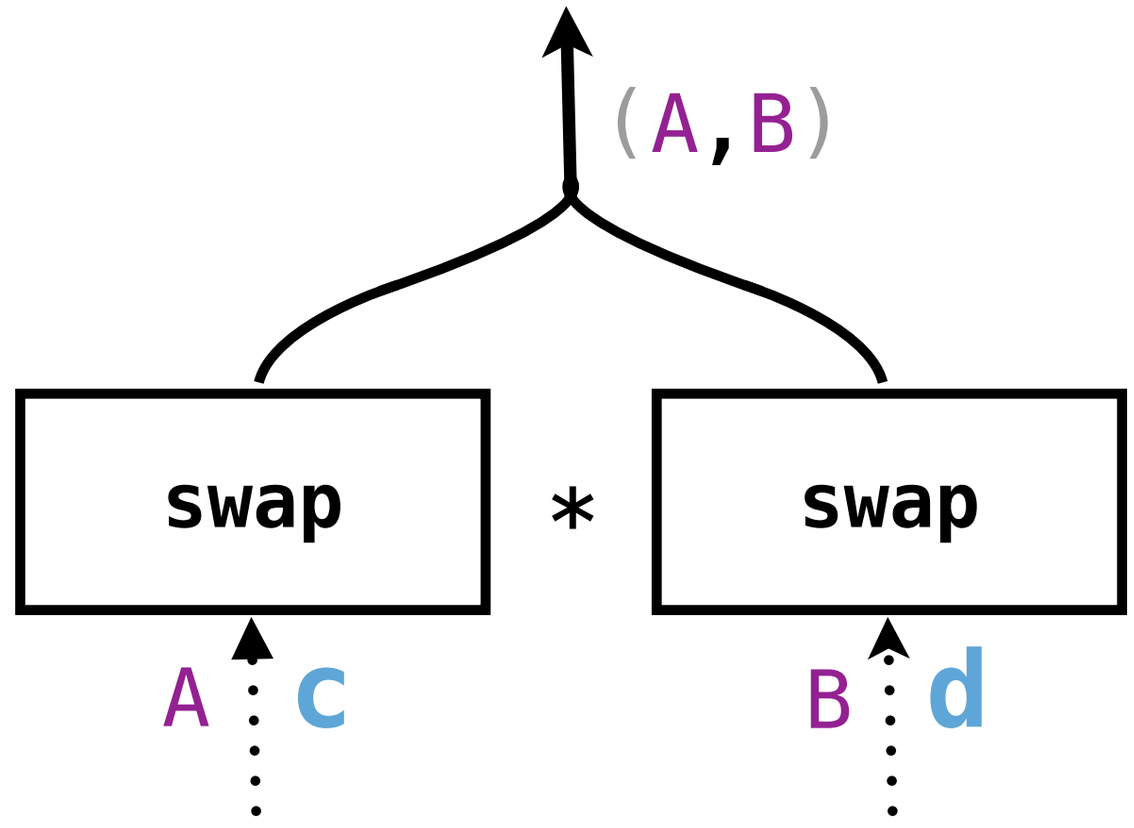
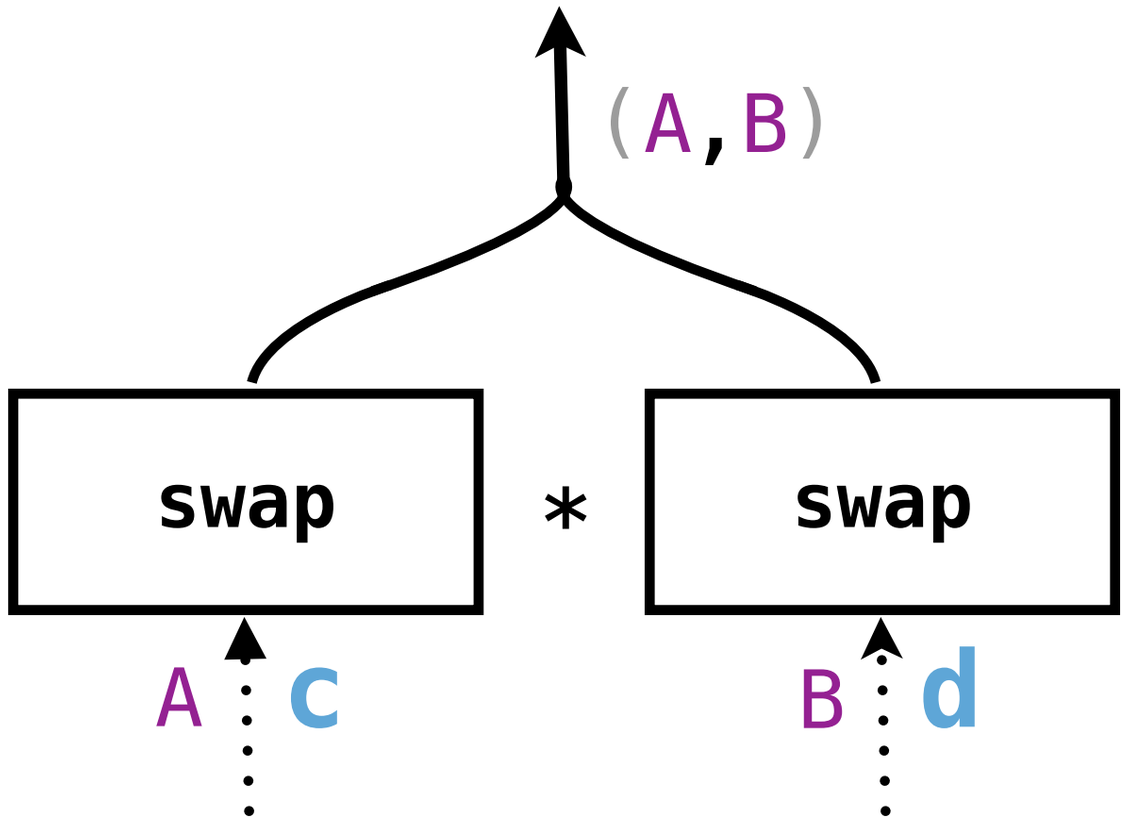


Conjunction

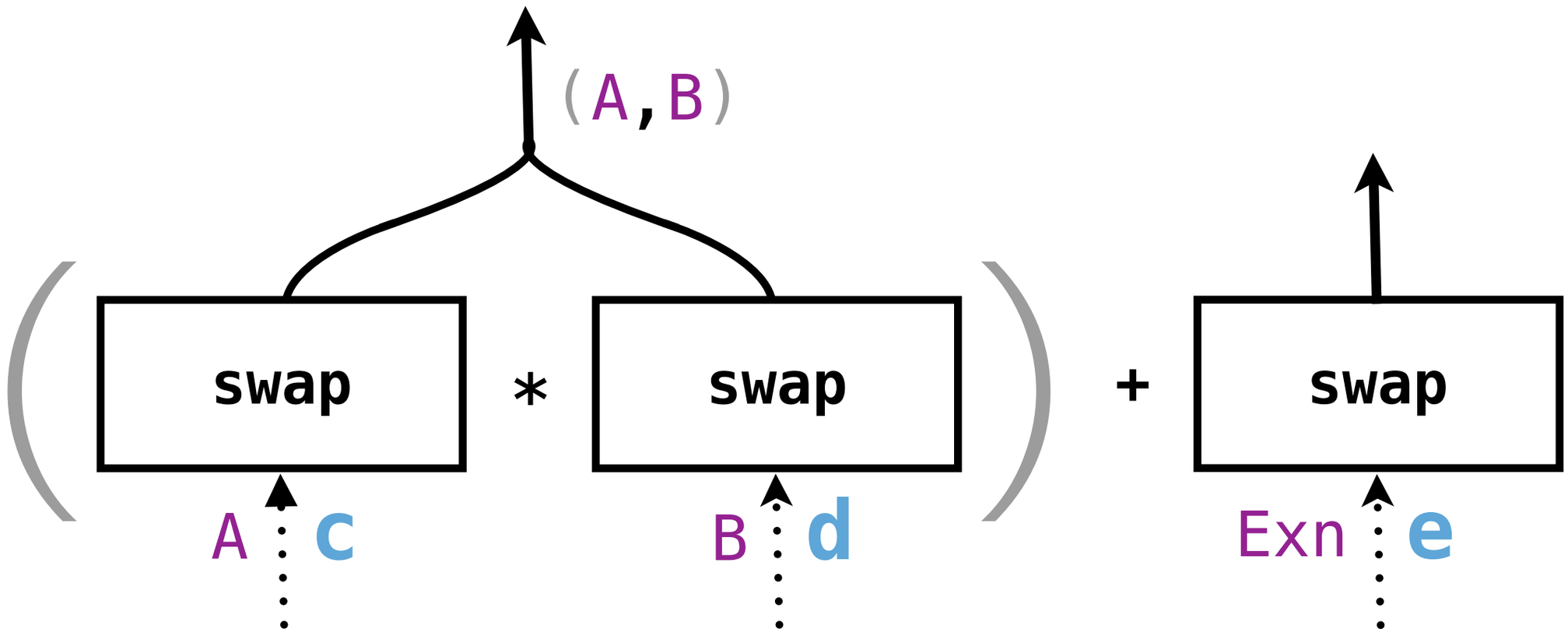



(A,B)
swap
*
swap
A
c
B
d

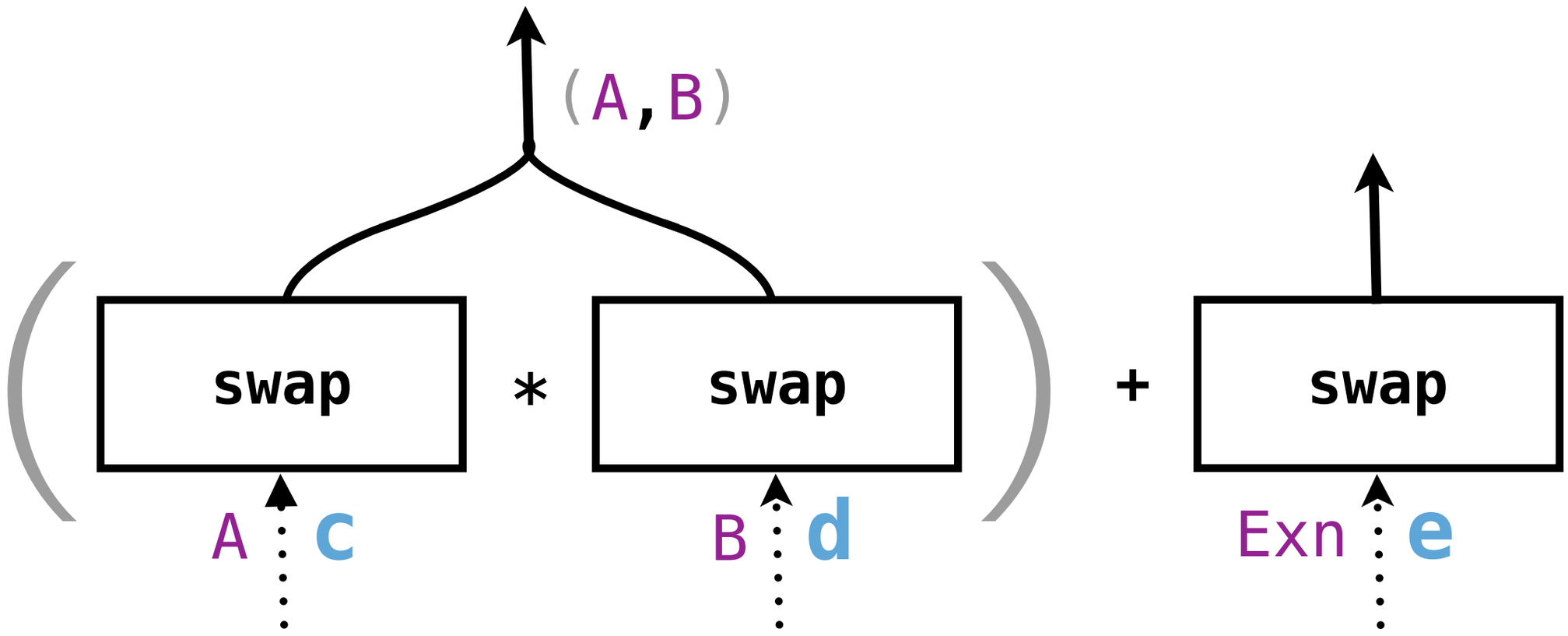
2-way join



2-way join



Abortable 2-way join



```scala
class TreiberStack [A] {
  private val head = new Ref[List[A]](Nil)
  val push    = upd(head)(cons)
  val tryPop = upd(head) {
    case (x :: xs) => (xs,  Some(x))
    case Nil       => (Nil, None)
  }
}
```

```
class TreiberStack [A] {
  private val head = new Ref[List[A]](Nil)
  val push    = upd(head)(cons)
  val tryPop = upd(head) {
    case (x :: xs) => (xs,  Some(x))
    case Nil       => (Nil, None)
  }
  val pop = upd(head) {
    case (x :: xs) => (xs,  x)
  }
}
```

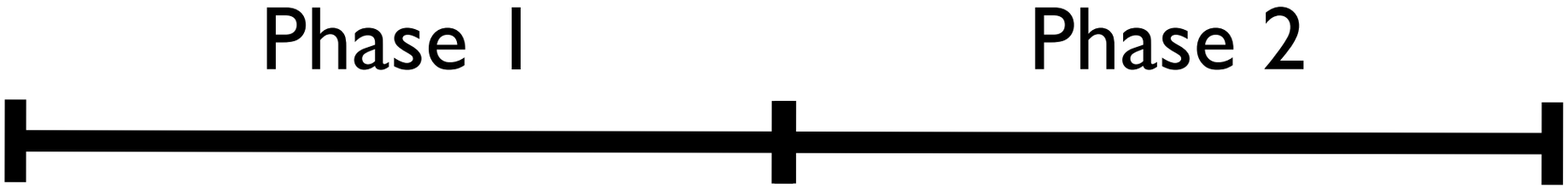
```
class TreiberStack [A] {
  private val head = new Ref[List[A]](Nil)
  val push    = upd(head)(cons)
  val tryPop = upd(head)(trySplit)
  val pop     = upd(head)(split)
}
```

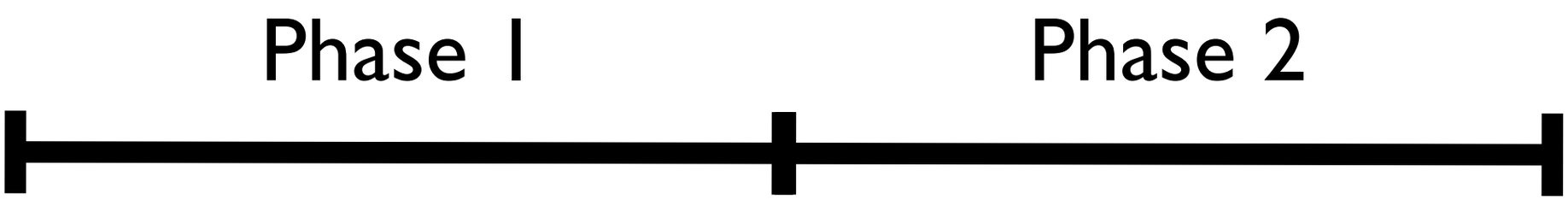
```
class TreiberStack [A] {
  private val head = new Ref[List[A]](Nil)
  val push    = upd(head)(cons)
  val tryPop = upd(head)(trySplit)
  val pop     = upd(head)(split)
}
```

```
class EliminationStack [A] {
  private val stack = new TreiberStack[A]
  private val (send, recv) = new Chan[A]
  val push = stack.push + swap(send)
  val pop  = stack.pop  + swap(recv)
}
```

stack1.pop >> stack2.push

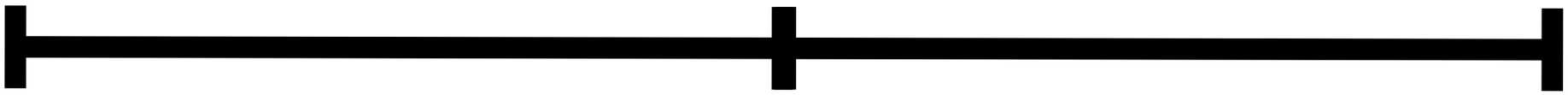
Implementation


Phase 1
Phase 2



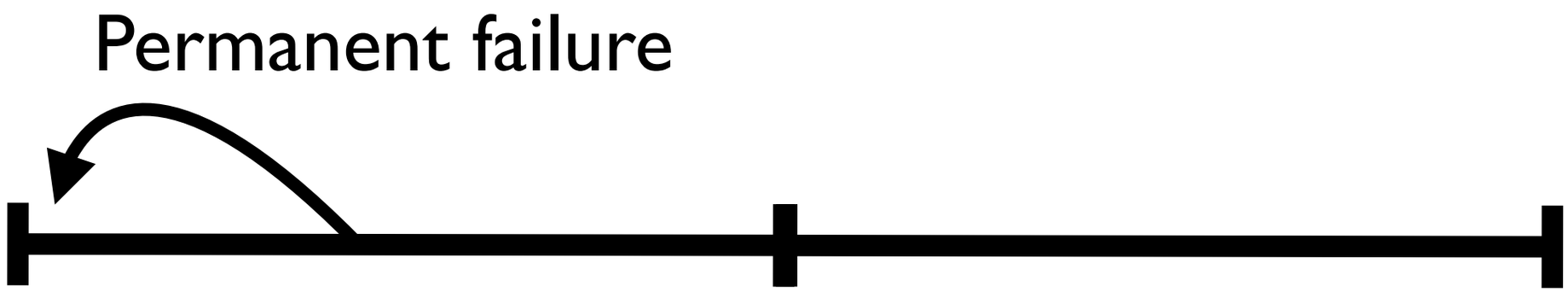
Accumulate CASes


Phase 1
Phase 2
Accumulate CASes
Attempt k-CAS



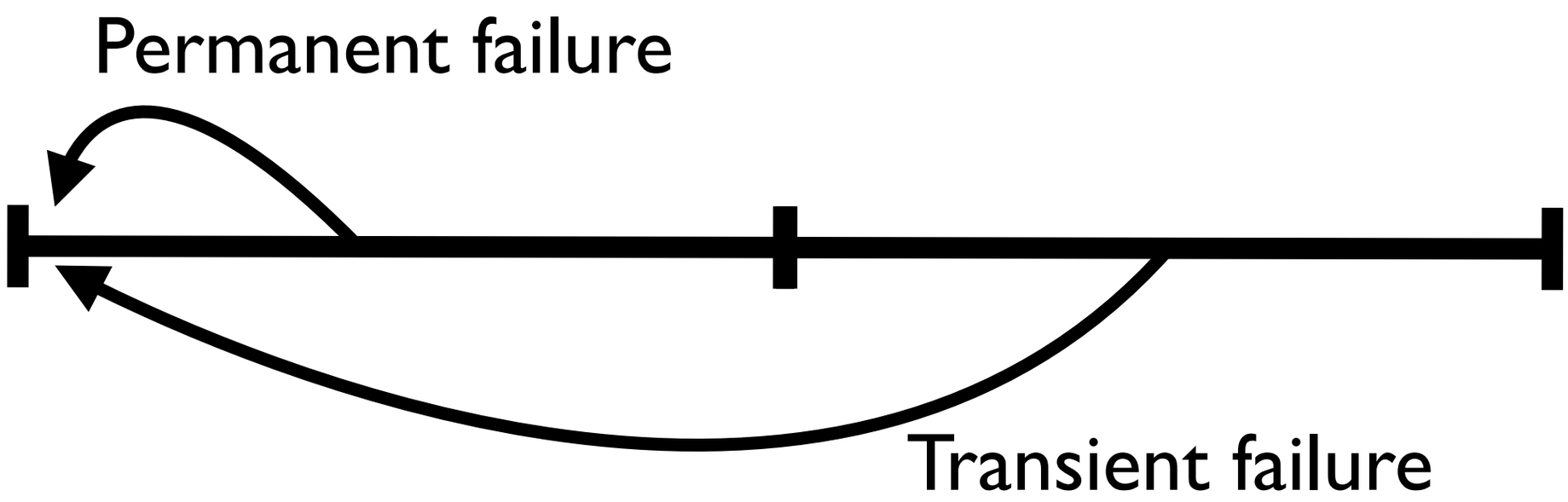
Accumulate CASes

Attempt k-CAS



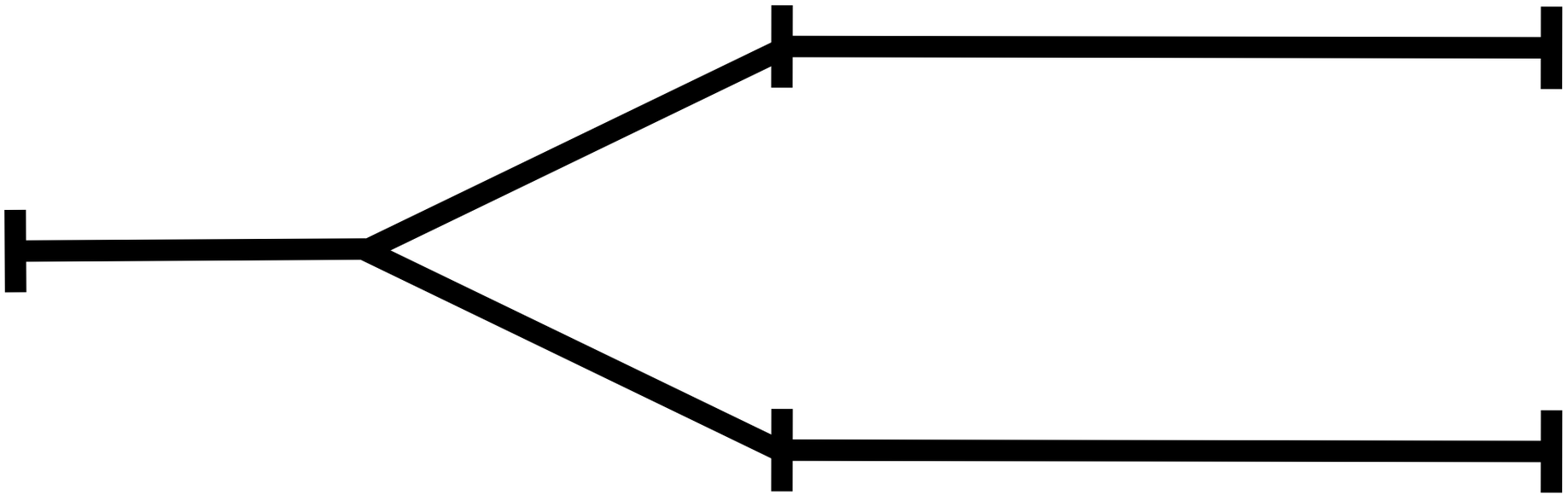
Accumulate CASes

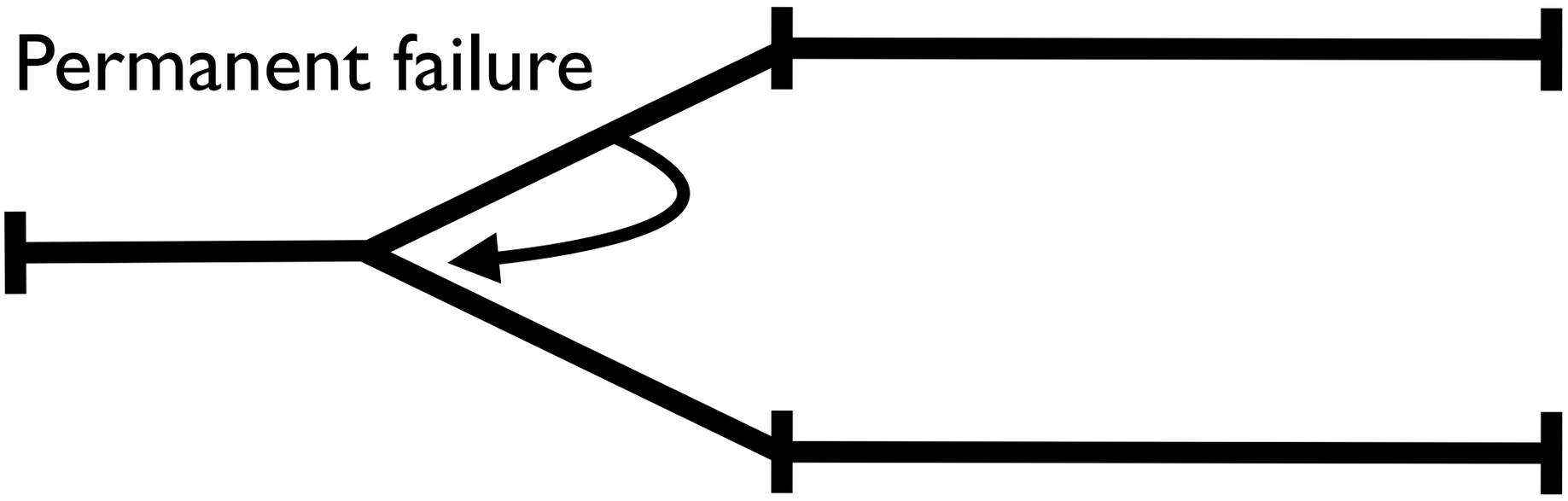
Attempt k-CAS

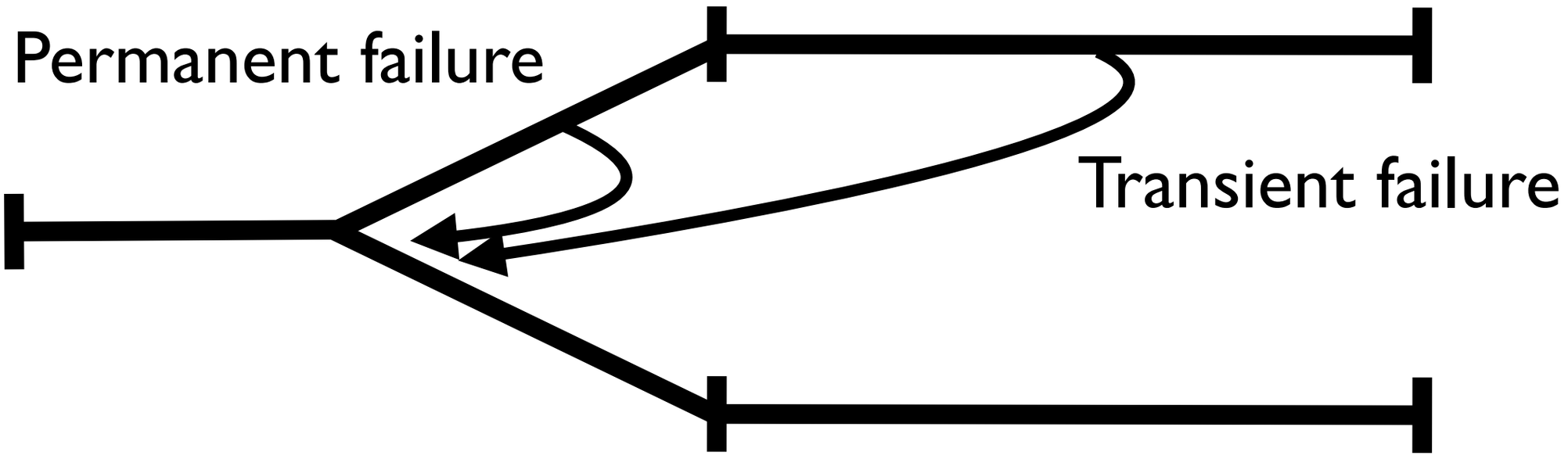


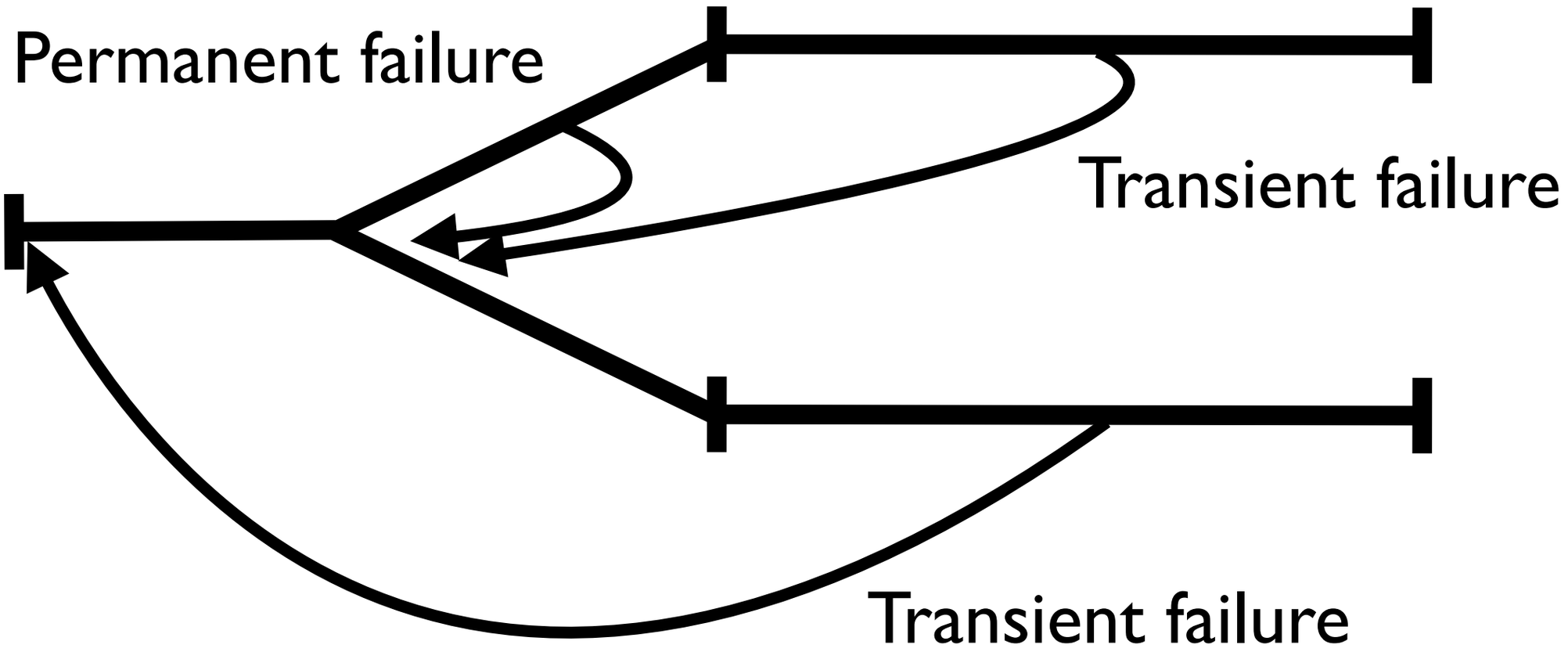
Accumulate CASes

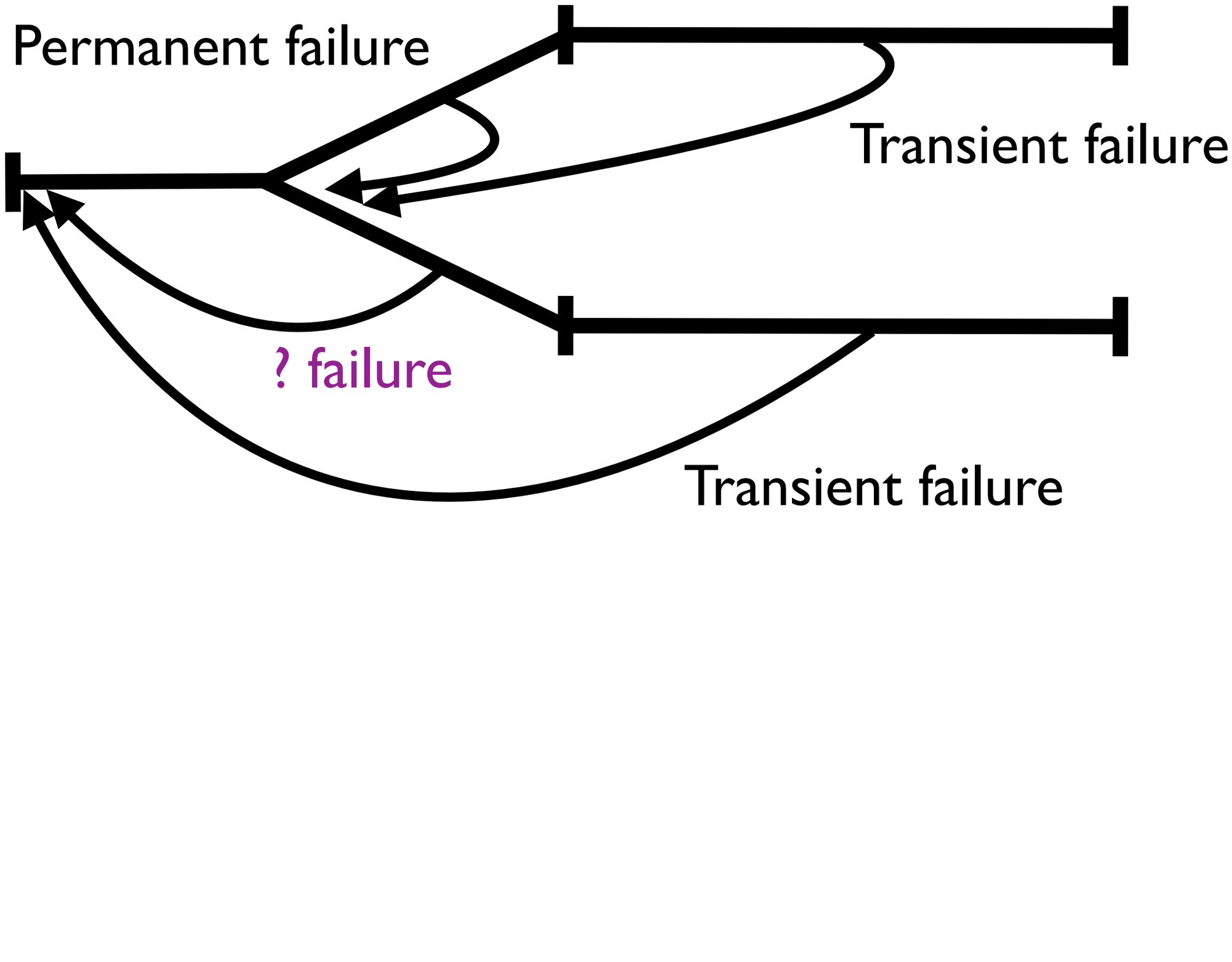
Attempt k-CAS

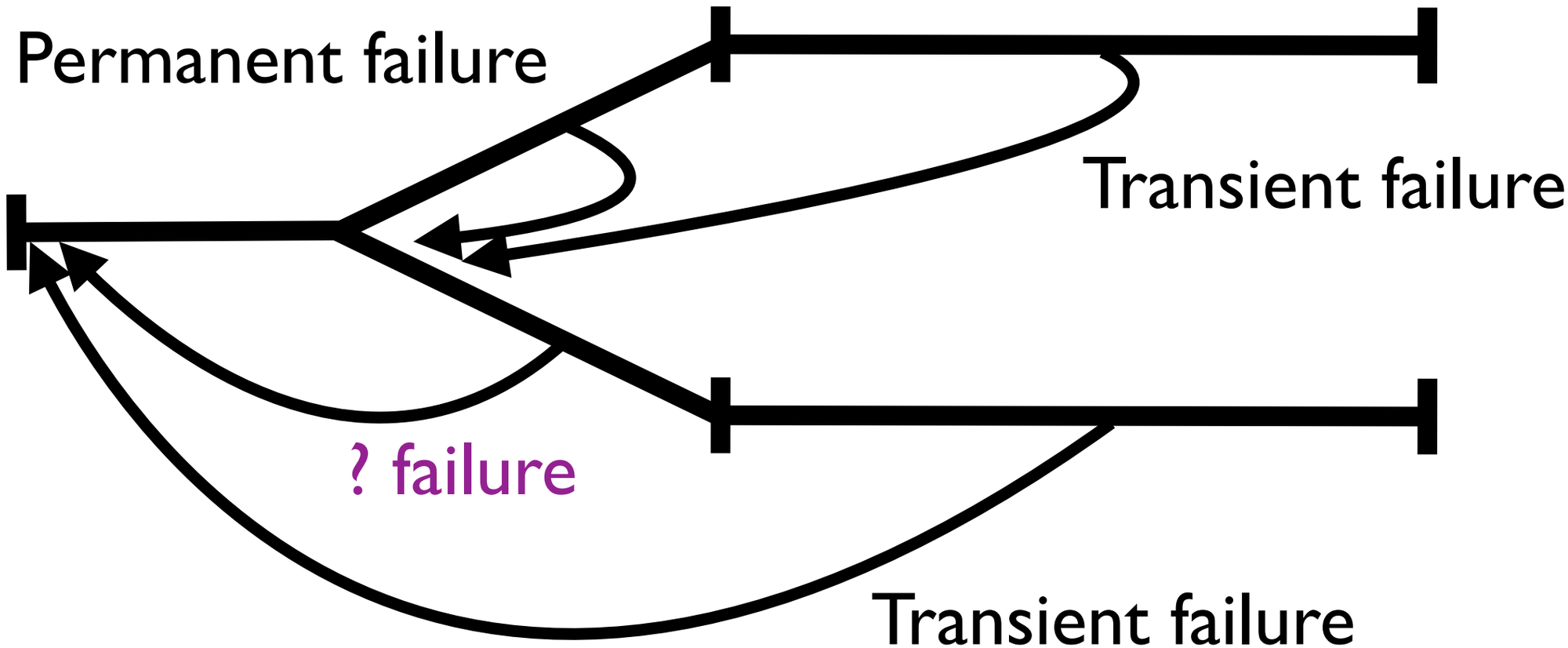



Permanent failure


Permanent failure
Transient failure


Permanent failure
Transient failure
Transient failure


Permanent failure
Transient failure
? failure
Transient failure



P & P = P

P & T = T

T & T = T

T & P = T

Is this just STM?

Is this just STM?

No:

- Single CAS collapses to single phase
- Multiple CASes to single location forbidden

So the "redo log" is write-only for phase 1

Therefore: **pay-as-you-go**

- Treiber stack is really a Treiber stack
- Pay for kCAS only for compositions

Is this just STM?

Isolation
Shared state

Interaction
Message passing

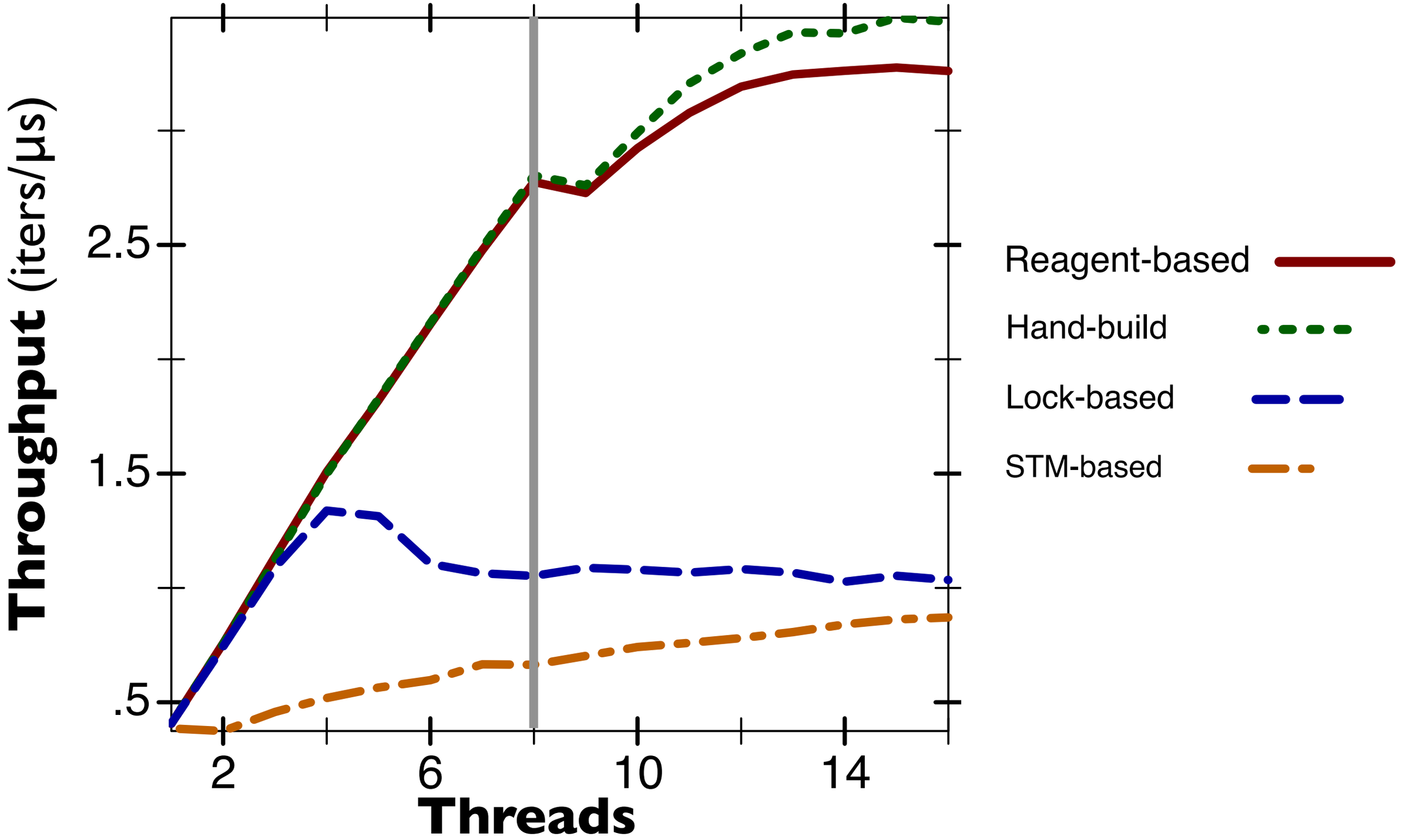
Is this just STM?

Isolation
Shared state

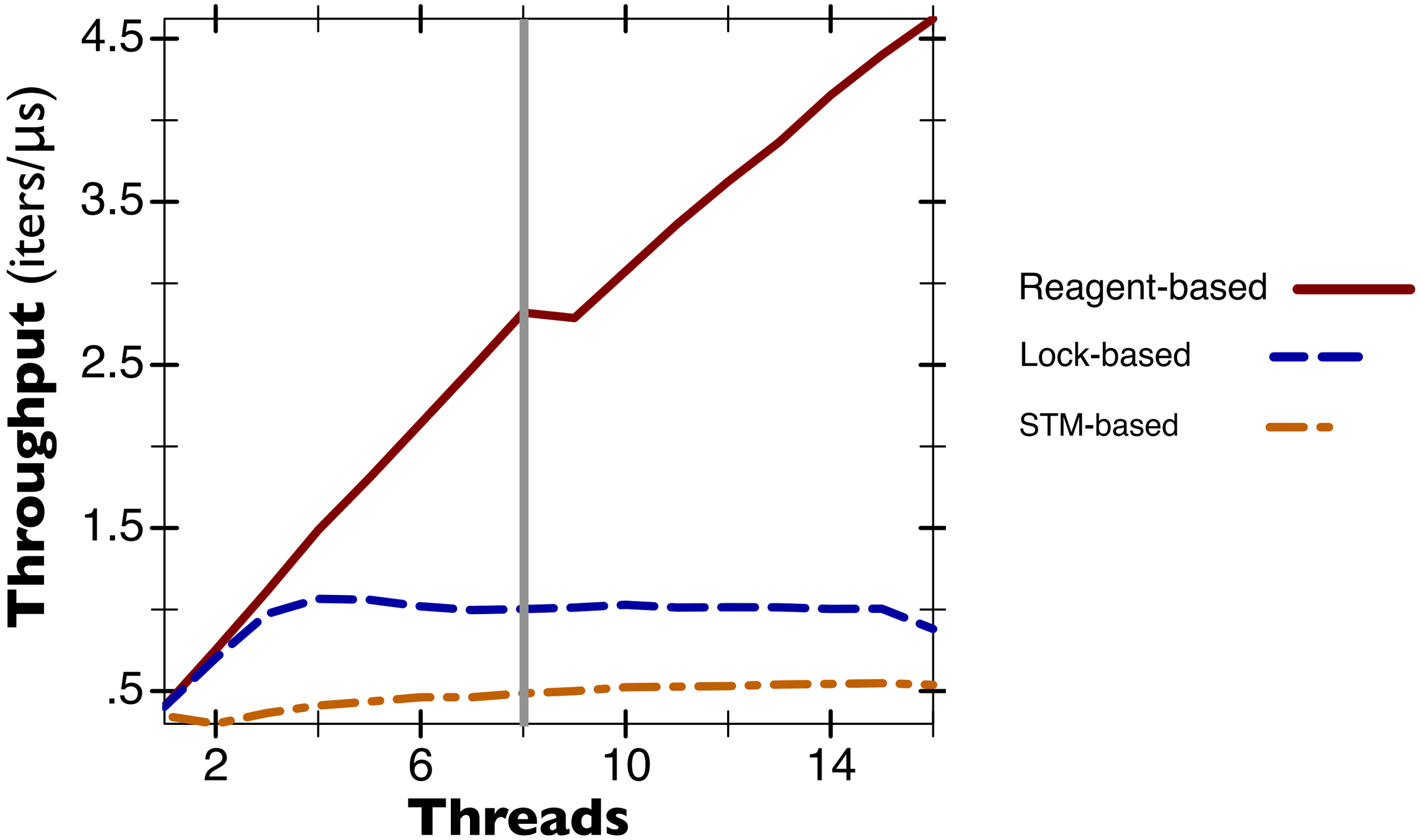
Interaction
Message passing

Using lock-free bags,
based on earlier work
with Russo [OOPSLA'11]

Treiber stack



Stack transfer



java.util.concurrent

Synchronization

Reentrant locks
Semaphores
R/W locks
Reentrant R/W locks
Condition variables
Countdown latches
Cyclic barriers
Phasers
Exchangers

Data structures

Queues
- Nonblocking
- Blocking (array & list)
- Synchronous
- Priority, nonblocking
- Priority, blocking

Deques
Sets
Maps (hash & skiplist)

CHEMISTRYSET

Synchronization

Reentrant locks
Semaphores
R/W locks
Reentrant R/W locks
Condition variables
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Data structures

Queues
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Deques
Sets
Maps (hash & skiplist)

The take-away:

Reagents enable scalable concurrent algorithms to be built and extended using abstraction and composition

https://github.com/aturon/ChemistrySet