Event-driven Programming in Clojure

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synchronous is simple

```
def handle_request(request)
  result = query_database(request)
  return generate_response(result)
```

- easy to read and reason about
- errors can be handled at any scope

asynchronous is complex

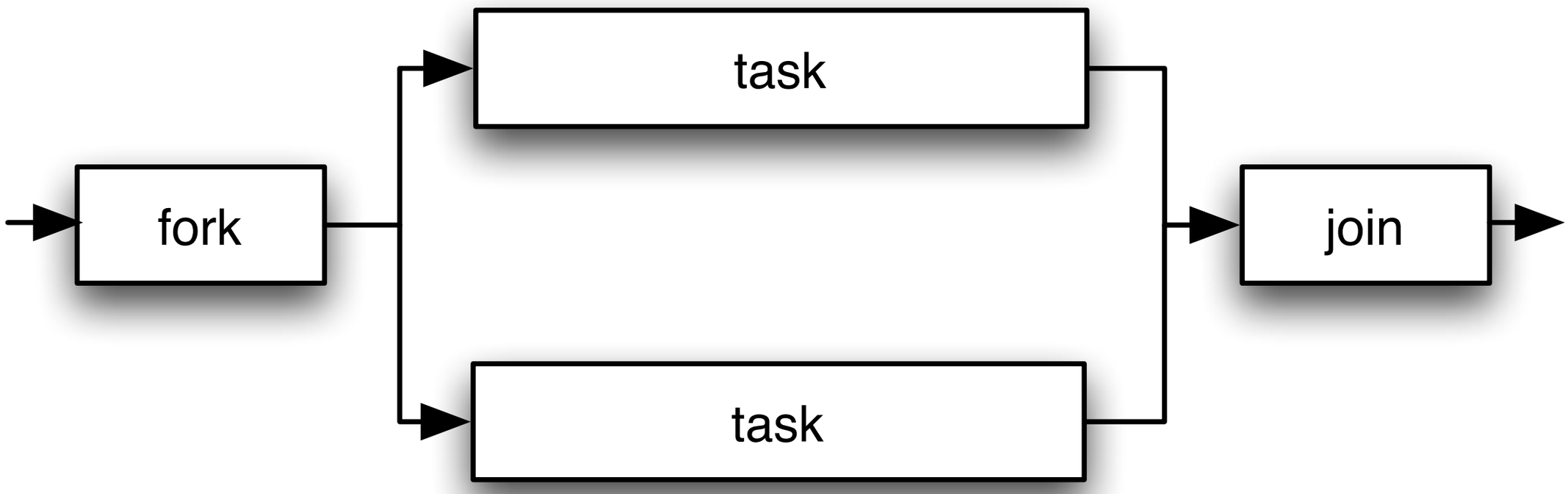
```
def handle_request(request)
  query_database(request,
    error => {
      handle_error(error)
    },
    result => {
      response = generate_response(result)
      send_response(response)
    })
```

- difficult to read and reason about
- errors must be handled locally

the importance of being concurrent

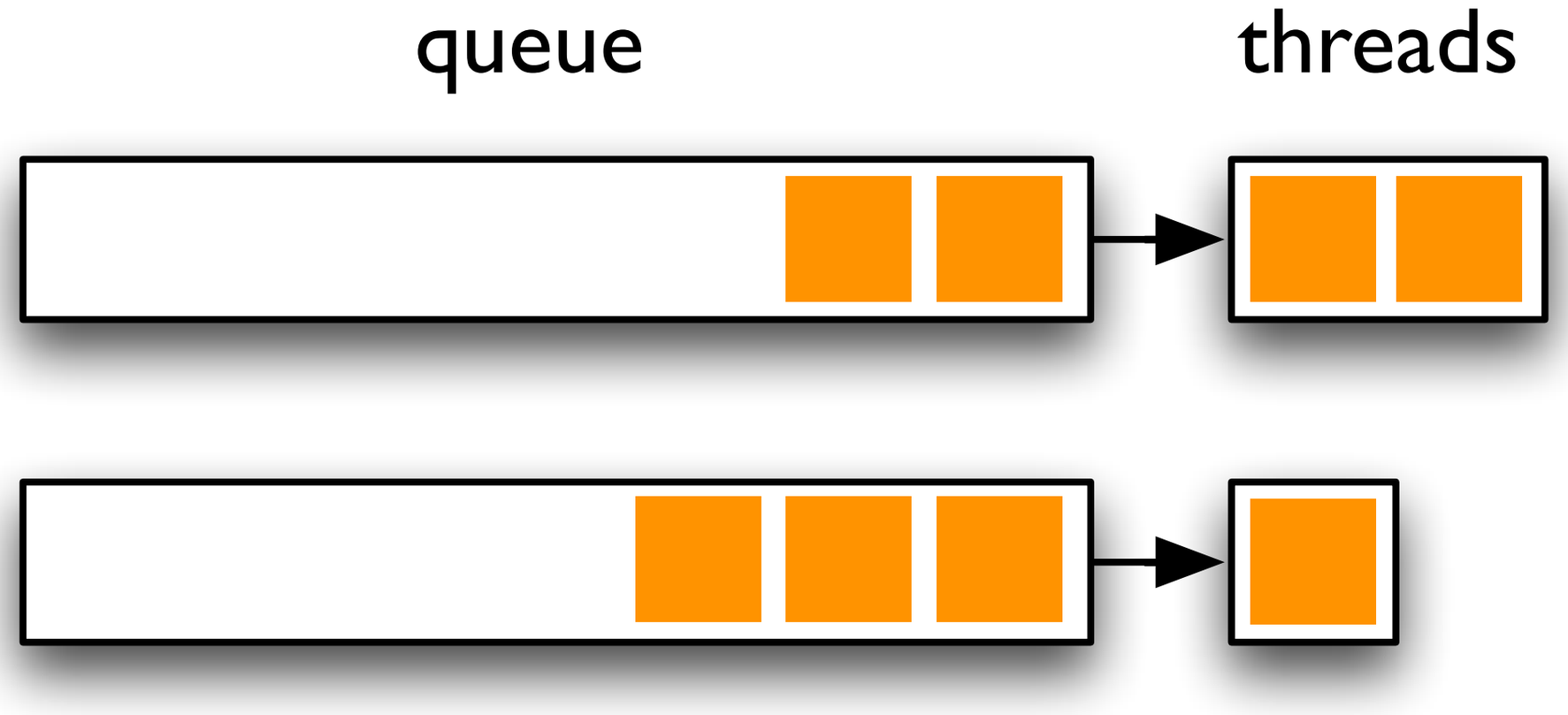
- we often spend more time **waiting** on data than we do **computing** our response
- we can respond more quickly if we wait for multiple things at once

synchronous concurrency

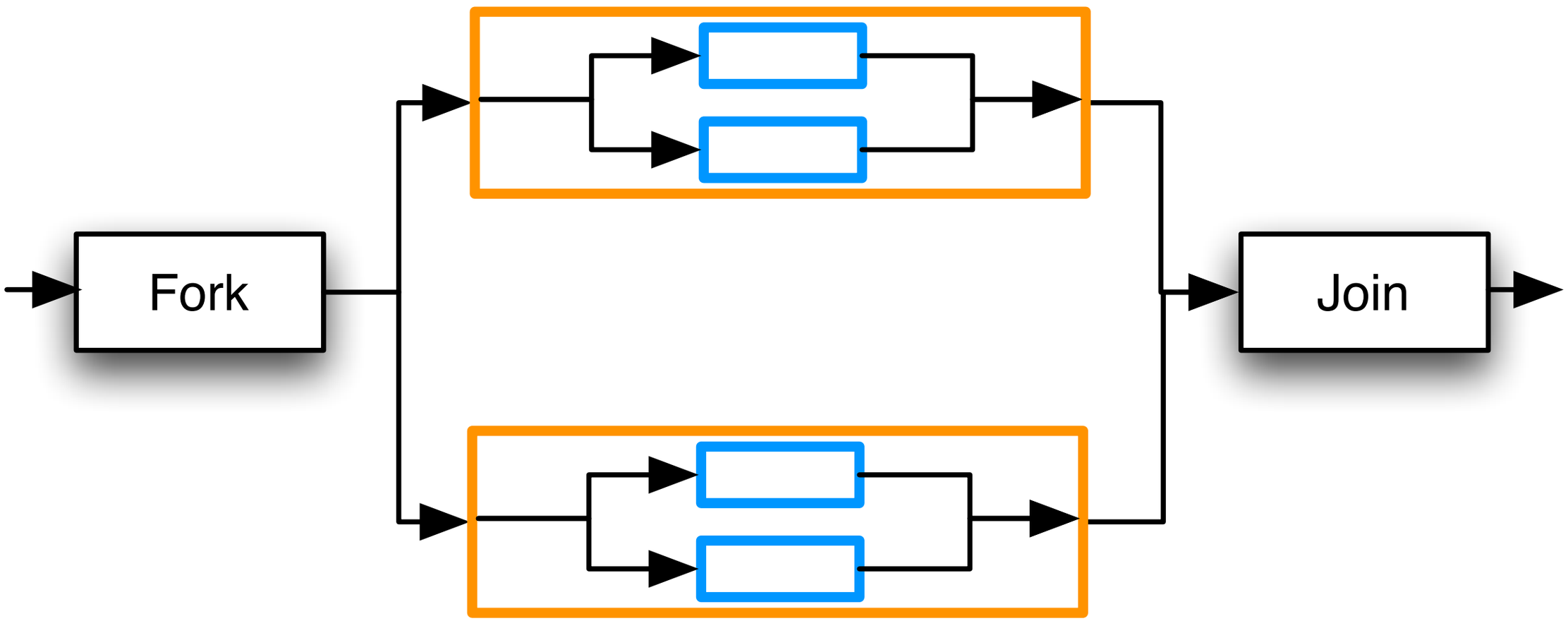


- still pretty simple
- requires one thread per task, plus the original thread

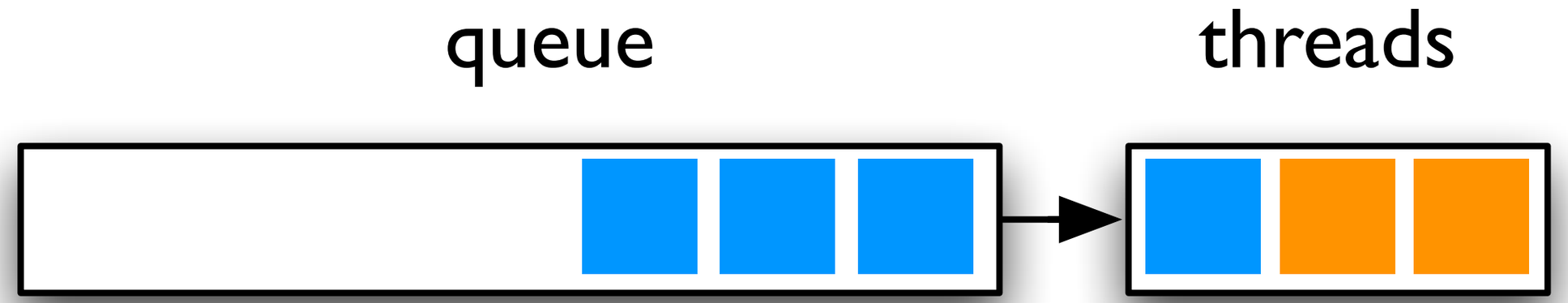
but threads don't grow on trees



nested concurrency



two tasks, one pool



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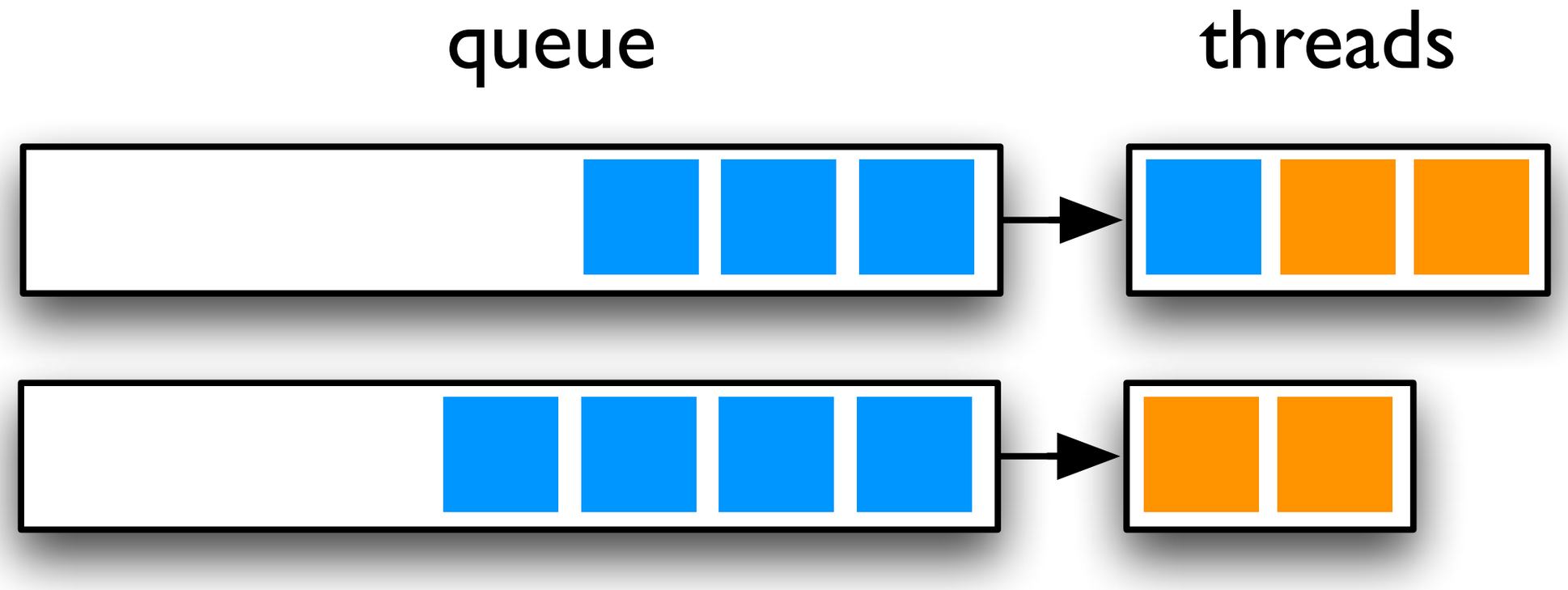


deadlock!

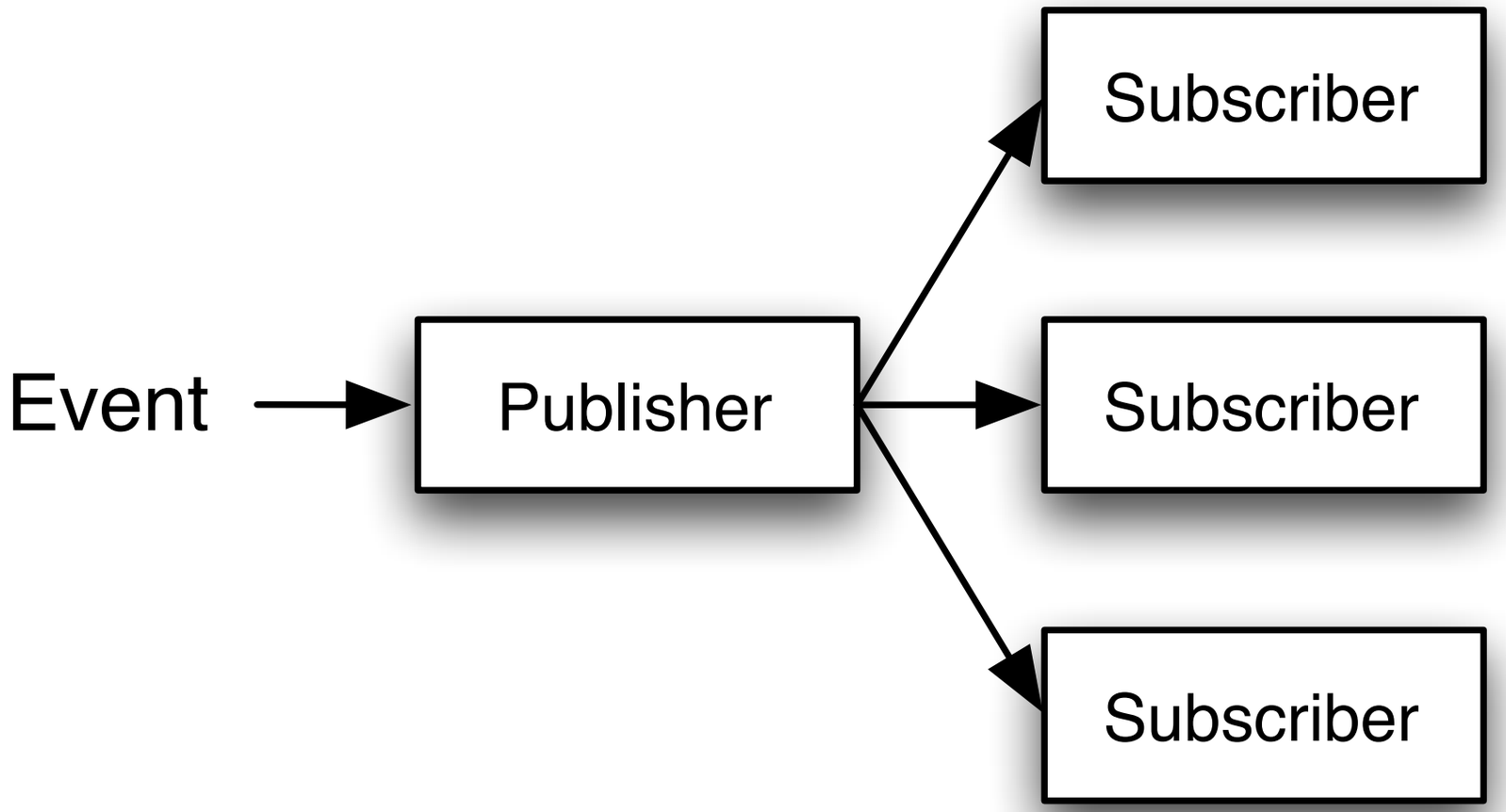
asynchronous exposes an inherent complexity

- everything is concurrent by default
- a less leaky abstraction (for highly coupled concurrent problems)

two great tastes

- these are not mutually exclusive approaches
- interop should be easy
- we want to simplify the asynchronous approach as much as possible

publisher/subscriber



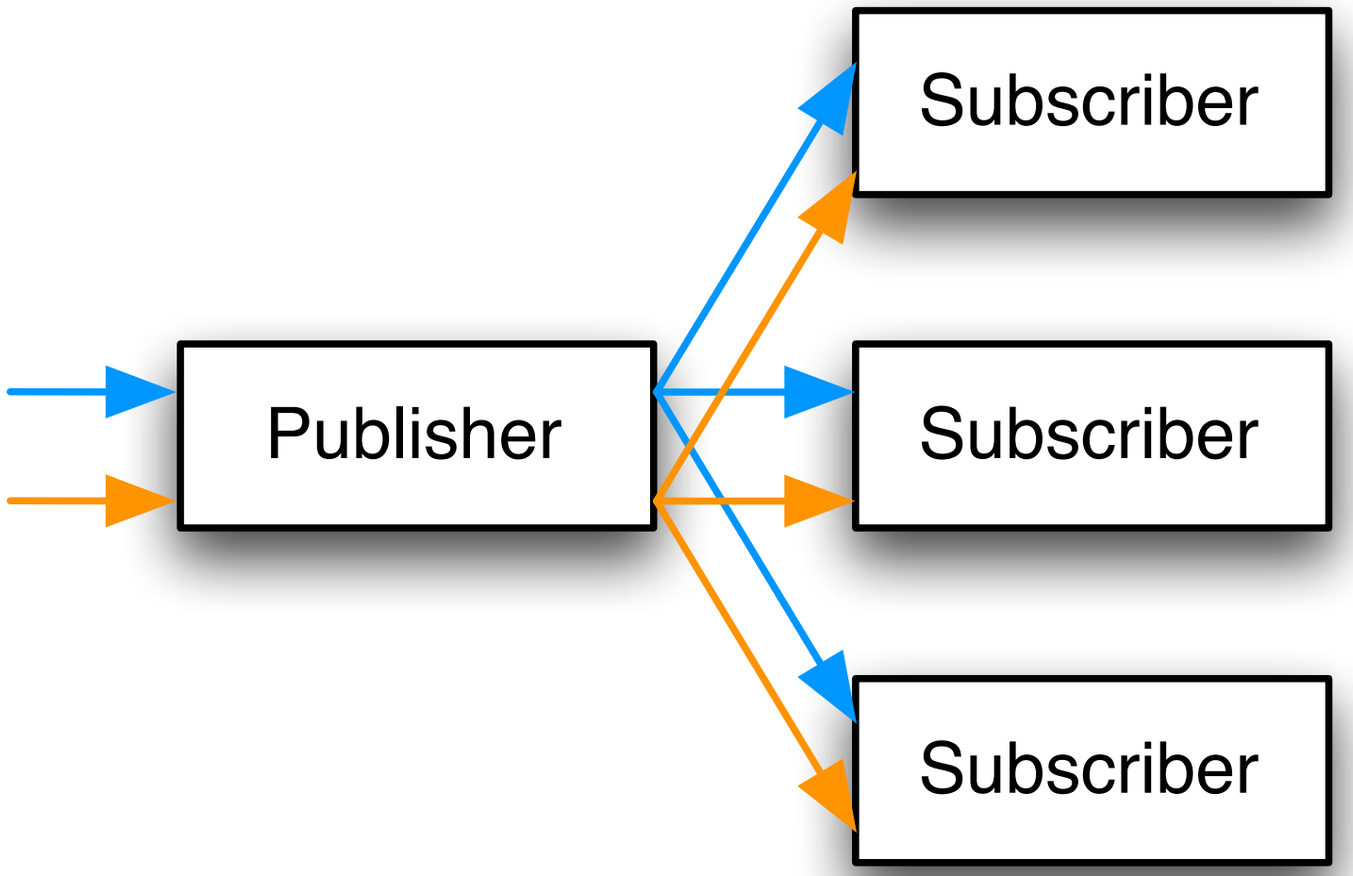
a naive implementation

```
subscribers = [ ]

def subscribe(callback)
  subscribers.add(callback)

def publish(event)
  foreach s in subscribers
    s(event)
```

stop the presses



The same callback can be executed on different threads with different data

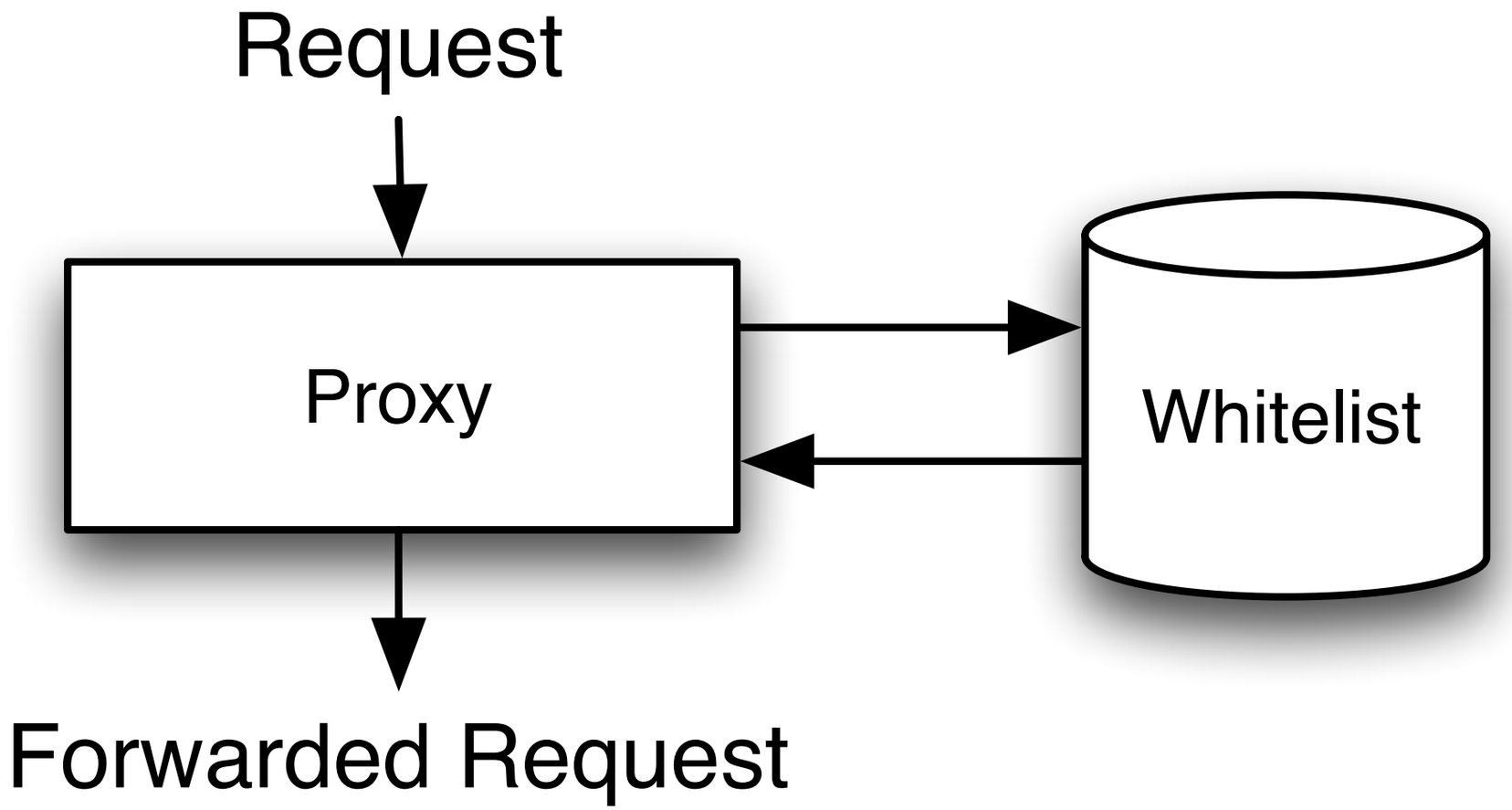
ordered vs. unordered

- mouse clicks and keystrokes need to be handled one at a time and in-order
- logging we can be less fussy about

a software koan

If an event has no subscribers, does it have any effect?

a simple example



a simple example

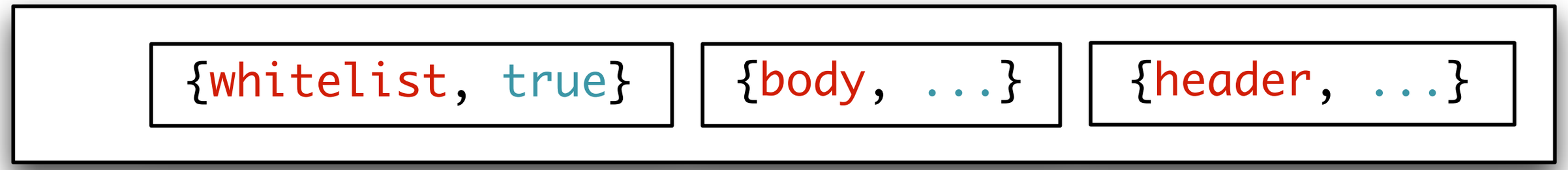
```
def handle_request(request)
  if whitelisted?(request.url)
    forward_request(request)
  else
    forbid_request(request)
```

the node.js approach

- receive headers
- send whitelist request, subscribe to response
- if it's whitelisted, forward the headers and subscribe to the body
- but what if the body arrived first?

the erlang approach

mailbox




```
receive {header, Header}

receive {whitelist, Response}

receive {body, Body}
```

push vs. pull

- the pub/sub model is **push**
- the erlang mailbox model is **pull**
- just because we get an event doesn't mean we know what to do with it

the story so far

- event streams can be **ordered** or **unordered**
- events can be published using **push** or consumed using **pull**

events in clojure

we need to consider:

- immutable data structures
- software transactional memory
- thread-agnosticism

immutability

all that, and a bag of chips

STM

- publishing is a side-effect
- side-effects inside transactions can be hazardous

threads

- Clojure is thread-agnostic
- what happens if an event is published before another thread subscribes?

a wish list

- support for push and pull event consumption
- efficient mechanisms for ordered and unordered event streams
- plays nicely with transactions

channels

- represents a **stream of messages**
- messages are consumed by callbacks
- if there are no callbacks, messages wait in the queue
- queue is transactional

unordered messages

```
(receive-all channel callback)
```

- callback is invoked by thread that enqueues the message
- bypasses the queue entirely

ordered messages

```
(receive-in-order channel callback)

(receive channel callback)
```

pull messages from the queue one at a time

closing channels

```
(close channel)
(on-closed channel callback)
(on-drained channel callback)
```

- when a channel is **closed**, no further messages can be enqueued
- when a closed channel is empty, it is **drained**

channel errors

```
(error! channel exception)
```

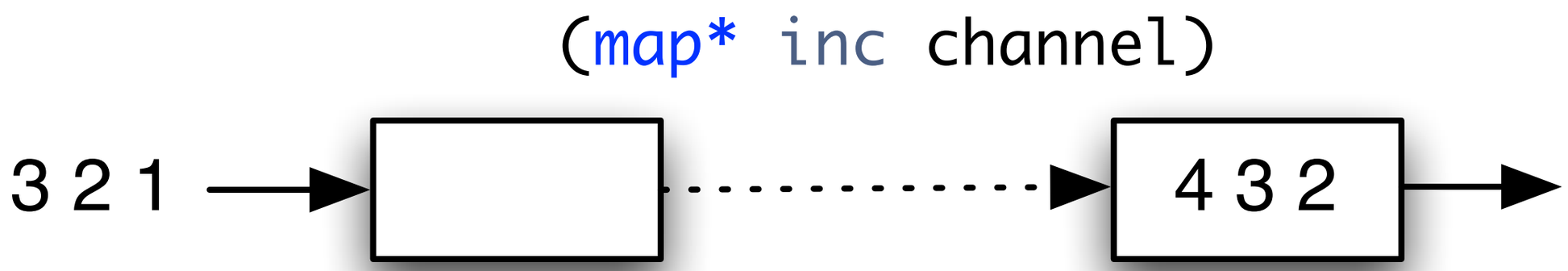
```
(on-error channel callback)
```

errors also close the channel

channel operators

- familiar operators such as `map*`, `filter*`, `reduce*`, `take*`, and `partition*`
- less familiar operators such as `sample-every*`, `partition-every*`, and `siphon`

channel operators

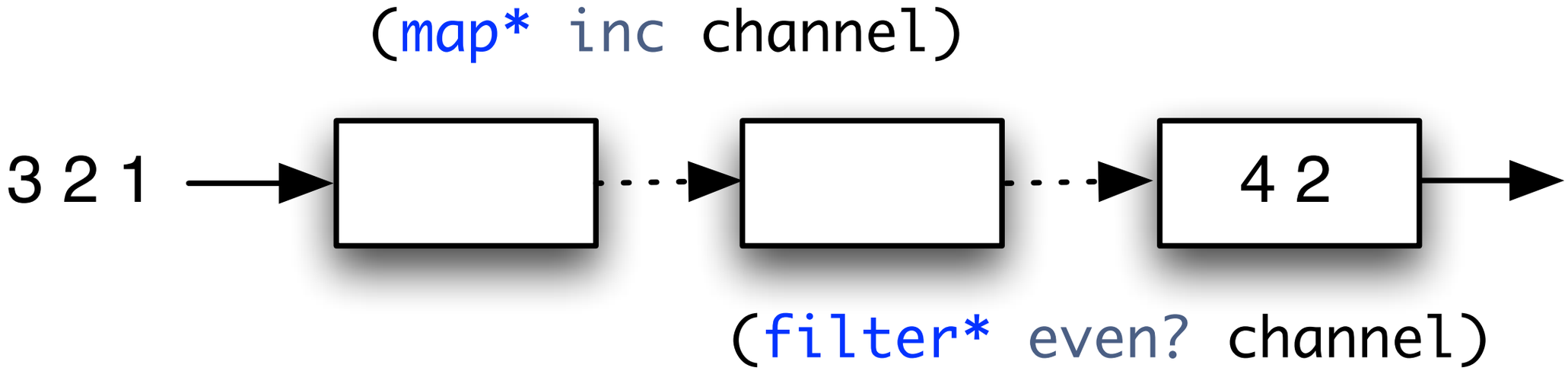


to create a derivative channel, you must consume messages from the source channel

channel operators

```
(->> channel (map* inc) (filter* even?))
```

channel operators



but what happens when we close the right-most channel?

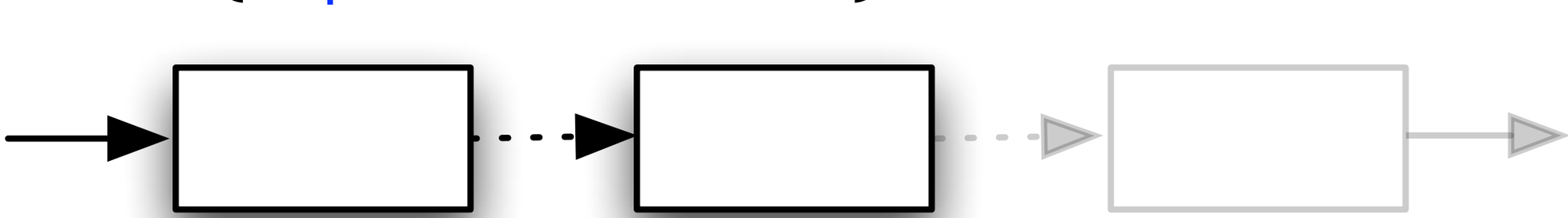
backpropagation

```
(map* inc channel)
```

```
(filter* even? channel)
```

backpropagation

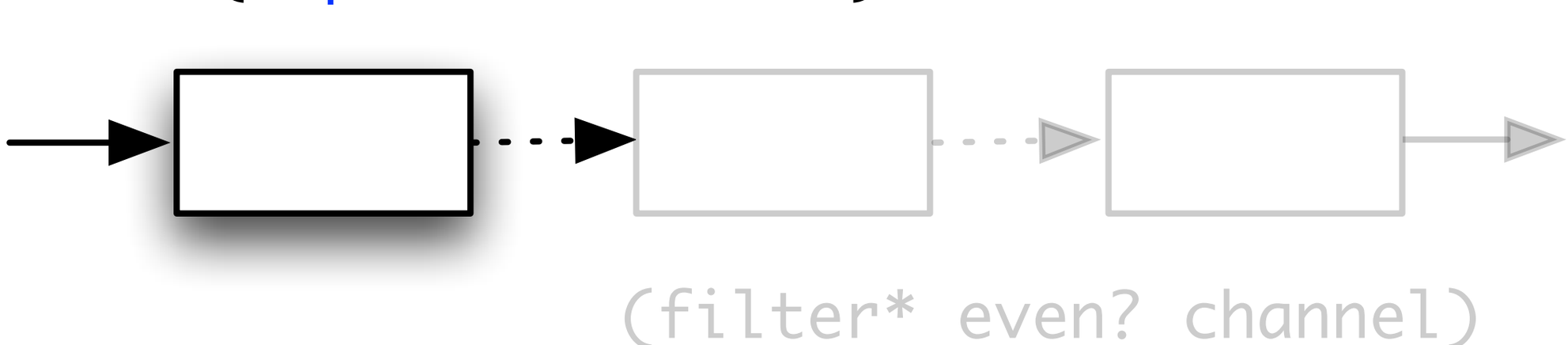
```
(map* inc channel)
```



```
(filter* even? channel)
```

backpropagation

```
(map* inc channel)
```



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backpropagation

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backpropagation

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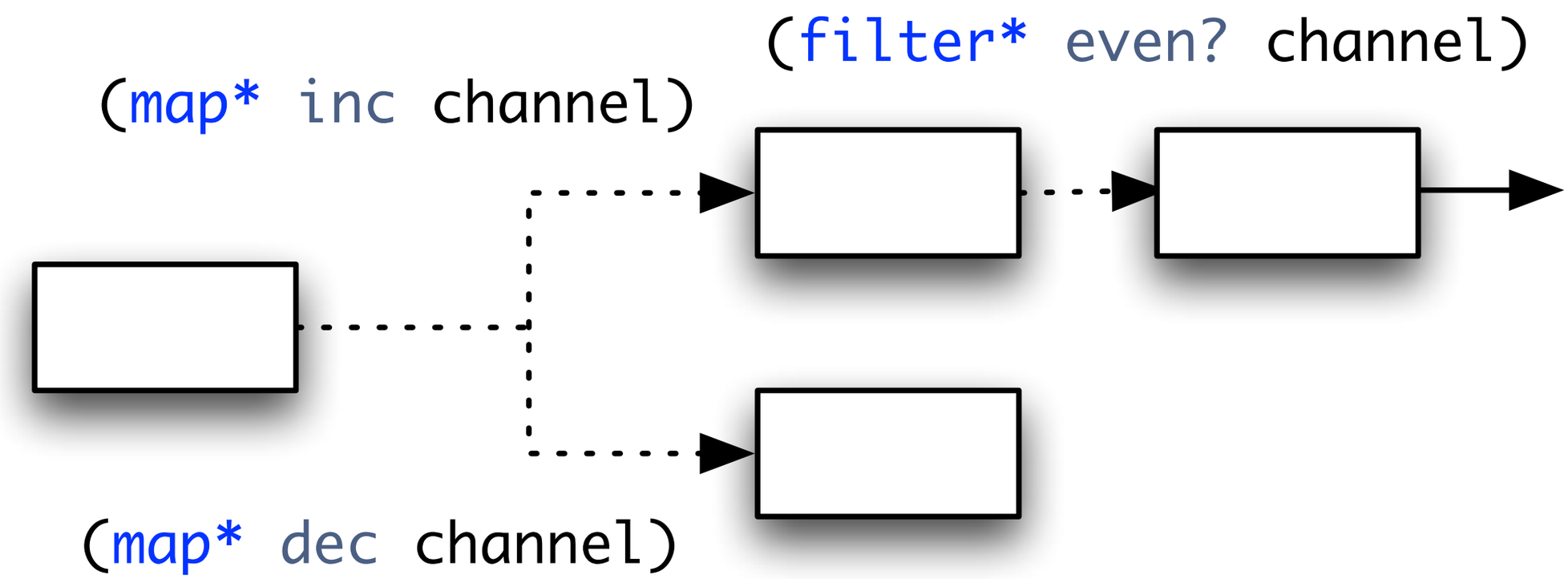
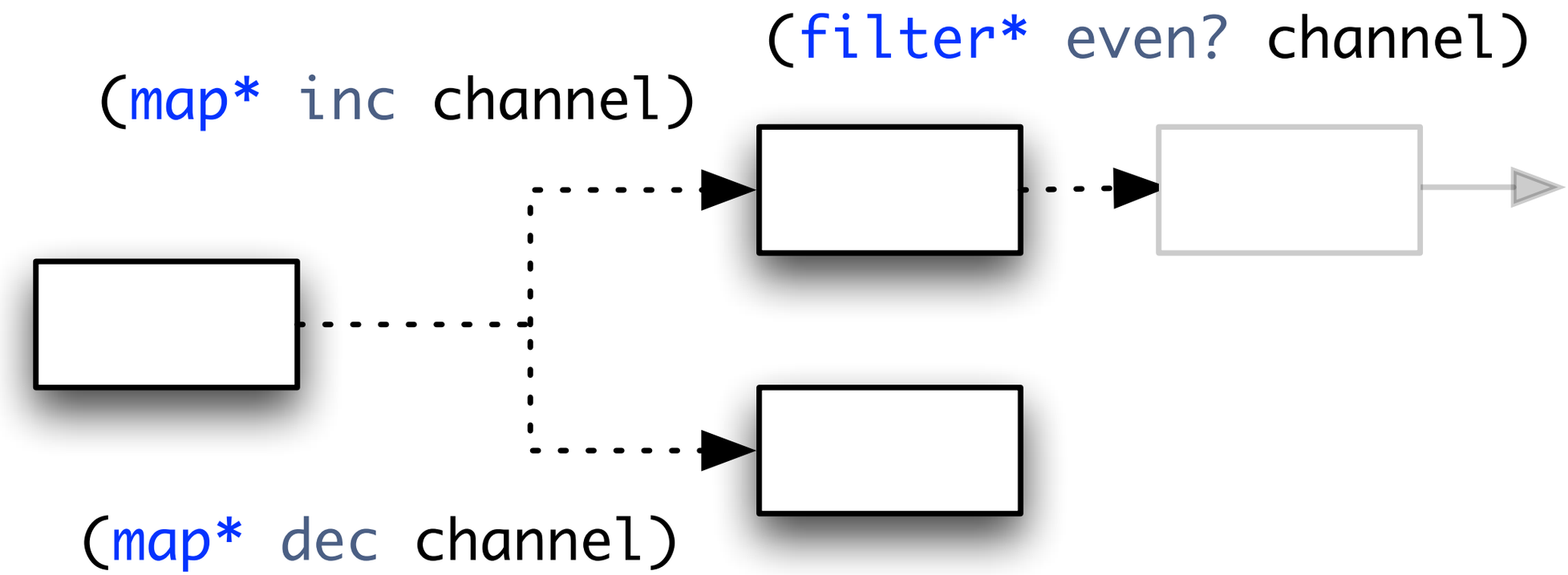
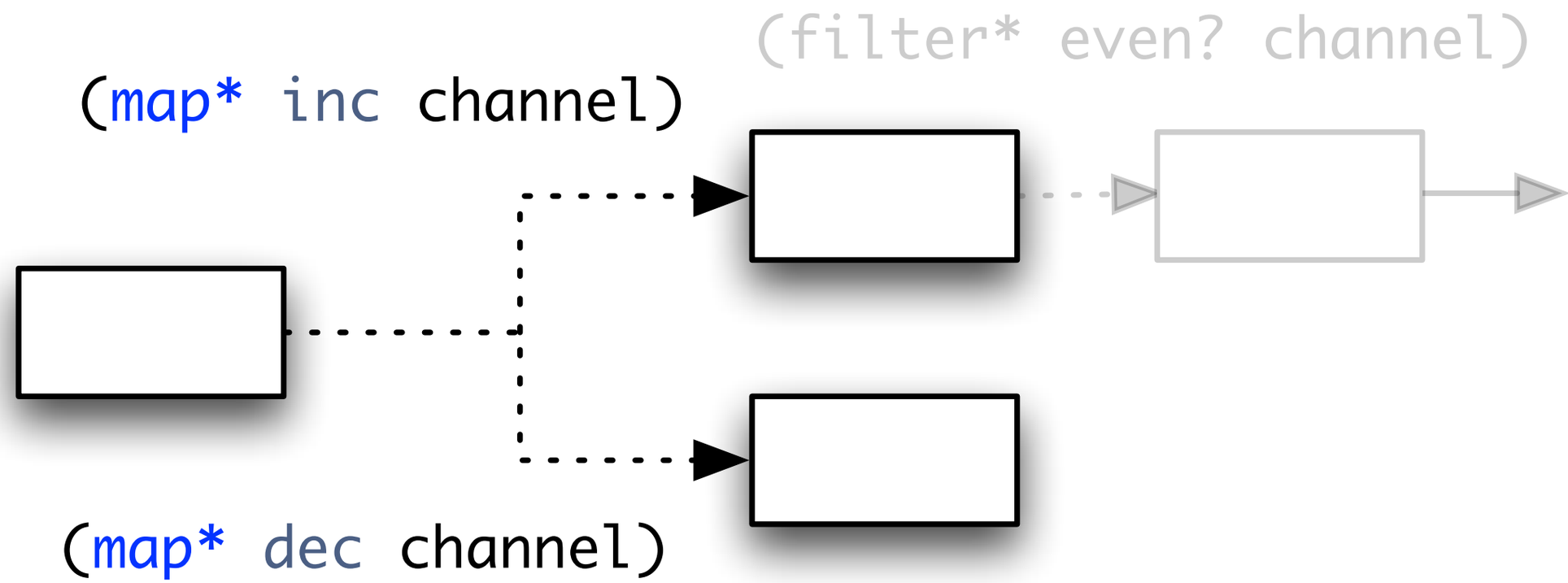
backpropagation



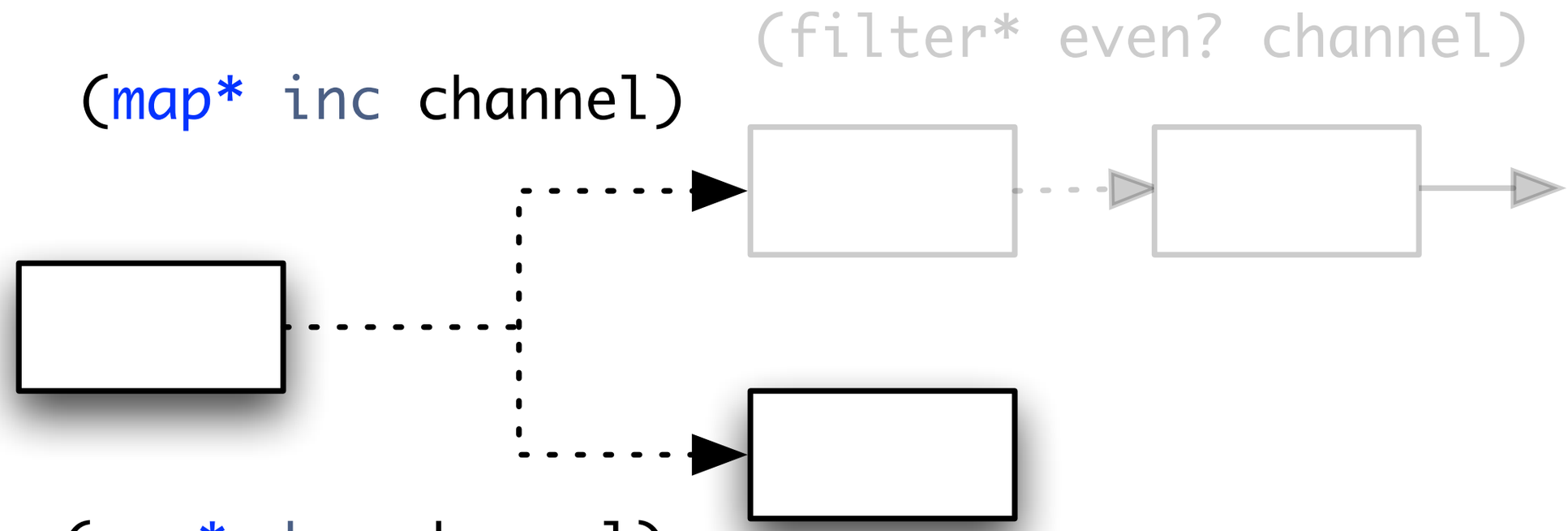
backpropagation



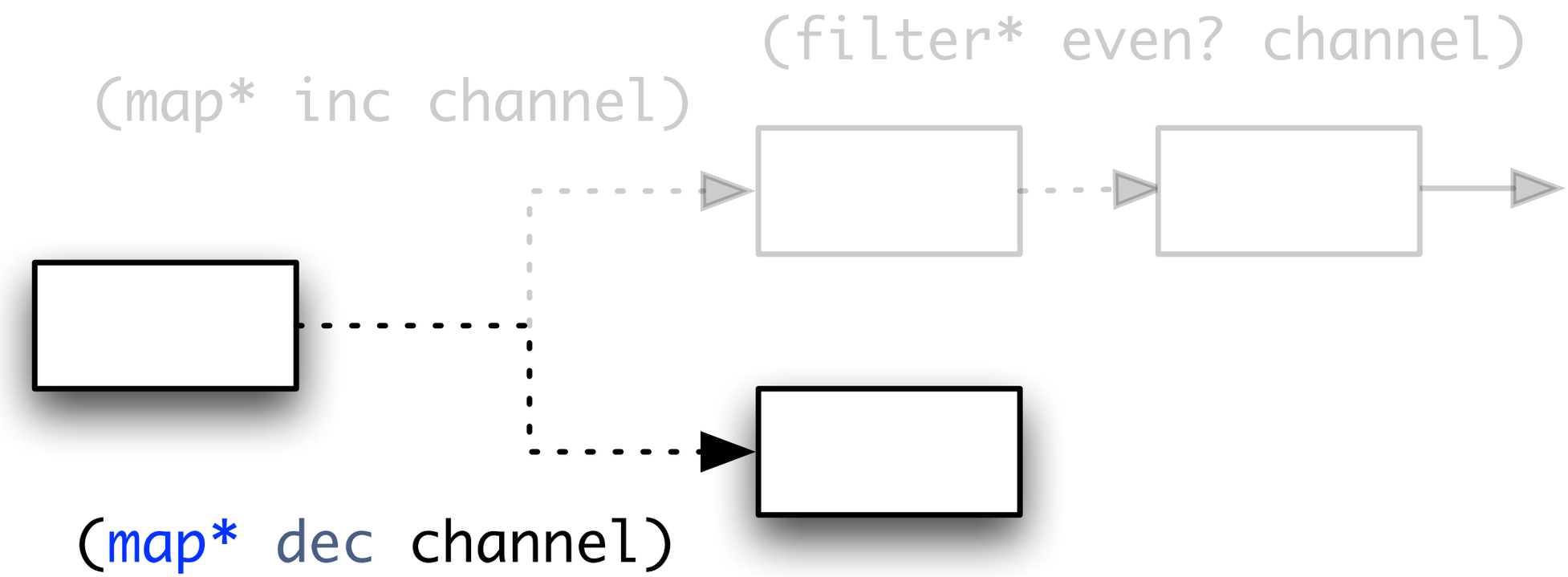
backpropagation



backpropagation



backpropagation



channels and seqs

- in channels, messages exist once they're enqueued
- in lazy-seqs, elements exist once they're consumed

channels and seqs

- in seqs, the same operator will always return the same result (`map` is idempotent)
- in channels, the same operator will not always return the same result (`map*` is not idempotent)

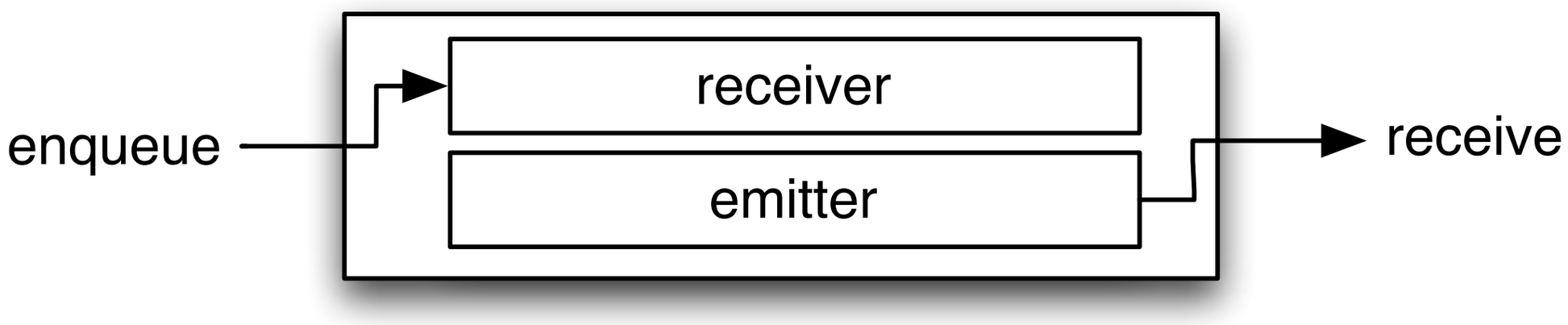
forking channels

```
(fork channel)
```

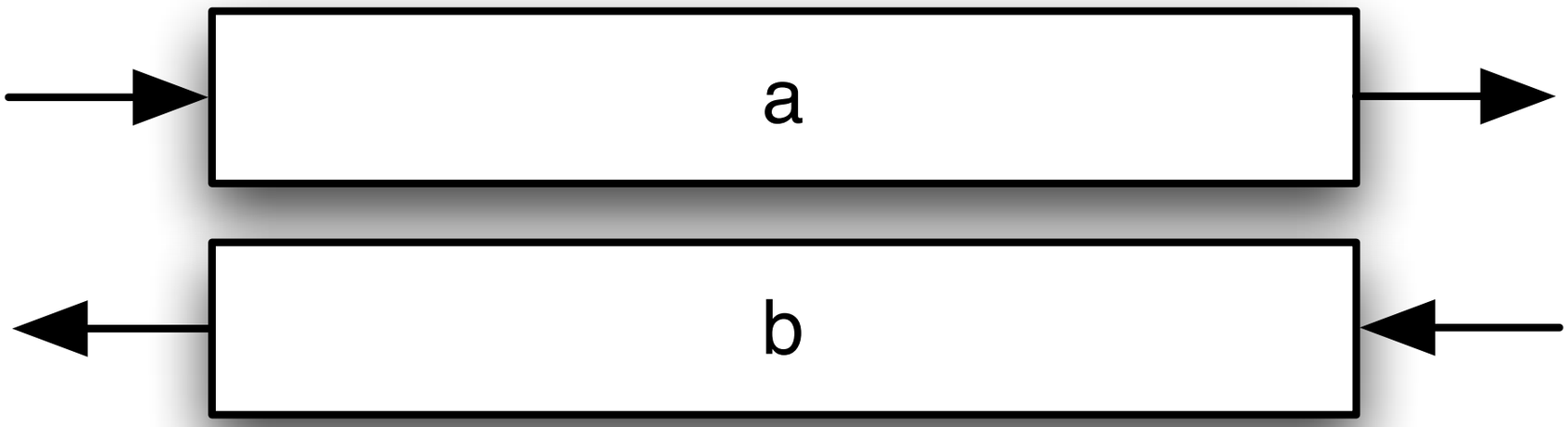
- returns a duplicate channel that can be independently consumed
- closing the original channel will close the forked channel, but not vise-versa

splicing channels

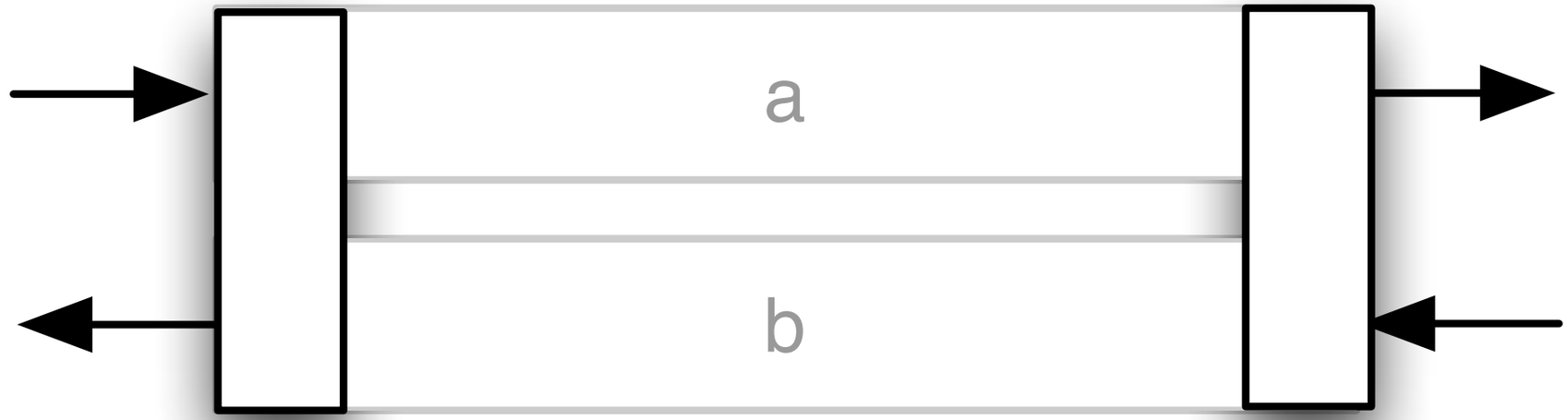
```
(splice emitter receiver)
```



splicing channels



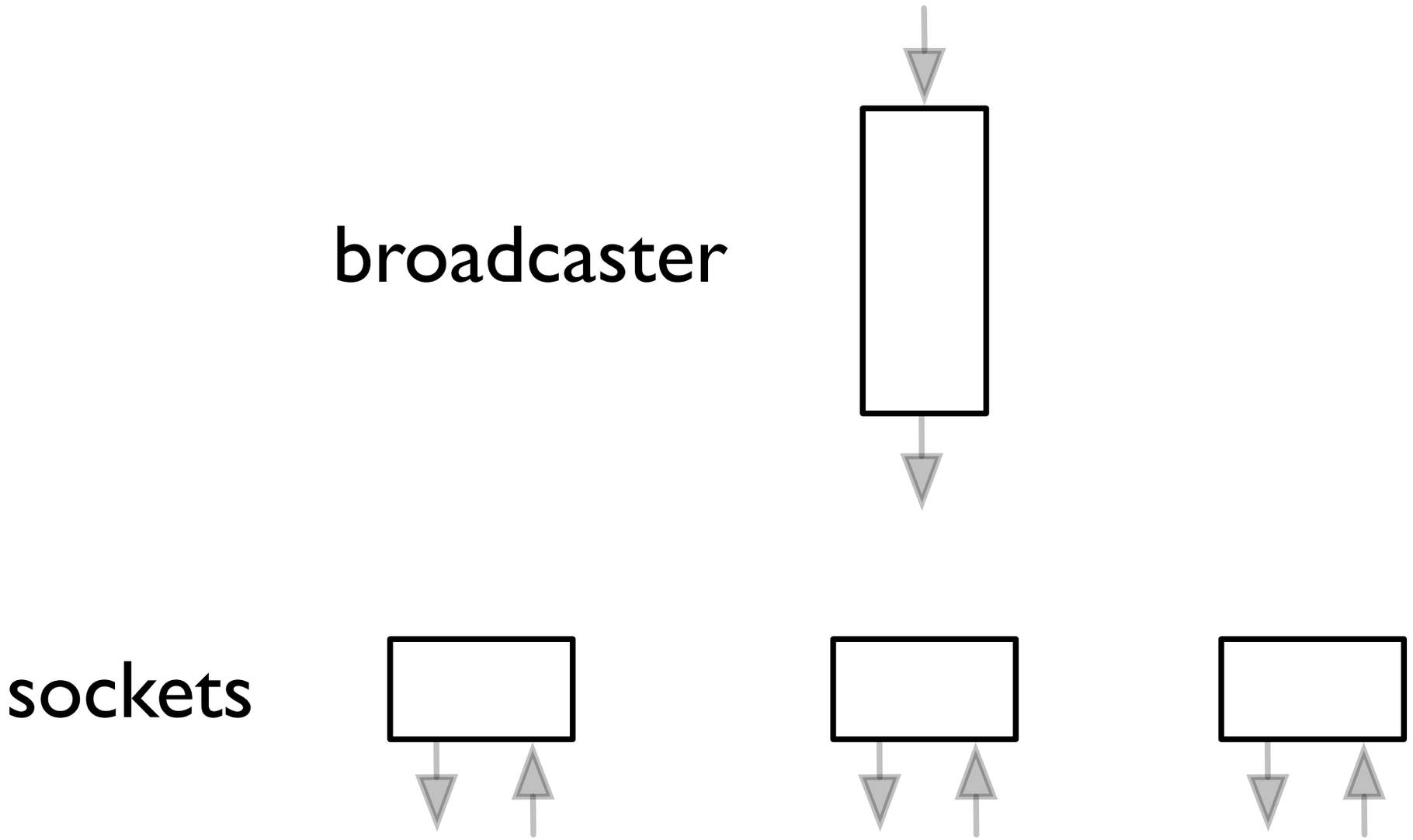
splicing channels




```
(splice a b)
```

```
(splice b a)
```

a simple chat server

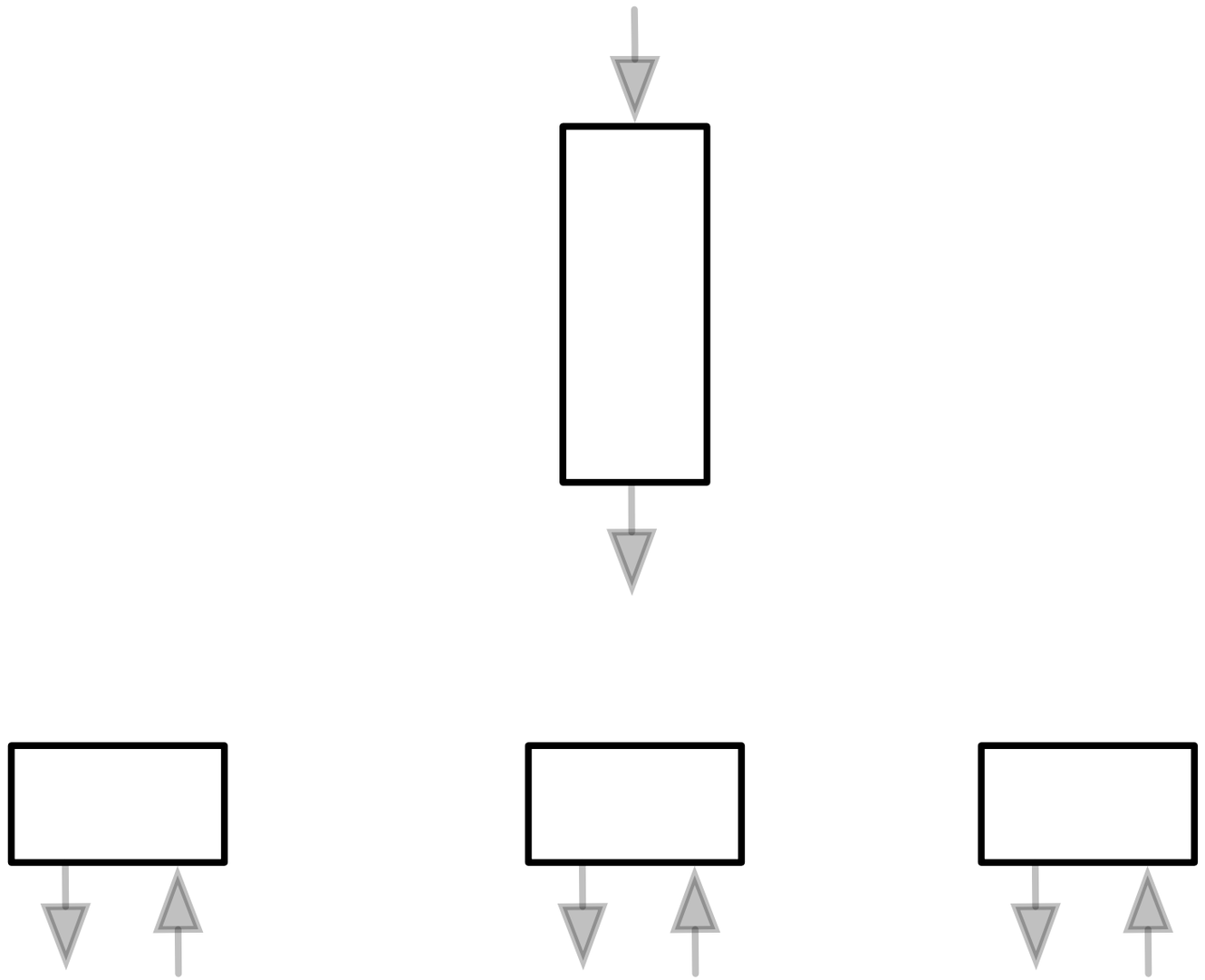


a simple chat server

```
(siphon broadcaster socket)

(siphon socket broadcaster)
```

a simple chat server



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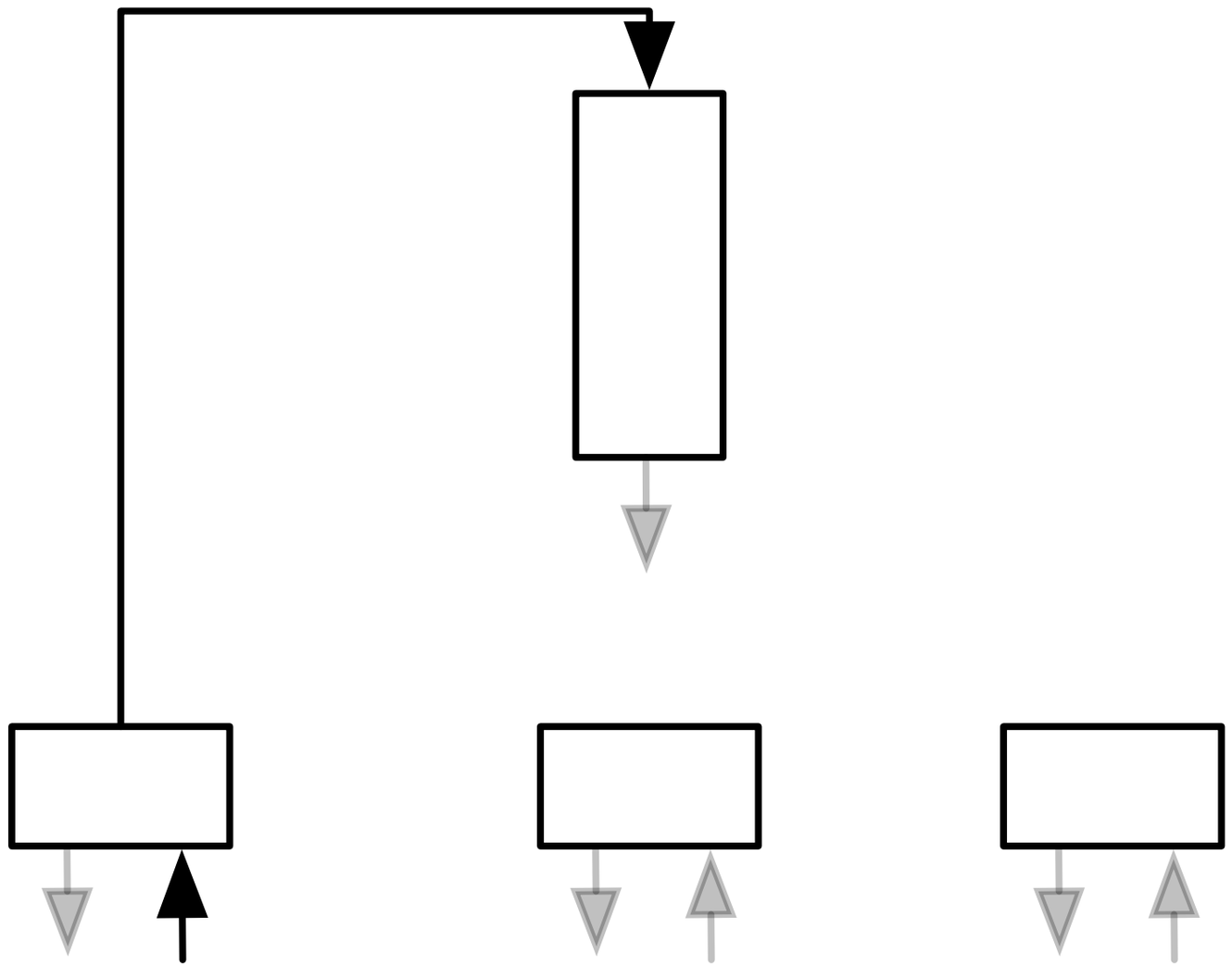
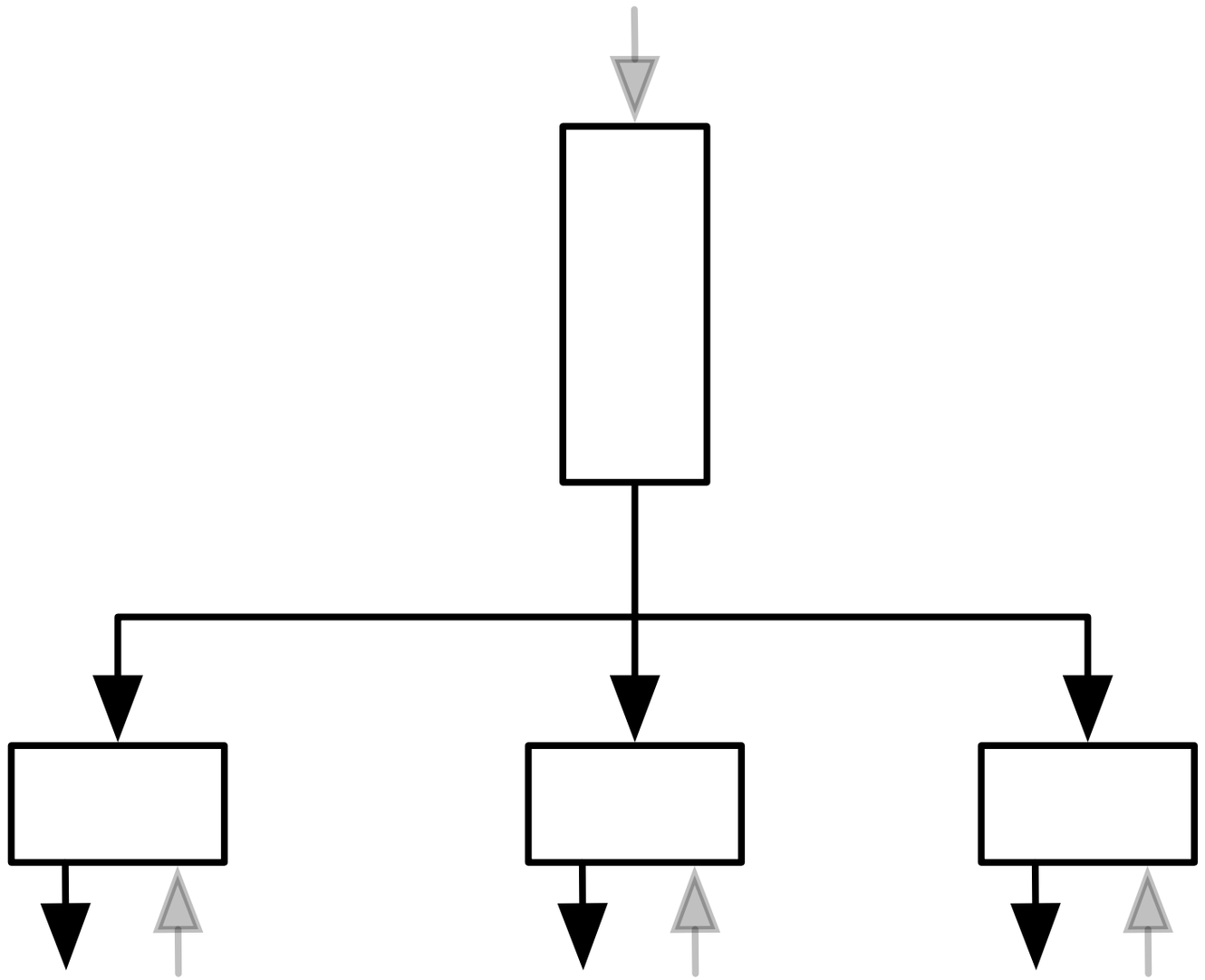


a simple chat server



result channels

- represents a single outcome: a **result** or an **error**
- only a single value can be enqueued, but that value can be received multiple times
- this is our bridge to the synchronous world

synchronous results

```
(wait-for-result result-channel timeout)

@result-channel
```

if the result-channel emits an error, synchronous accessors will throw an exception

asynchronous contamination

returns a sum:

```
(+ 2 @(request-a-number))
```

asynchronous contamination

returns a sum:

```
(+ 2 @(request-a-number))
```

returns an eventual sum:

```
(async (+ 2 (request-a-number))
```

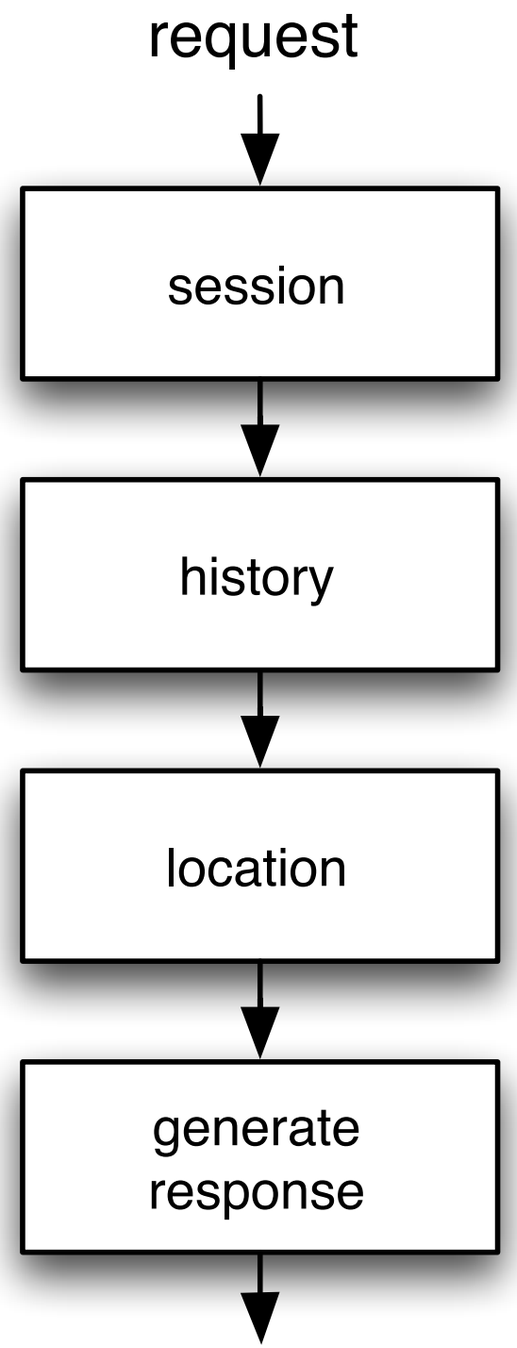
a request workflow

- receive a request
- fetch the **session** data
- if the session doesn't have the **user history**, fetch it
- if the session doesn't have the **user location**, fetch it
- generate a response based on the request, session, history, and location

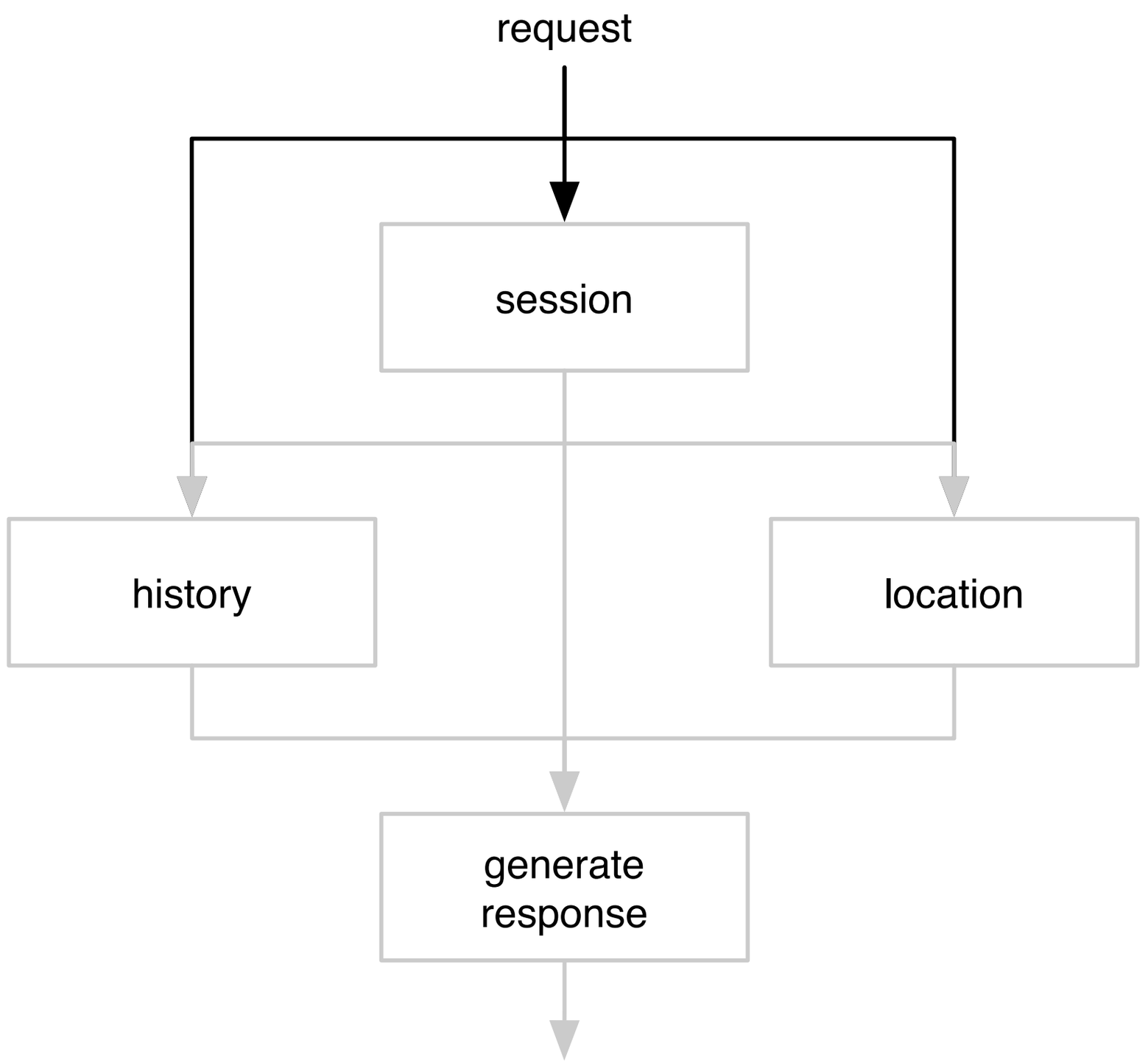
a request workflow

```
(defn handler [request]
  (let [session (get-session request)
        history (or (:history session)
                    (get-history request))
        location (or (:location session)
                     (get-location request))]
    (generate-response
      request
      session
      history
      location))
```

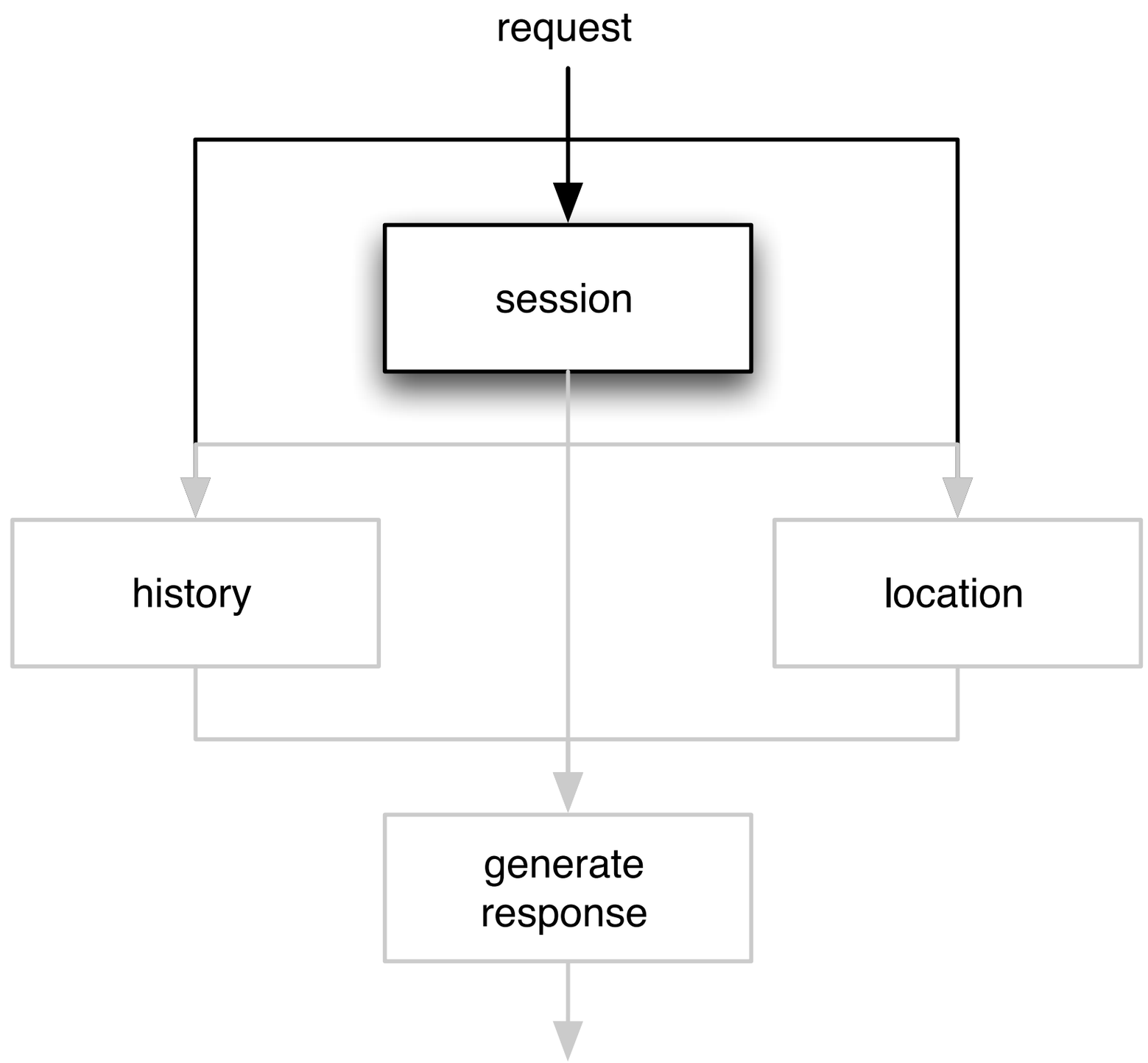
flow of execution



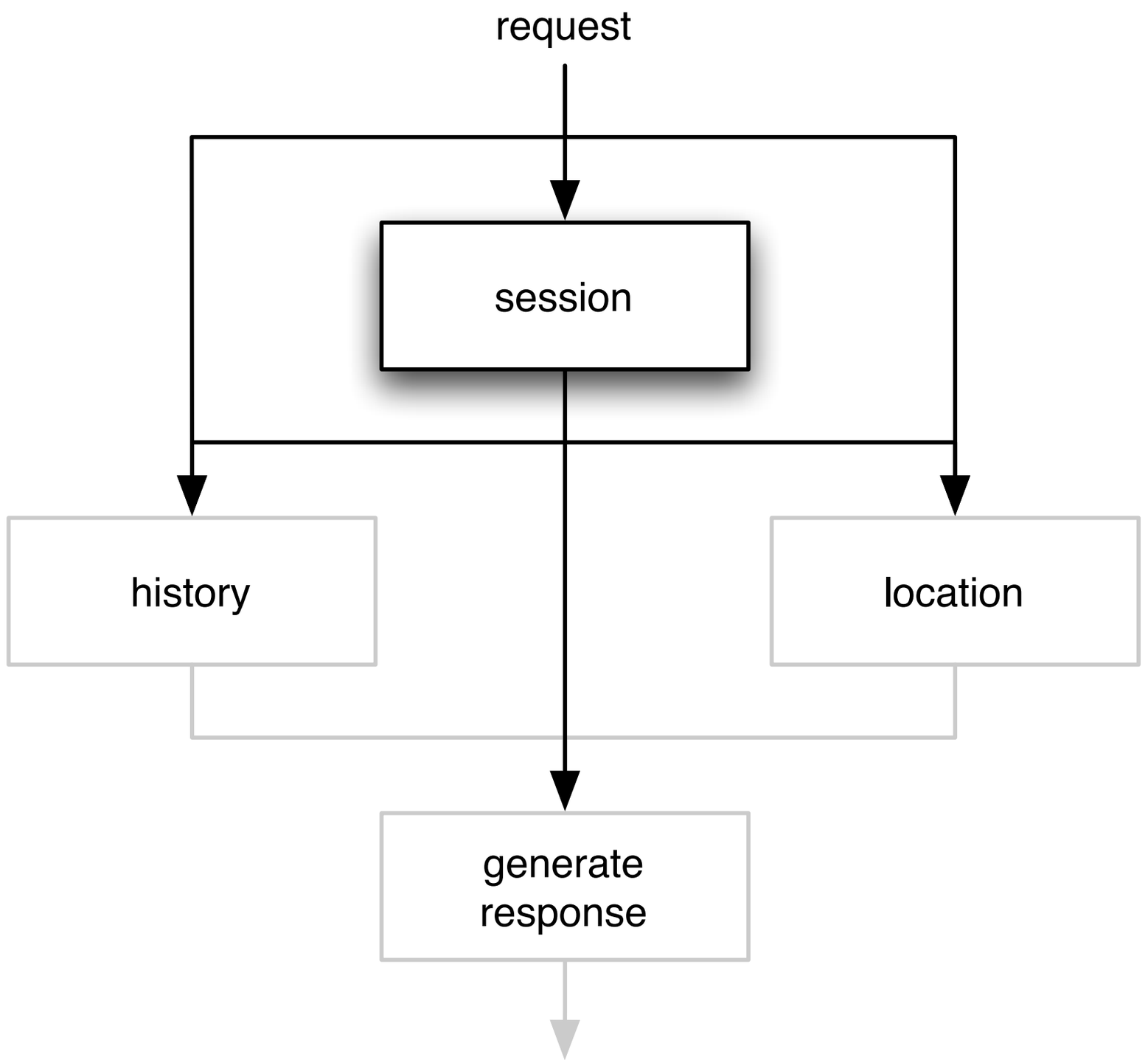
flow of data



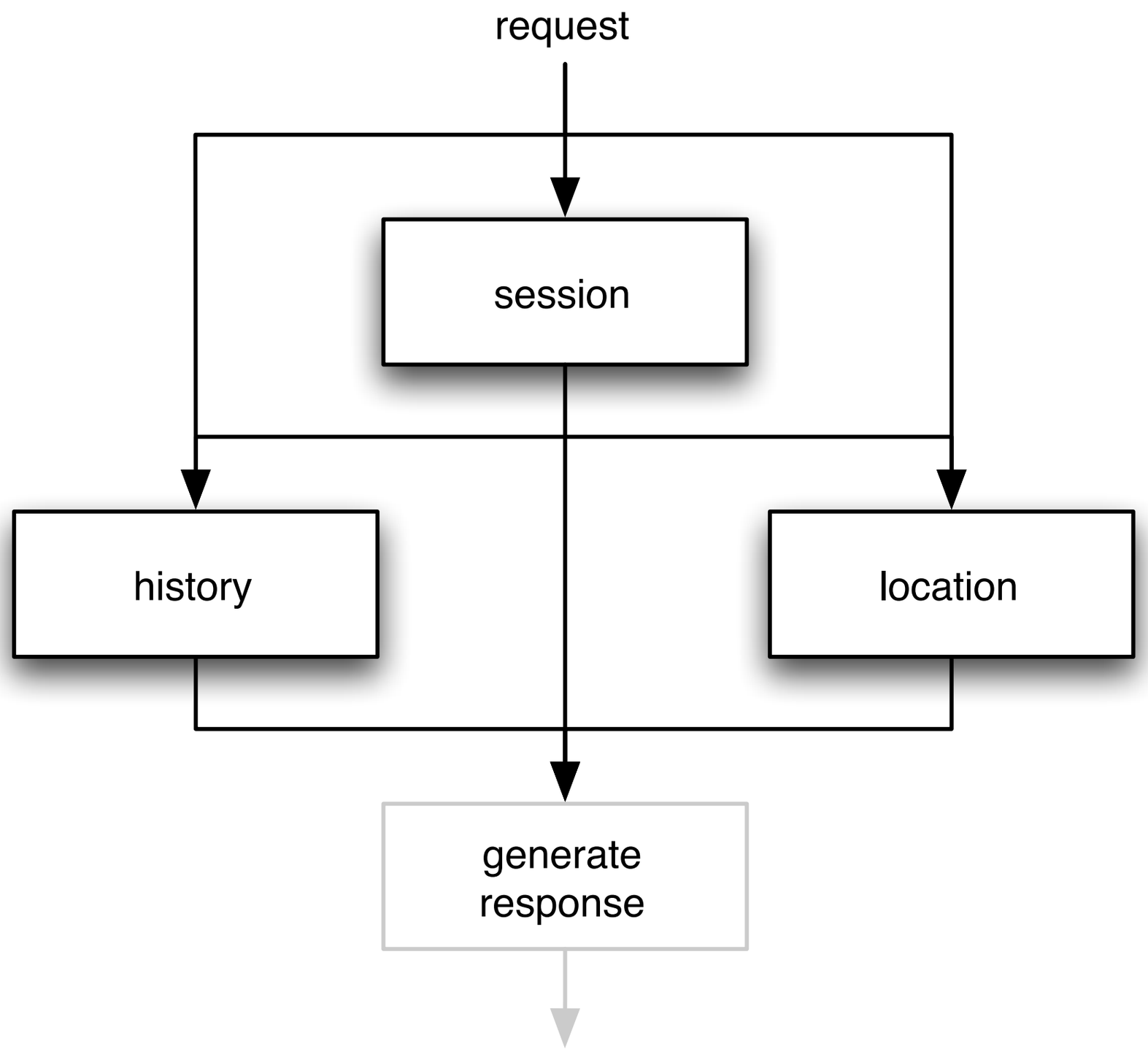
flow of data



flow of data



flow of data



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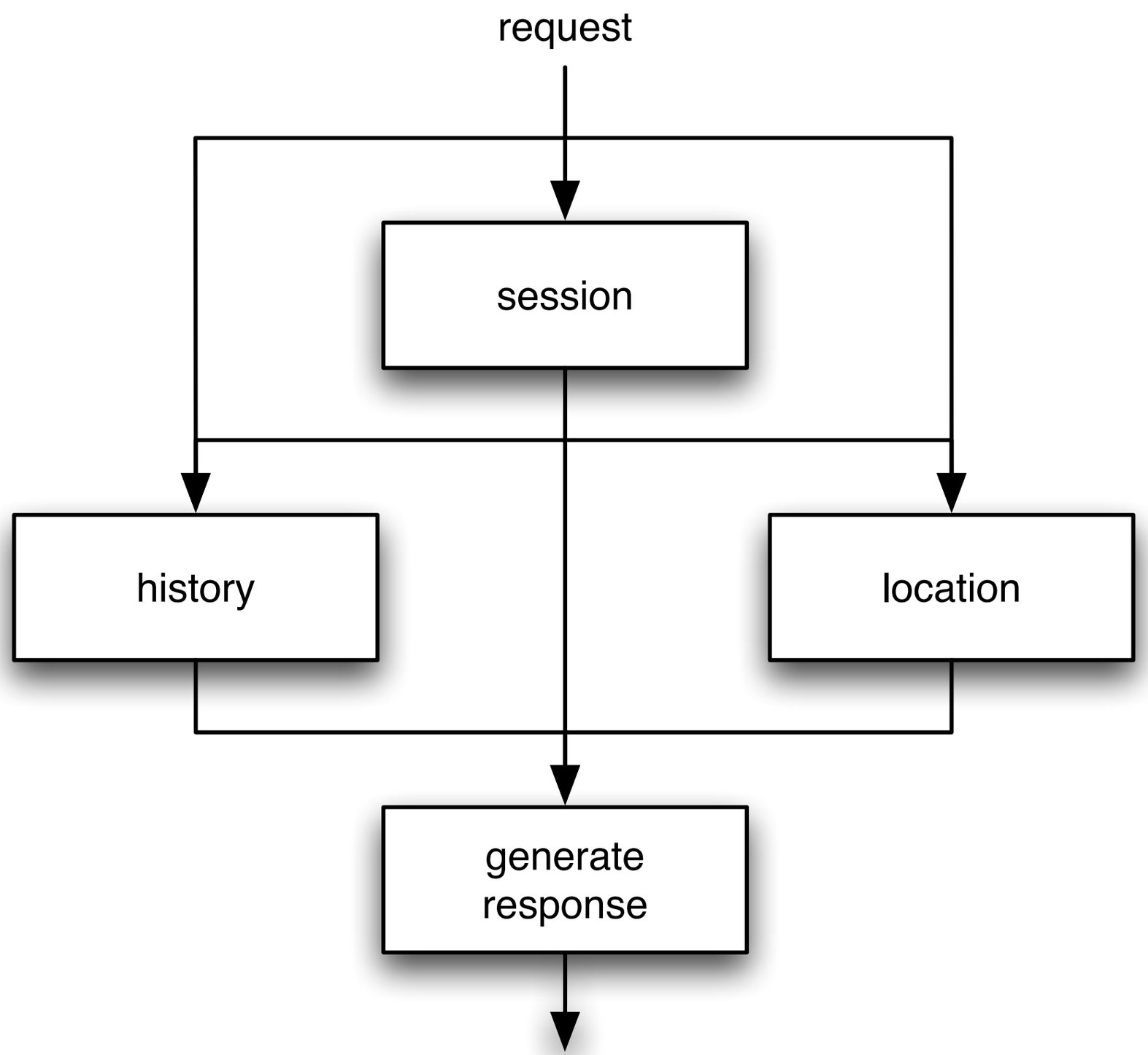

flow of data

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(defn handler [request]
  (let [session (get-session request)
        history (or (:history session)
                    (get-history request))
        location (or (:location session)
                     (get-location request))]
    (generate-response
      request
      session
      history
      location))
```

the code is a perfect expression of the dataflow!

the async macro

- expressions immediately return a result-channel representing the eventual result
- execution of expressions are deferred until all parameters are realized
- if a parameter emits an error, the expression emits the same error

the async macro

```
(defn handler [request]
  (async
    (let [session (get-session request)
          history (or (:history session)
                      (get-user-history request))
          location (or (:location session)
                       (get-user-location request))]
      (generate-response
        request
        session
        history
        location))))
```

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      (generate-response
        request
        session
        history
        location))))
```

async try/catch

```
(async
  (try
    (handler request)
    (catch Exception e
      (handle-error e))))
```

error handling doesn't have to be local!

task

```
(async
  (= 3 (task (calculate-pi))))
```

- returns result-channel, executes body on thread-pool
- is just an **annotation**, not a structural change
- because async expressions will return when they can't continue, deadlock is impossible

async side-effects

```
(async
  (do
    (query-moon-base)
    (query-database)))
```

- the moon base's response isn't part of our dataflow
- if there's an error, how do we know?

force

```
(async
  (do
    (force (query-moon-base))
    (query-database)))
```

- makes an expression a pre-requisite for all subsequent expressions
- an error will cause subsequent expressions to also error out

however, async is opaque

- no way to examine partially complete flows
- difficult to debug
- complicated flows are still complicated, under the covers

future work

- improved debugging for async workflows
- improved instrumentation for distributed systems
- ClojureScript!

the projects

- all functionality discussed is contained in **lamina** (http://github.com/ztellman/lamina)
- it is used to model network communication in **aleph** (http://github.com/ztellman/aleph)

questions?