Unit 3 – Middleware. ZeroMQ

Network Information System Technologies

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1. Introduction

- Large Scale Distributed Systems Components are
  - Specified and Developed independently
    - No big committee nailing all possible use cases
  - Deployed autonomously
    - Each one designed as a Distributed Systems Agent
    - But Establish dependencies among themselves
      - Consuming or providing functionality from/to other agents
- Need to easily interact usefully
  - E.g. a routing planning service may depend on a GIS service providing basic distance information.
  - E.g. an entrance authorization system may need to contact a remote biometrical recognition service

1. Introduction

- Even close-knit systems
  - Developed by more than one developer
  - Multiple components clearly interdependent
- In all cases:
  - Need to deal with the complexities of the distributed environment
  - The product needs to be as error-free as possible
    - Debugging problems is orders of magnitude more complex in a distributed system
  - Submission to strict development schedules
    - Lose the least amount of time in coding

1. Introduction

- How to make sure we do not need absolute geniuses
  - To write the millions of lines of code needed
  - To manage the systems deployed
- One Problem is the Complexity of the details
  - Dealing with complexity is a source of errors
  - Dealing with too many details at once is a recipe for disaster
    - And long debugging sessions
      - Often in production
- Another problem is the fact that many tasks are repetitive
  - And we can save resources by providing common implementations

1. Introduction

- Complexity sources
- <u>Mainly from Making requests to a service</u>
  - Thus, communications related
  - Finding servers implementing services
    - How can clients contact services without knowing the exact machine of their servers
    - How are servers addressed
    - How are clients addressed back in a request
  - Specifying the functionality of services
    - What is the API of a service
    - How to find is the version has changed

1. Introduction

- Formatting information transmitted
  - How can developers build and interpret requests to services
    - E.g., how is byte 8 interpreted?
  - Compatibly with the programming environments being used at both ends
    - Eg. Client uses Java, Server uses C
- Synchronization between requester and server
  - Ordering of actions: how do clients know services have reacted to their requests
  - Reception of results: how do servers return results, and clients retrieve them
- Security
  - How can developers of services know when to process a requests
  - How can security properties be ensured
- Failure handling
  - How do agents know when to take remedial actions for failures
  - E.g. how to figure out when a server dies
  - E.g. How to figure out if information transmitted has been lost?
  - …

1. Introduction

- Complexity-taming approaches
  - Standards (de facto and de jure)
    - Introduce streamlined ways to do things
      - Practice makes masters
    - Helps build familiarity for developers
      - They do not have to learn something new every time
    - Help interoperability
      - Greater choice for system's integrators/managers
    - Providing High Level functionality
      - Less code to write for the developer
      - Less complexity to deal with
  - Middleware

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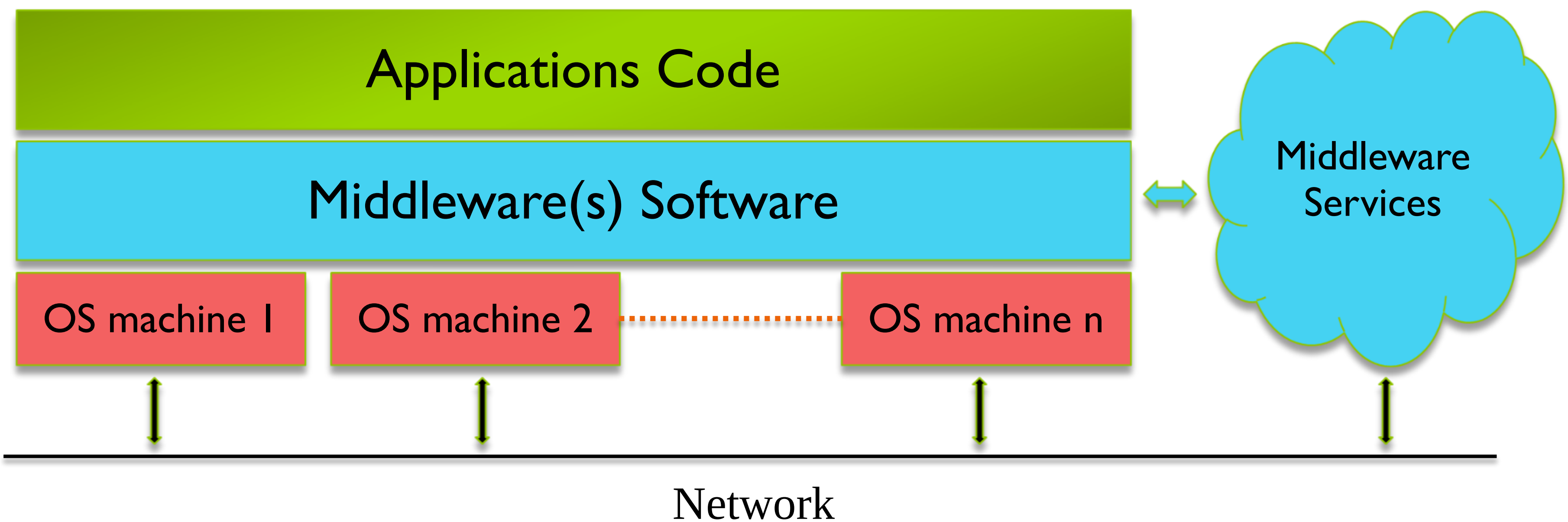
2. Middleware

- Layer(s) of software and services between application software and Network/Communications layer
- Introduces various "Transparencies"
- Transparency
  - Reduction of complexity by hiding and dealing with details in a uniform way



2. Middleware: Desirable Characteristics

- Developer's perspective
  - Easy to write
    - Clear and well defined concepts
    - Low complexity in elements handled
      - Avoid coding errors
  - Reliable result
    - Well understood defined/established/standardized ways of doing things
  - Maintainable
    - Changes in the API should have low impact in modifications
- Manager's perspective
  - Easy set-up, change
  - Easy/possible to interact with products from third parties (interoperability)

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3. Messaging systems

- Asynchronous in nature
  - Decoupling between sender and receiver
- Sending discrete pieces of information
  - Message: atomically transmitted (all or nothing)
  - Arbitrary sizes
  - Support for structuring messages
  - Queuing
    - With some guarantees of order
- No shared state imposed view
  - Potentially better to produce scalable systems
  - Potentially better to avoid concurrency difficulties
- Examples
  - Big Standard: AMQP
    - E.g. RabbitMQ
    - Apache ActiveMQ
  - STOMP
  - 0MQ

3. Messaging systems: Approaches

- Two main approaches
  - Transient (stateless) systems
    - Require the recipient to be up to receive a message
  - Persistent
    - Messages saved in buffers: recipient does not have to be up at sending time
- Within Persistent implementations
  - Broker-based
    - Specific servers store messages and provide strong guarantees
    - Overhead derived from the need to persistently store in secondary storage
    - E.g. AMQP
  - Broker-less
    - Senders/receivers maintain the queues
      - Typically in memory
    - Weaker persistence guarantees
      - But still, decoupling between sender and receiver readiness to send/receive
    - Can be used to build broker-based system when needed
    - E.g. 0MQ

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4. ZeroMQ

4.1. Introduction: Goals of ØMQ

- Simple communications middleware
  - Easy configuration: URLs to name endpoints
  - Easy & familiar to use: BSD-like socket API
- Widely Available
  - Portable implementation
- Support basic patterns
  - Eliminate need for each developer to re-invent the wheel
  - Make it very useful right away
- Performance
  - No unnecessary overhead
  - Tradeoff between reliability and performance
- The same code can be used to connect
  - Threads within a process
  - Processes, within a machine
  - Machines, through an IP network.
  - Only URL changes needed

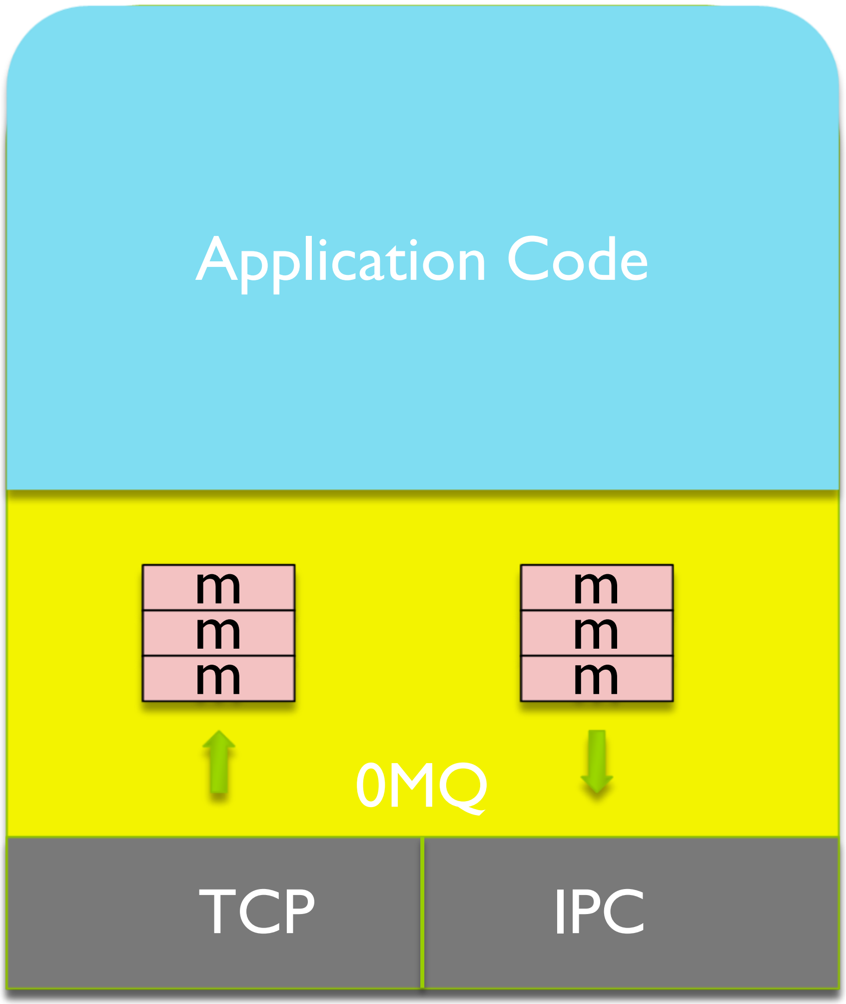
4.1. Introduction: Main Characteristics

- Message - based
  - Weakly persistent: main memory queues
- It is just a library
  - No need to start specific middleware servers anywhere
  - Implemented in C++
  - Available on most OS
    - Linux_XYZ
    - Windows
    - BSD
    - MacOSX
  - Bindings available for most programming languages/environments

4.1. Introduction: Technology

- Provides sockets to send and receive messages
  - send/receive, bind/connect interface for a socket
- Can use the following transports:
  - Inter-process
    - TCP/IP
    - IPC (Unix sockets)
- Transport used to instantiate socket
  - Easily changed by a configuration change

4.1. Introduction: View of a ØMQ Process



- Application links with ØMQ library
- ØMQ maintains in-memory queues
  - At sender
  - At receiver
- ØMQ uses communication layers

4.1. Introduction: Installation

- **ØMQ is a library**
  - It must be installed before its usage in processes
  - In order to use it in NodeJS programs, a module should be imported: **zeromq**
    - To this end, this line is needed:
      - const zmq = require('zeromq')
    - When that module is installed, it also installs the library.

- **To install the module, use this command:**
  - **npm install zeromq**

4. ZeroMQ

4.2. Messages: Message oriented middleware

- Messages are what's sent
  - No framing problem for the app
  - Buffering is taken care of
- Messages can be "multi-part" (i.e., multi-segment)
  - Simple structuring support for messages
- Messages are atomically delivered
  - All parts are delivered, or nothing is delivered
- Message send/receive is asynchronous
  - Internally, 0MQ moves messages back-and-forth the in-memory queues to the transports
- Connections/reconnections among peers automatically handled

4.2. Messages

- Message content is transparent to 0MQ
- No support for marshaling
  - No format required
  - Messages are Blobs to 0MQ
    - But 0MQ API supports simple string serialization into a message

```
zsock.send([“this is", "a", "message“]);
```

7	this is
1	a
7	message

- NOTE
  - Some socket types use the first segment

4.2. Messages: Consequences

- You must design your own payload format/protocol
- In many cases it may be as simple as just using plain strings
- It is possible to use ANY encoding
  - Binary is fine
- Simple approach: XML messages
  - Use XML parsers
- Simpler approach: JSON messages
- Simplest approach
  - Use each segment for a different piece of information, encoded its own way: e.g
    - Segment 1 is the name of the interface being invoked, as a string
    - Segment 2: is the version of the API interface, as a string
    - Segment 3: Is the name of the operation
    - Segment 4: is an integer: the first argument
    - Segment …

4. ZeroMQ

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4.3. 0MQ API

1. Sockets
   - Sending/receiving uses sockets
   - Several socket types
   - Sockets can bind/connect
2. Patterns of communication
   - Supported by specific socket types

4.3.1. 0MQ Sockets

- Creating a socket is simple:

```
const zmq = require('zeromq')

const zsock = zmq.socket(<SOCKET TYPE>)
```

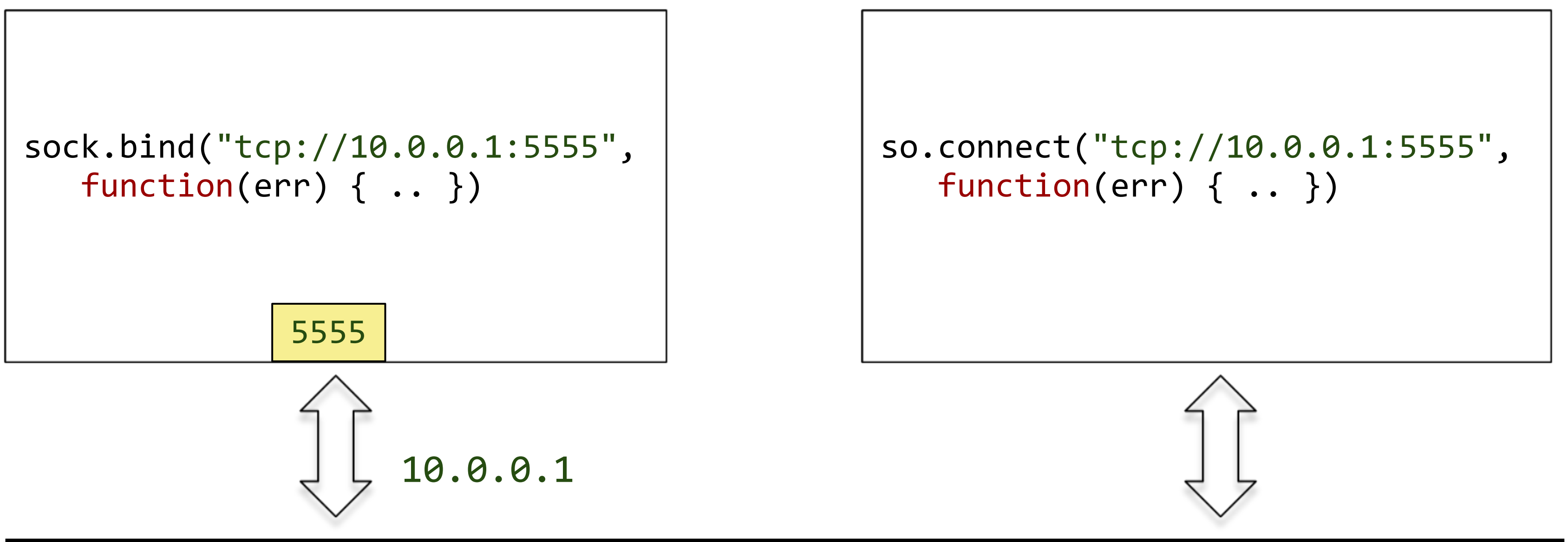
- Where <SOCKET TYPE> is one of

req	push	pub
rep	pull	sub
dealer	*pair*	*xsub*
router		*xpub*

- What types to use will depend on the connection patterns they intervene in

4.3.1. Sockets: Establishing communication paths

- One process performs a **bind**
- Other processes perform **connect**
- When done, **close**
- **bind/connect** are decoupled: no ordering requirements



4.3.1. Sockets: multiple connections are possible

```
so1
.connect("tcp://10.0.0.1:5555",
   function(err) { .. })
so1
.connect("tcp://10.0.0.2:5556",
   function(err) { .. })
```

```
so2
.connect("tcp://10.0.0.1:5555",
   function(err) { .. })
```

```
so3
.connect("tcp://10.0.0.2:5556",
   function(err) { .. })
```

10.0.0.1

```
sock.bind("tcp://10.0.0.1:5555"
,
   function(err) { .. })
```

5555

10.0.0.2

```
sock.bind("tcp://10.0.0.2:5556"
,
   function(err) { .. })
```

5556

4.3.1. Sockets: Connections and queues

- Sockets have message queues associated
  - incoming queues, to hold messages from connected peers
    - They raise the "message" event when holding some message
  - outgoing queues, holding messages to be sent to peers
    - Where messages sent from the application are held
- router sockets keep one pair of outgoing/incoming queues per connected peer
  - The rest of the sockets do not distinguish among peers
  - pub sockets fall out of this discussion
- pull and sub sockets only set up an incoming queue
- push and pub sockets only have outgoing queues

4.3.1. Sockets: binding or connecting

- When to **bind** and when to **connect**
  - Most times indifferent: configuration convenience
- Observations
  - All peers must meet at an endpoint
  - Endpoints are referred to by their URL
  - For TCP transport
    - The IP address must belong to one of the bind socket's interfaces
      - The bind socket only needs local IP configuration (or none)
        - Does not need to know where the other peers are
    - The connect socket needs to know where the binding socket is (IP)

4.3.1. Sockets: Transports: TCP

- URL: `tcp://<address>:<port>`
- Three ways to specify the address

```
sock.bind("tcp://192.168.0.1:9999")
```

```
sock.bind("tcp://*:9999")
```

```
sock.bind("tcp://eth0:9999")
```

- *: binds to all interfaces
- “eth0”: binds to all addresses associated with interface “eth0”

4.3.1. Sockets: Transports: IPC

- Inter Process Communication (Unix sockets)
- URL: ipc://<path-to-socket>

```
sock.bind("ipc:///tmp/myapp")
```

- Need *rw* (read & write) permissions over socket at <path-to-socket>

4.3.1. Sockets: Sending messages

- Segments can be extracted in one call from an array, …

```
sock.send(["Segment 1”, "Segment 2"])
```

- Segments must be **buffers** or **strings**.
  - Strings are converted to buffers, using UTF8 encoding
    - Non-strings are first converted to strings

4.3.1. Sockets: Receive

- Based on “message” events on the socket
  - **arguments** of handler contain the segments of the message
  - NOTE: segments are binary buffers

```
sock.on("message", function(first_part, second_part){
        console.log(first_part.toString())
        console.log(second_part.toString())
});
```

- For variable number of segments, use “arguments” directly…

```
sock.on("message", function() {
    for (let key in arguments) {
        console.log("Part" + key + ": " + arguments[key])
    }
})
```

- … or convert to array first

```
let segments = Array.from(arguments)
segments.forEach(function(seg) { … })
```

4.3.1 Sockets: socket options

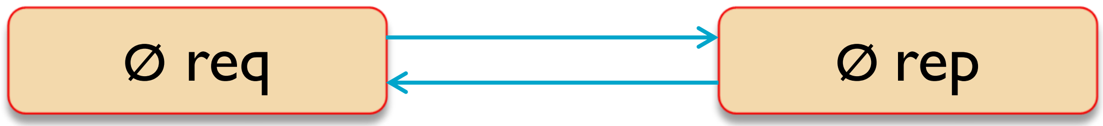
- Many.
- Two important ones: **identity**, and **subscribe**

```
sock.identity = ’frontend’
sock.subscribe(‘SOCCER’)
```

- **identity** convenient when connecting to *router* sockets
  - Sets the ID of a connecting peer to the router
  - **It should be set before invoking the connect() method!!!**
- **subscribe**, used by *sub* sockets.
  - Sets the prefix filter applied by the *pub* socket

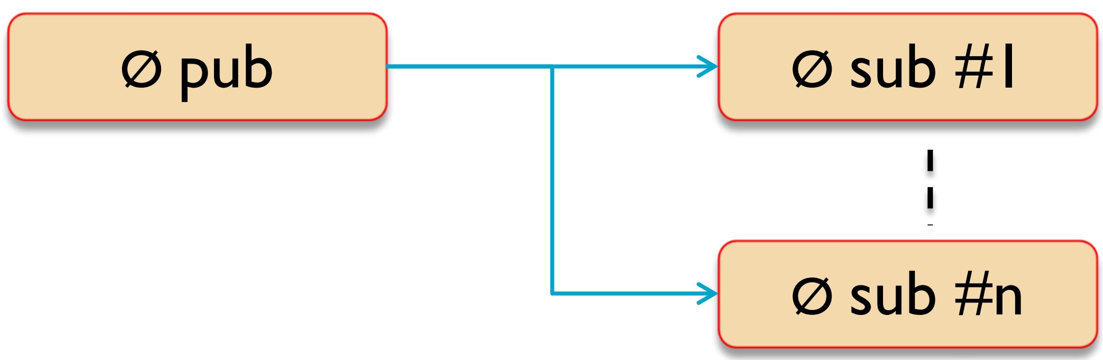
4.3.2. Basic patterns

- Request/Reply (synchronous)



- Push-pull

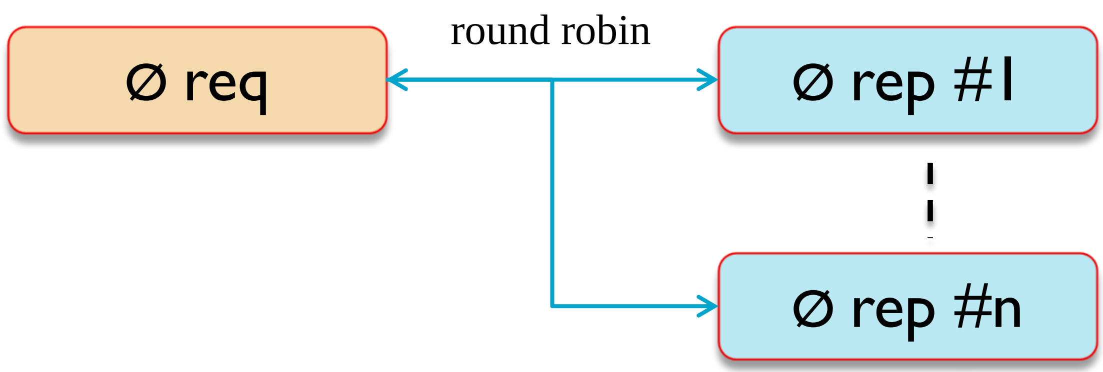
- Pub-Sub



4.3.2. Basic Patterns: request/reply

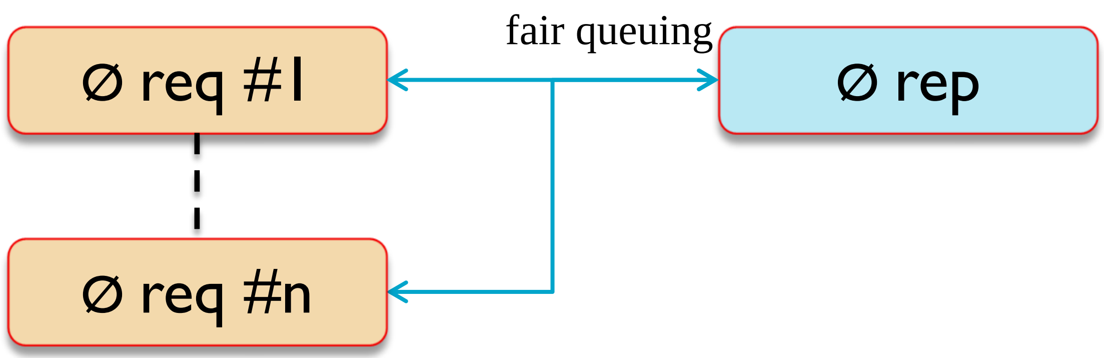
- Implemented using **req** sockets for the client
  - **rep** sockets for the server
- Each message sent via **req** needs to be matched with a corresponding reply from the **rep** socket of the server
- Synchronous communication pattern
  - All request/reply pairs are totally ordered
  - Endpoints can react asynchronously, though.
- When a message has been sent through a **req** socket sending a new message through that socket queues it locally
  - Until the response message is received
    - Then the waiting message is sent
- When a request has been received through a **rep** socket, the arrival of a new request through that socket gets it queued
  - Until the first request is answered
    - Then the waiting message is delivered
- Each reply message sent beforehand through a **rep** socket remains enqueued until its associated request is received
  - When such request arrives, that reply propagation is resumed

4.3.2. Basic Patterns: request/reply with distribution



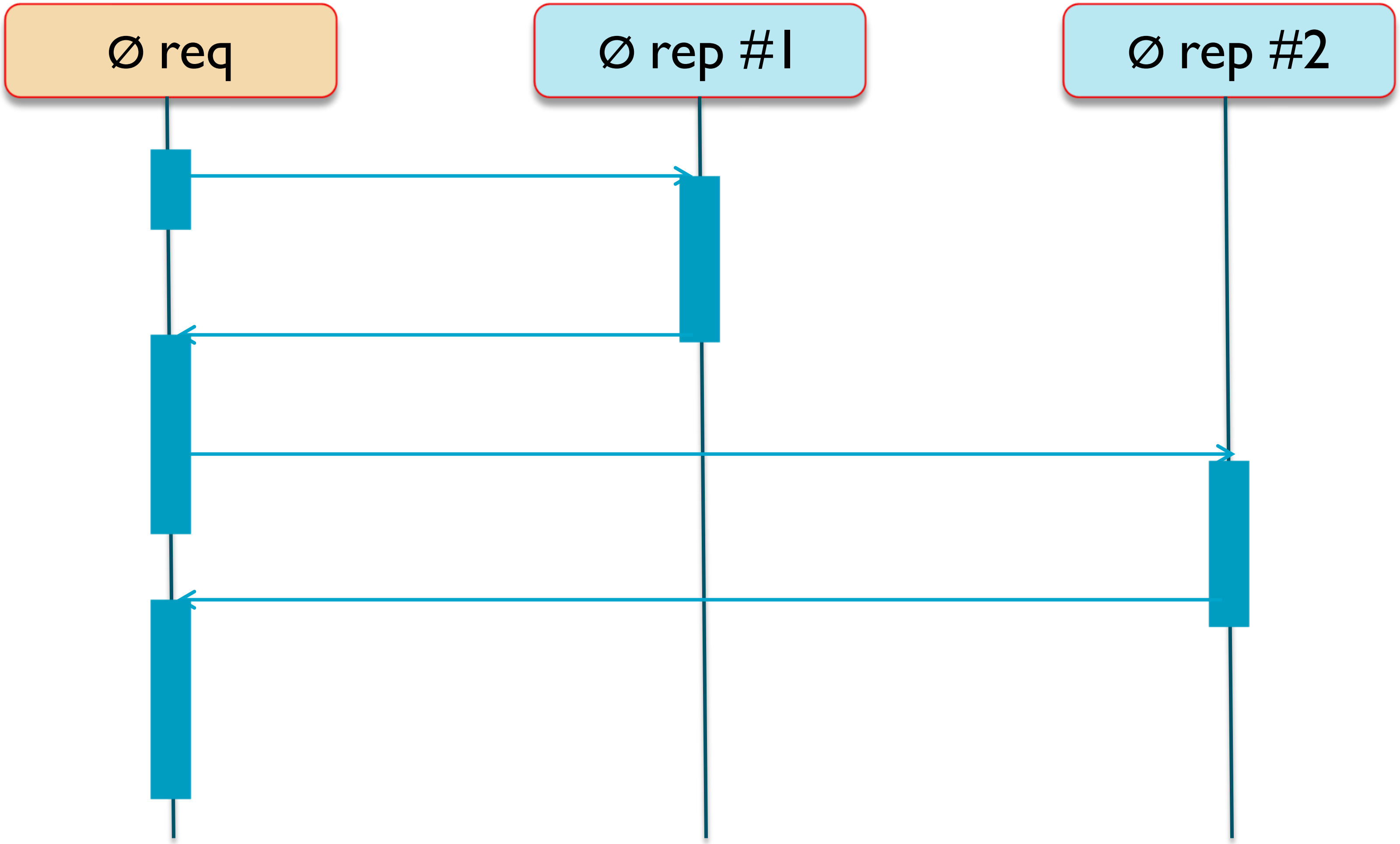
- When a **req** connects to more than one rep, each request message is sent to a different **rep**,
  - Follows a round-robin policy.
- Operation continues being synchronous:
  - 0MQ will not send new requests until each reply is received
  - No parallelization of requests

4.3.2. Basic Patterns: multiple requesters

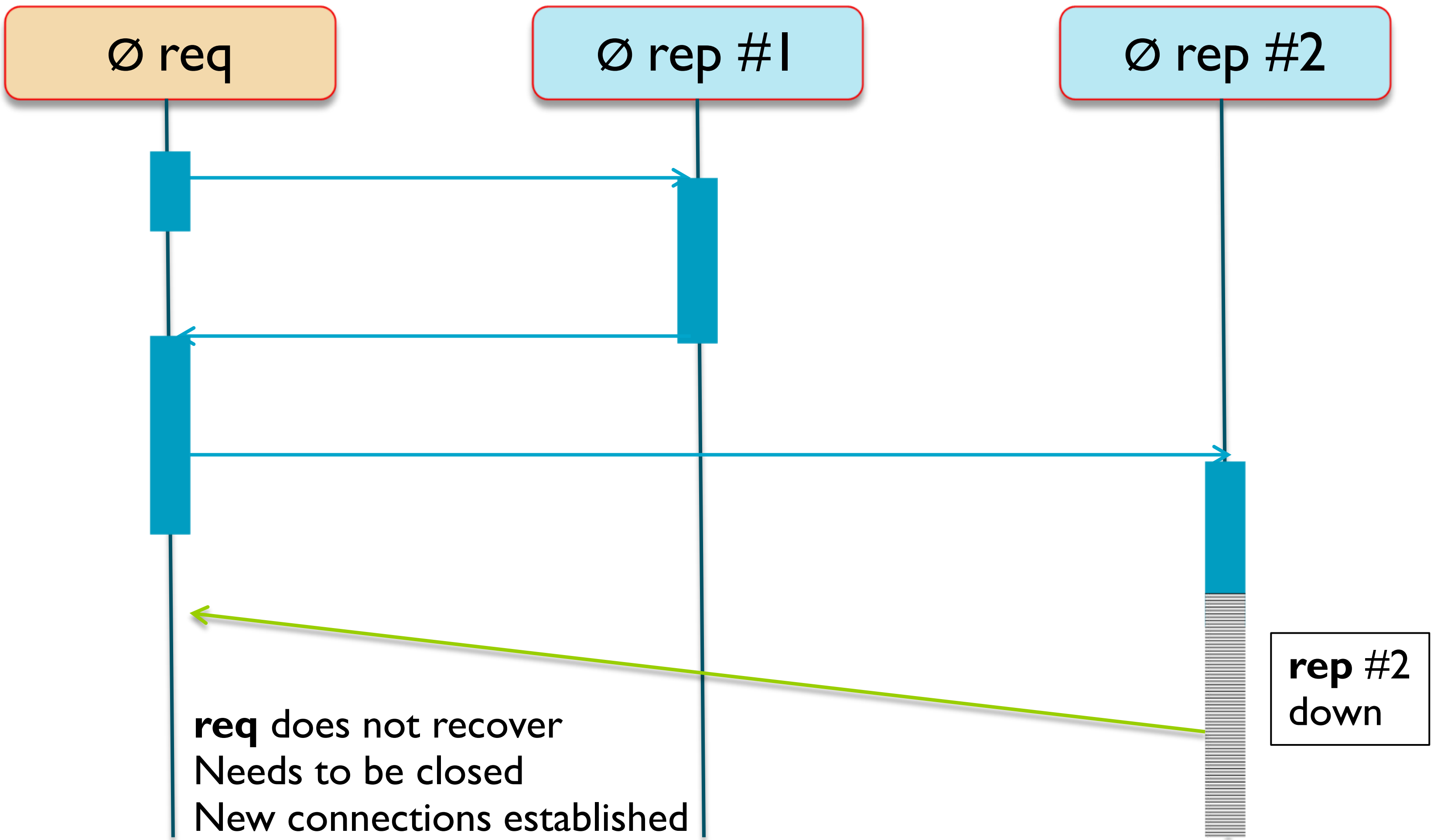


- Typical set-up for a server
- rep socket fairly queues incoming messages
  - No req socket is starved

4.3.2. Basic Patterns: Request/reply sequence



4.3.2. Basic Patterns: Request/reply failures



4.3.2. Patterns: Basic req/rep

```
const zmq = require('zeromq')
const rq = zmq.socket('req')
rq.connect('tcp://127.0.0.1:8888')
rq.send('Hello')
rq.on('message', function(msg) {
   console.log('Response: ' + msg)
})
```

```
const zmq = require('zeromq')
const rp = zmq.socket('rep')
rp.bind('tcp://127.0.0.1:8888',
     function(err) {
        if (err) throw err
     })
rp.on('message', function(msg) {
   console.log('Request: ' + msg)
         rp.send('World')
})
```

4.3.2. Basic Patterns: Basic req/rep, two servers

```
const zmq = require('zeromq')
const rq = zmq.socket('req')
rq.connect('tcp://127.0.0.1:8888')
rq.connect('tcp://127.0.0.1:8889')
rq.send('Hello')
rq.send('Hello again')

rq.on('message', function(msg) {
   console.log('Response: ' + msg)
})
```

```
const zmq = require('zeromq')
const rp = zmq.socket('rep')
rp.bind('tcp://127.0.0.1:8888',
     function(err) {
        if (err) throw err
     })
rp.on('message', function(msg) {
   console.log('Request: ' + msg)
         rp.send('World')
})
```

```
const zmq = require('zeromq')
const rp = zmq.socket('rep')
rp.bind('tcp://127.0.0.1:8889',
     function(err) {
        if (err) throw err
     })
rp.on('message', function(msg) {
   console.log('Request: ' + msg)
         rp.send('World 2')
})
```

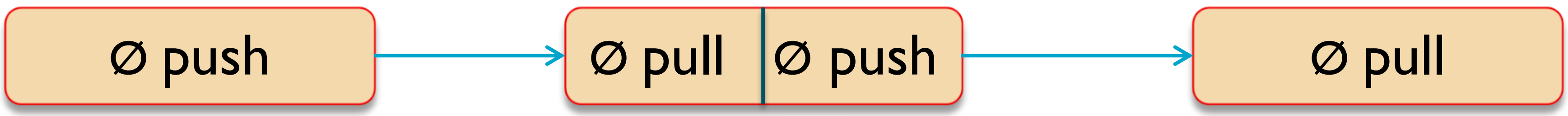
4.3.2. Patterns: req/rep, structure of message

- Messages exchanged have a first segment empty
- Referred to as the delimiter
- The req socket adds it, without app intervention
- The rep socket removes it before handing it to the application
  - But it adds it again on the reply
- The req socket removes it from the reply.

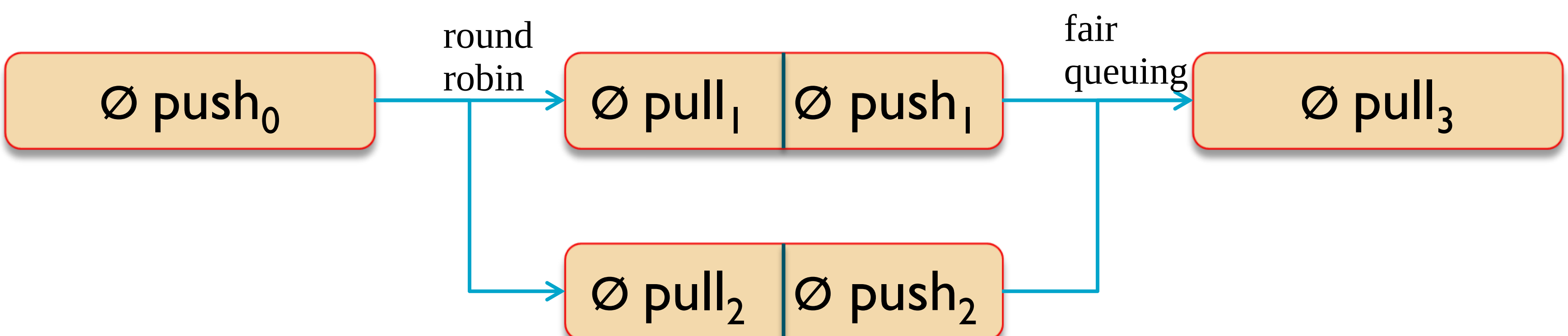
0	“”
7	“this is”
1	“a”
7	“request”

4.3.2. Basic Patterns: push/pull

- Unidirectional data distribution
- Sender does not expect a reply back.
  - Messages do not wait for replies: concurrent sending.



- Accepts also multiple connections.
  - E.g., typical map-reduce organization:



4.3.2: Patterns: push/pull example, producer/consumers

```
const zmq = require("zeromq")
const producer = zmq.socket("push")
let count = 0

producer.bind("tcp://*:8888", function(err) {
  if (err) throw err

  setInterval(function() {
    let t = producer.send("msg nr. " + count++)
    console.log(t)
  }, 1000)
})
```

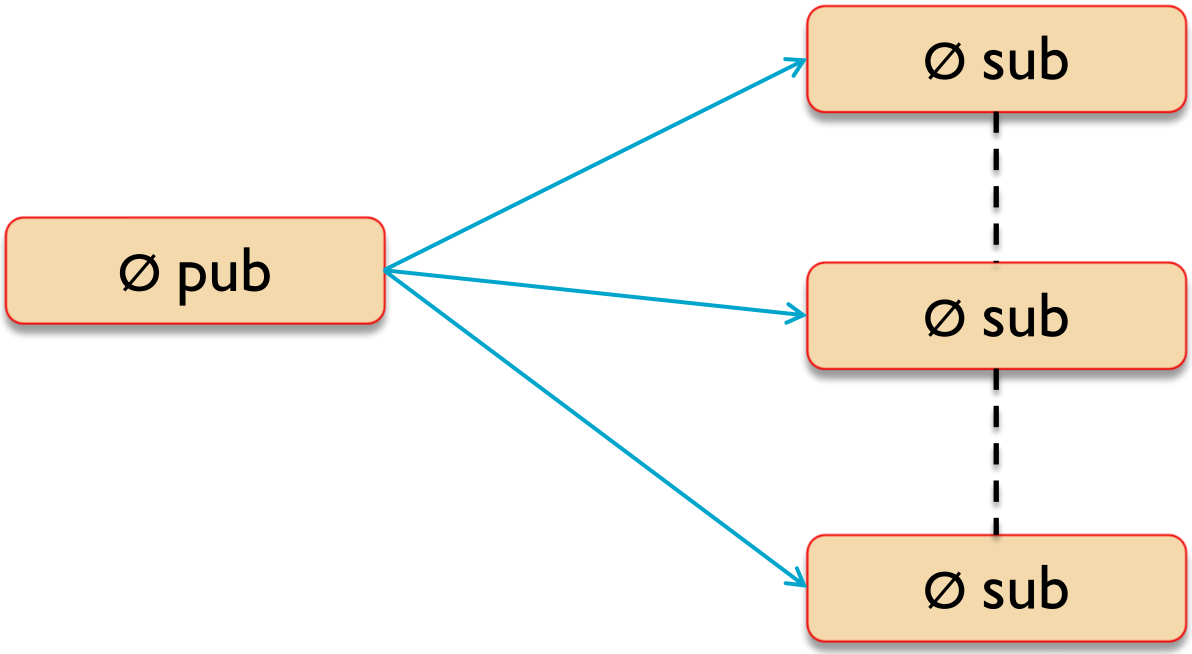
```
const zmq = require("zeromq")
const consumer = zmq.socket("pull")

consumer.connect("tcp://127.0.0.1:8888")

consumer.on("message", function(msg) {
  console.log("received: " + msg)
})
```

4.3.2. Basic Patterns: Publish/Subscribe (pub/sub)

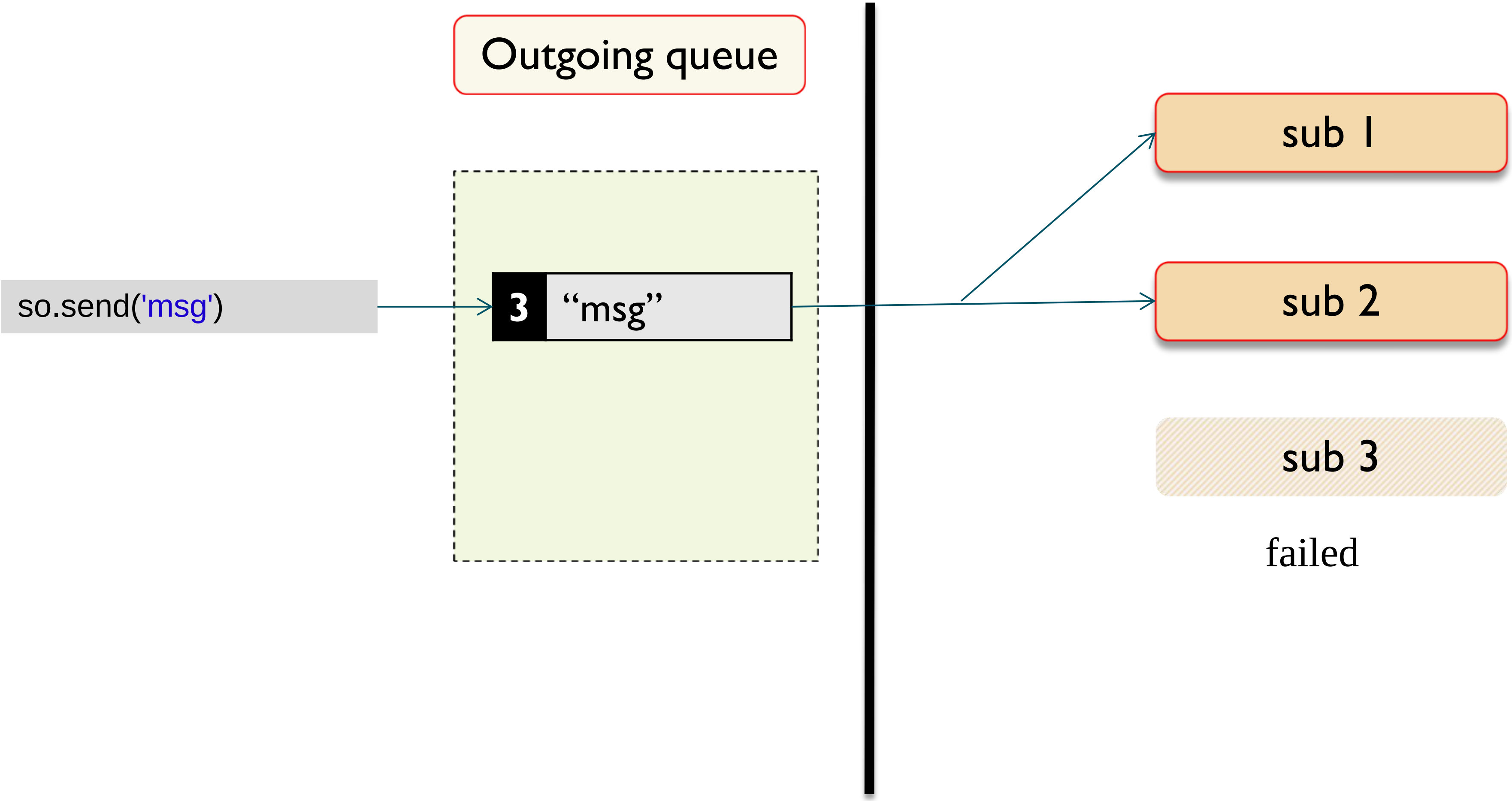
- Pattern implements message broadcasting…



- … with a twist: receivers can decide to subscribe to only some messages
  - Thus multicast

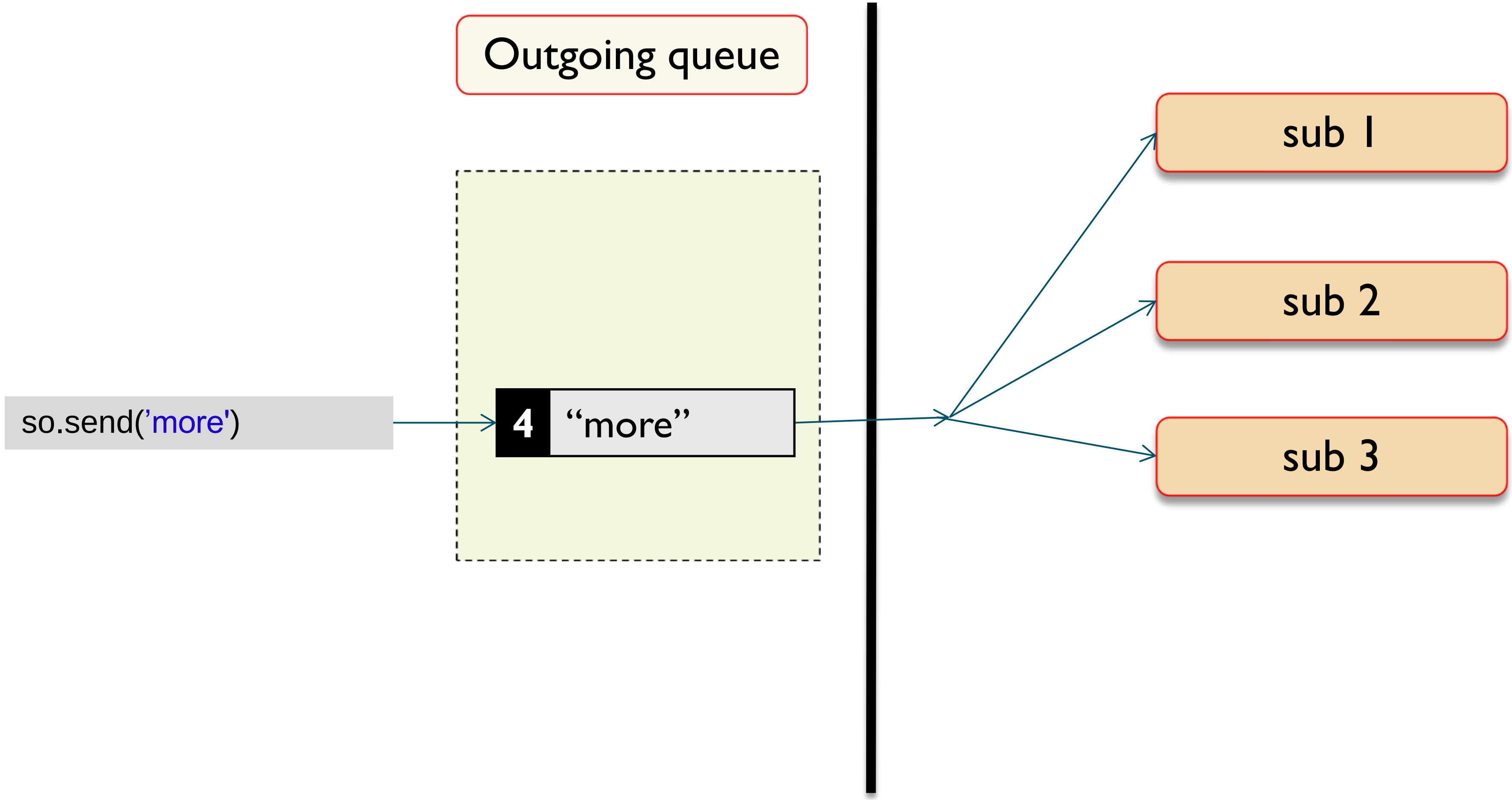
4.3.2. Basic Patterns: pub/sub

- Messages are sent to all connected and available peers



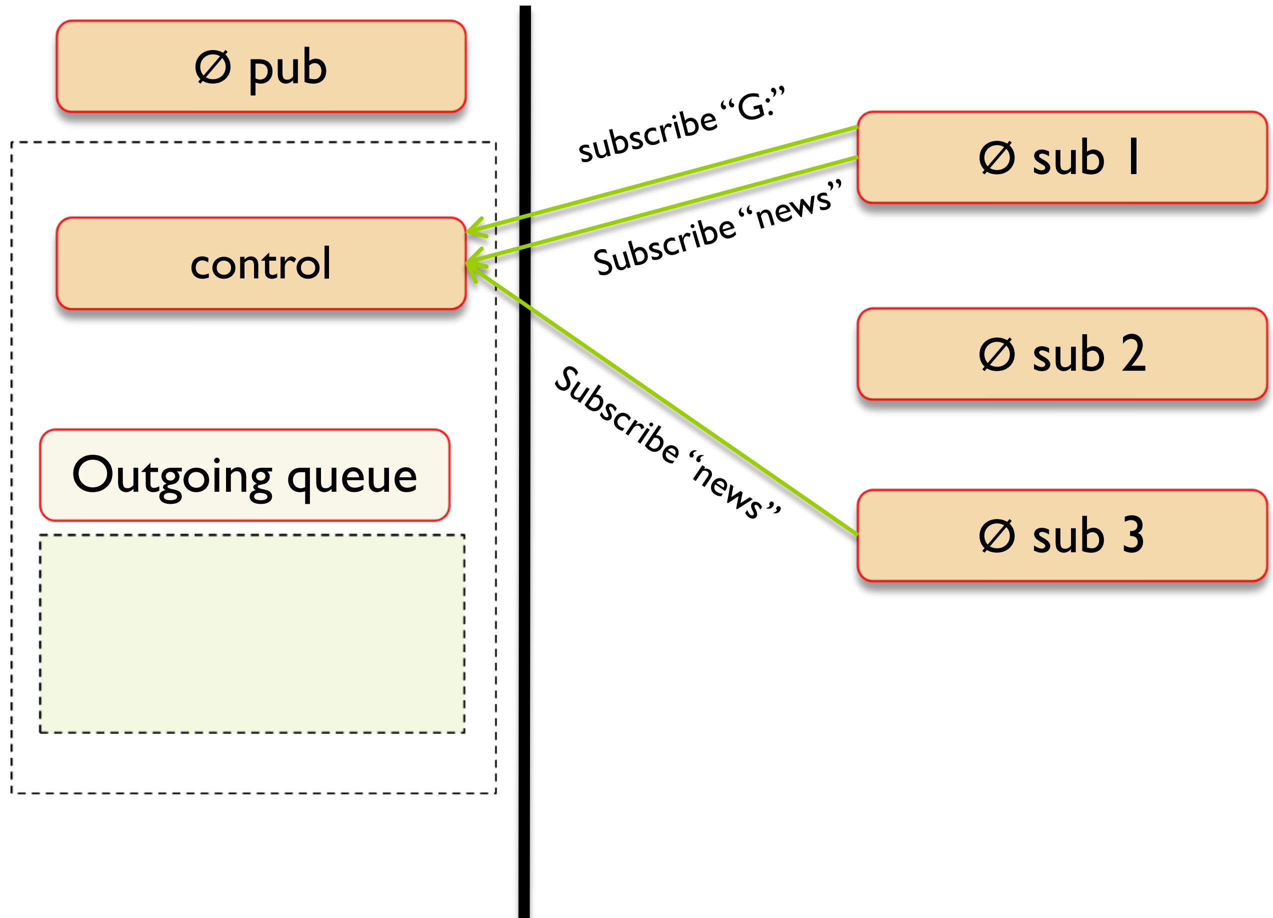
4.3.2. Basic Patterns: pub/sub

- Messages are sent to all connected and available peers



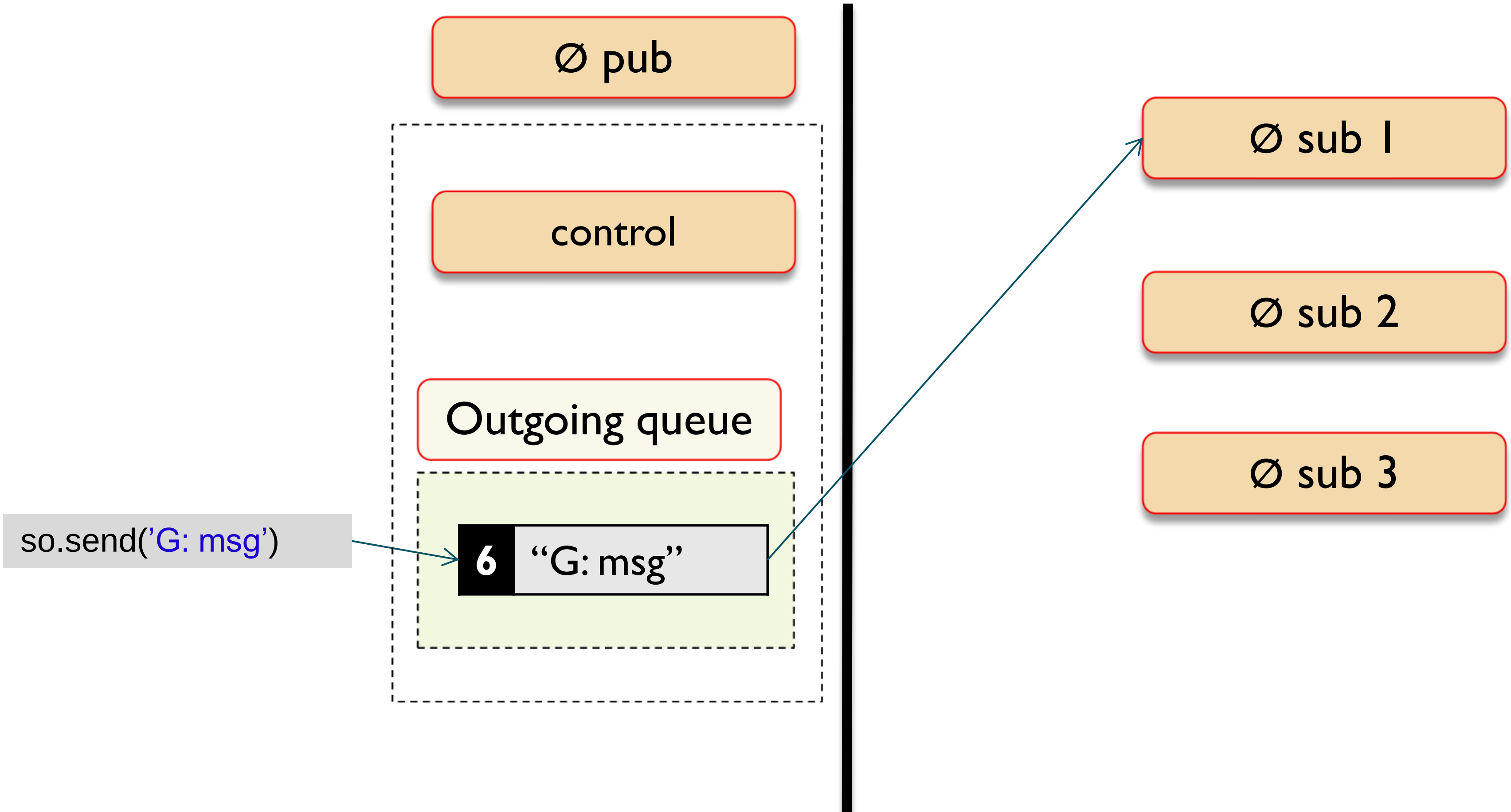
4.3.2. Basic Patterns: pub/sub: Subscribing/filtering

- Subscribers can specify filters as prefixes of messages
  - They can specify several prefixes



4.3.2. Basic Patterns: pub/sub: Subscribing/filtering

- Subscribers can specify filters as prefixes of messages
  - They will receive only messages with those prefixes



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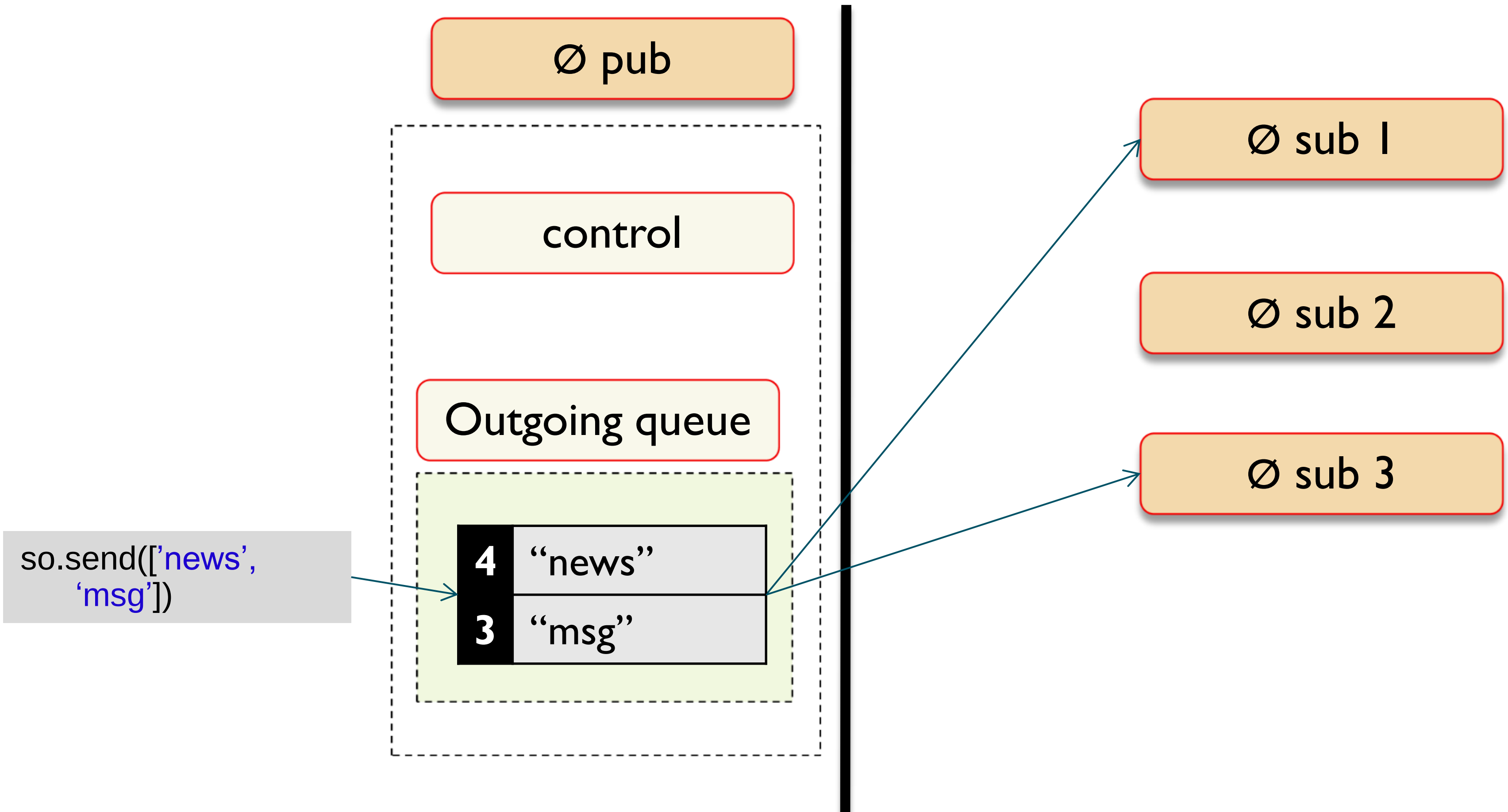

4.3.2. Basic Patterns. pub/sub coding example

```
const zmq = require("zeromq")
const pub = zmq.socket('pub')
let count = 0

pub.bindSync("tcp://*:5555")

setInterval(function() {
  pub.send("TEST " + count++)
}, 1000)
```

```
const zmq = require("zeromq")
const sub = zmq.socket('sub')

sub.connect("tcp://localhost:5555")
sub.subscribe("TEST")
sub.on("message", function(msg) {
  console.log("Received: " + msg)
})
```

Older messages might be lost, if subscriber starts late

4. ZeroMQ

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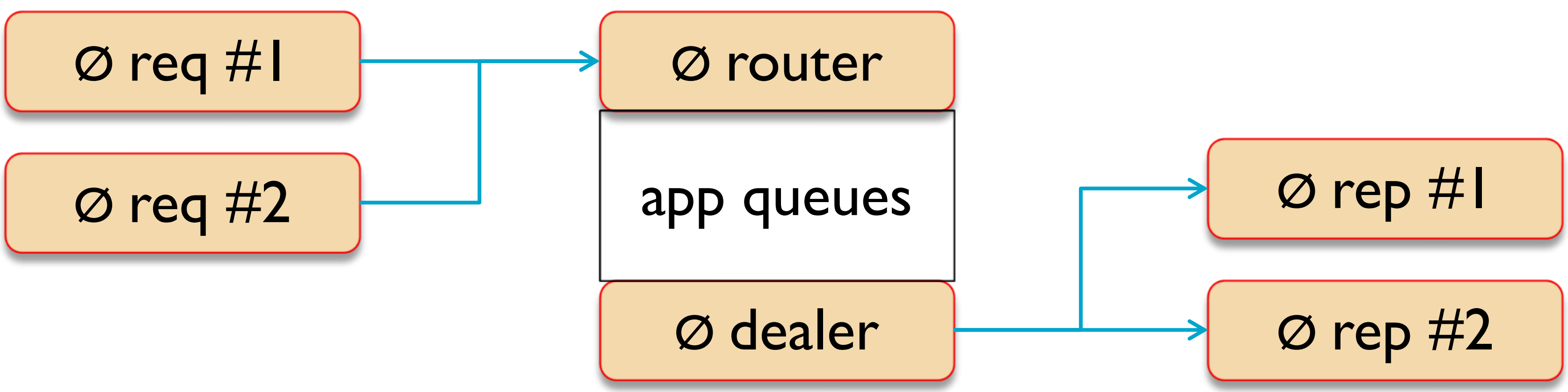
4.4. Advanced socket types

1. Dealer
   - Similar to a req, but asynchronous
2. Router
   - Similar to a rep, but asynchronous, and with ability to distinguish its peers (for routing replies)

- Typically found together in the same agent

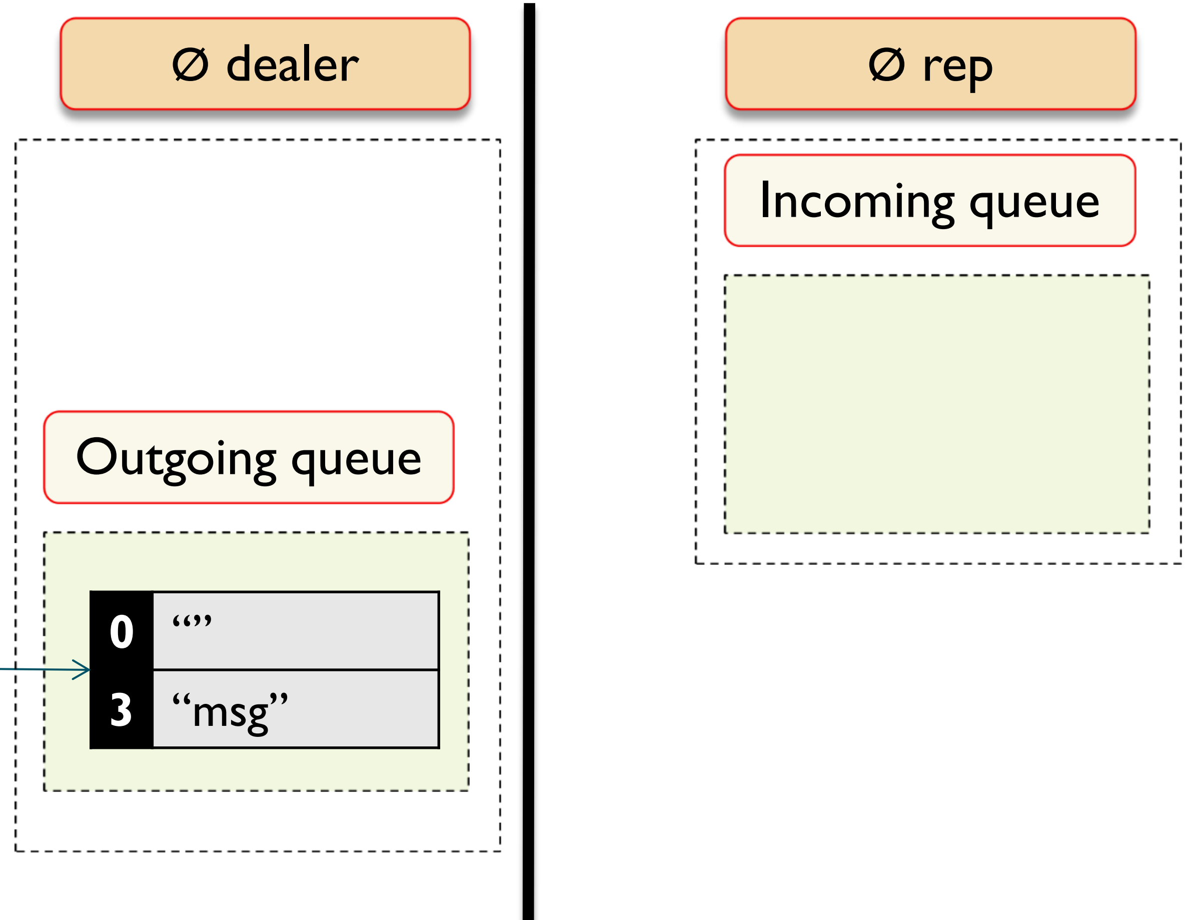


4.4.1. Dealer sockets

- General purpose async socket
- Used frequently as an async **req** socket
  - Does not get blocked by failures of peers
  - BUT, must build a proper request message
    - Empty segment (delimiter) before the actual message body
    - Can prepend the delimiter with any number of segments

4.4.1. Dealer sockets: handling request/reply

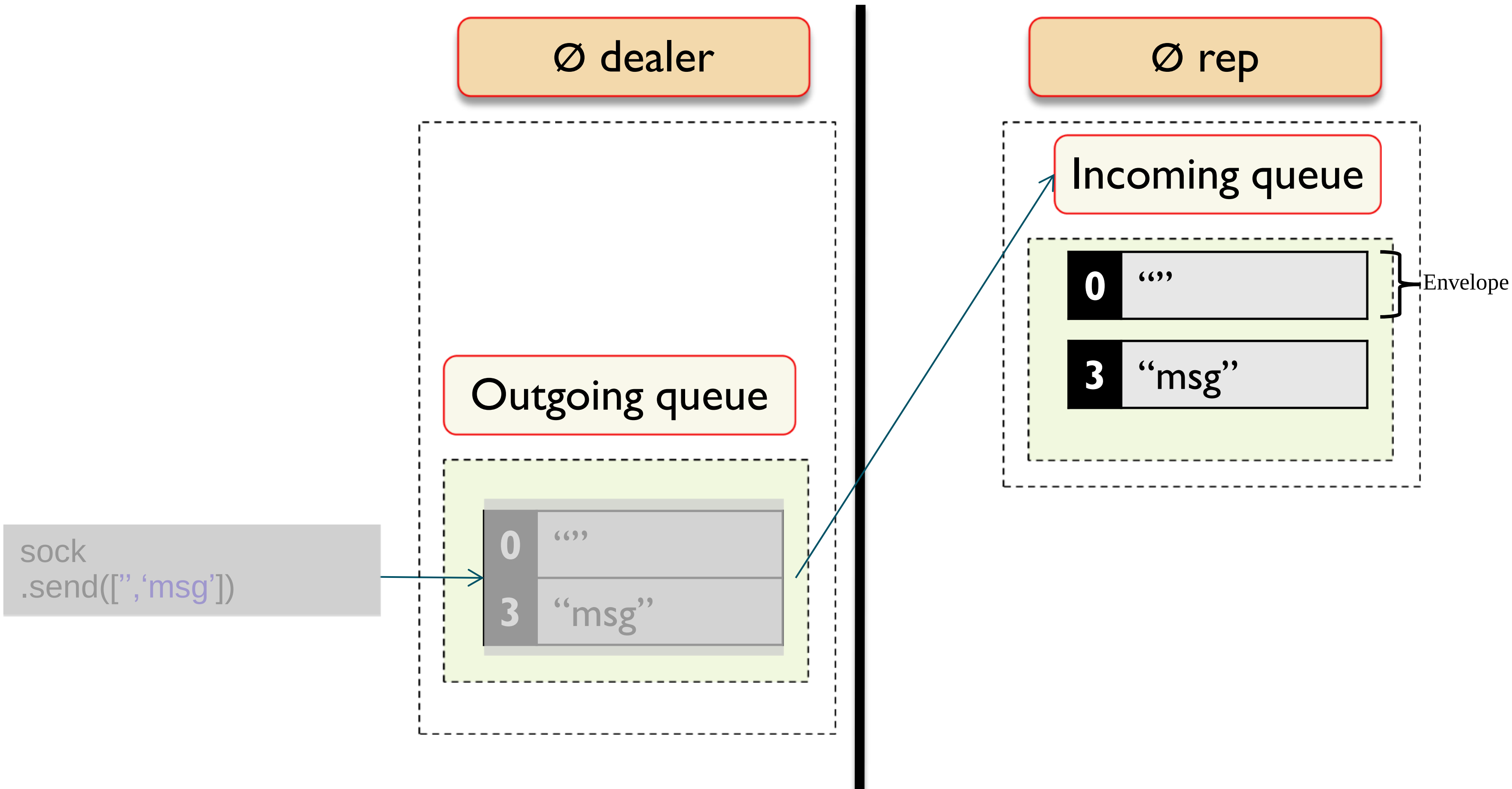
- Delimiter must be prepended to talk to a rep:




```
sock
.send([’’,‘msg’])
```

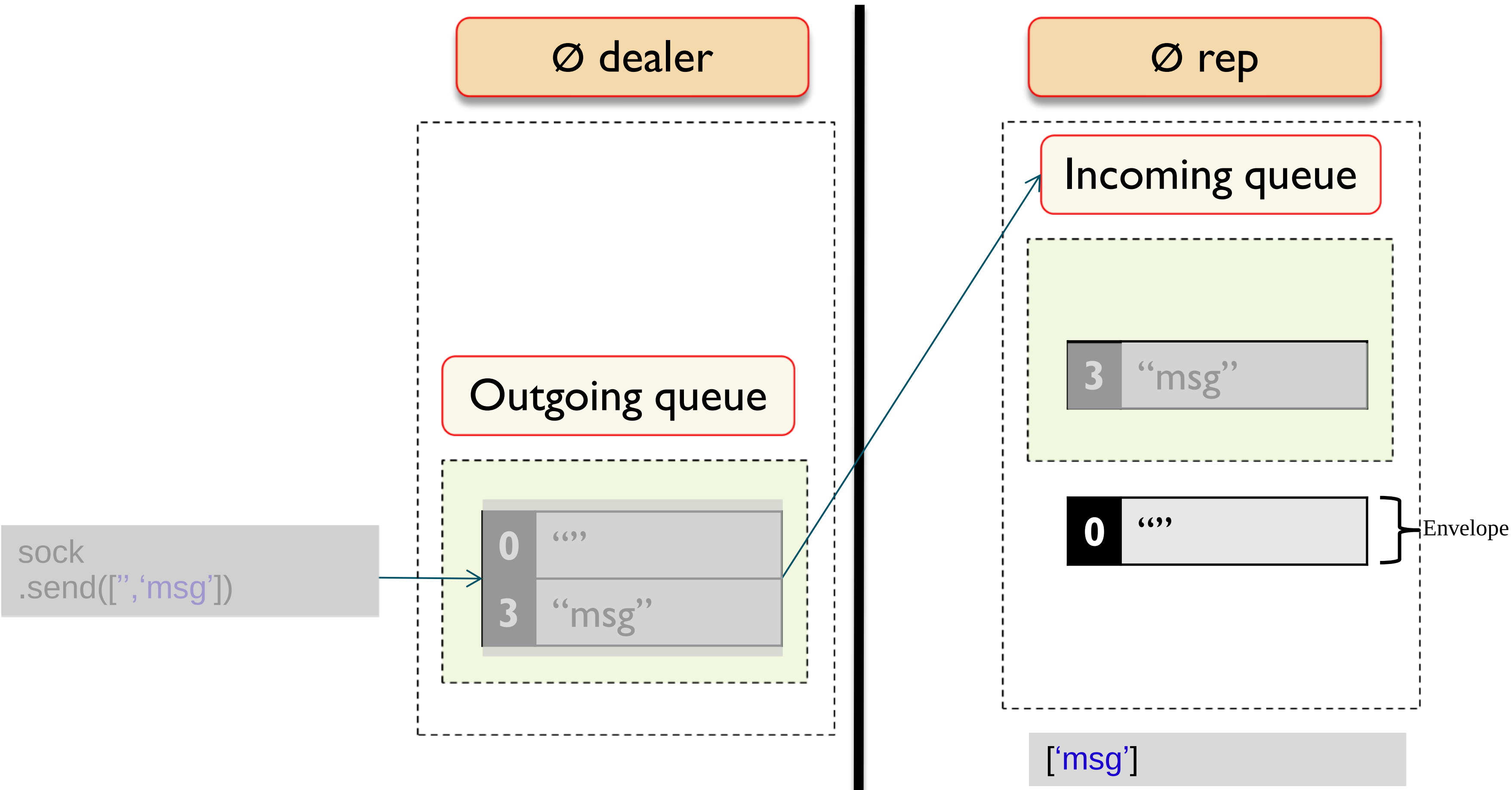
4.4.1 Dealer sockets: handling request/reply

- When received, the rep socket splits the *Envelope*



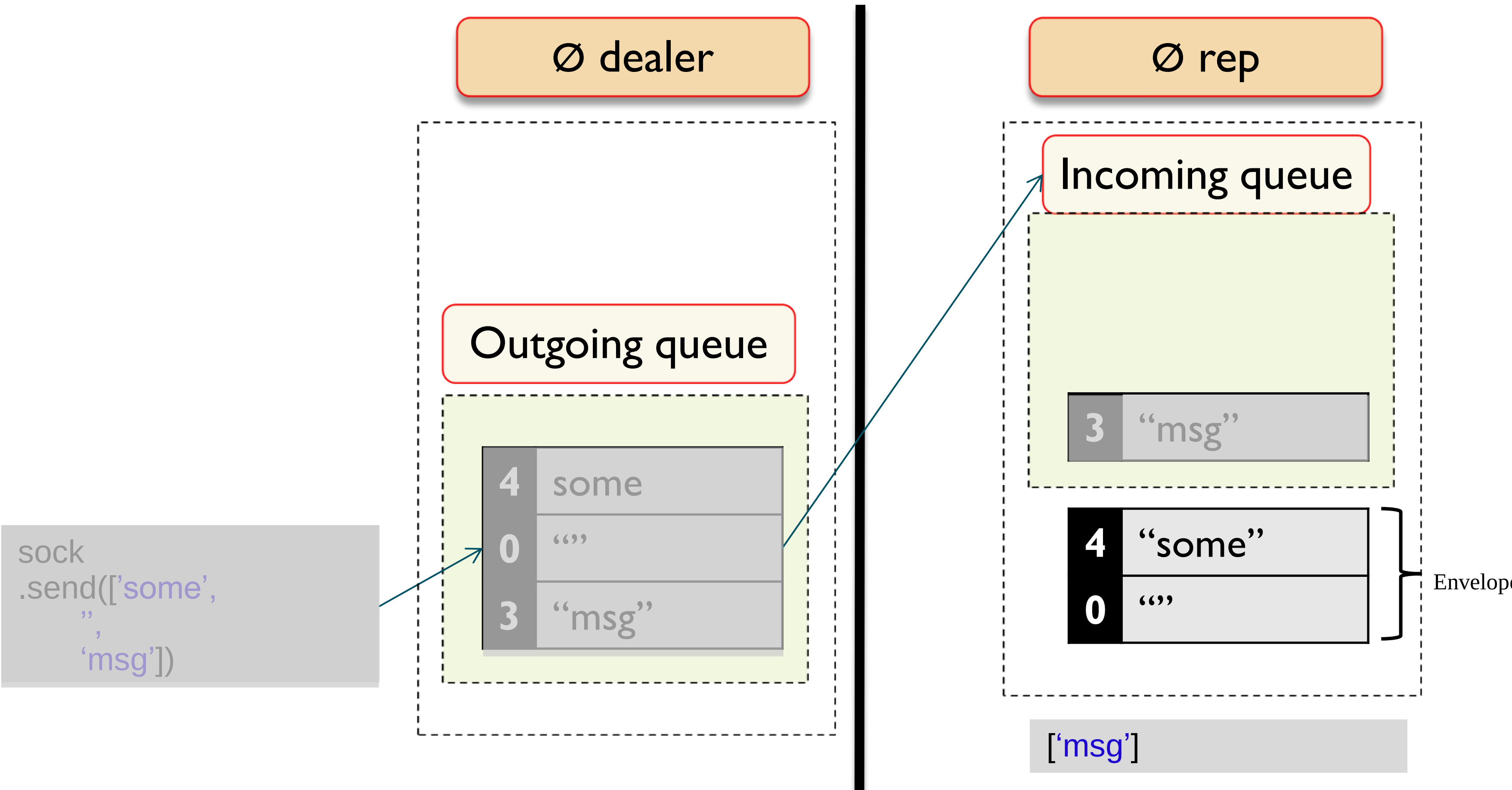
4.4.1 Dealer sockets: handling request/reply

- When received, the rep socket splits the *Envelope*
  - App sees only the rest of the message



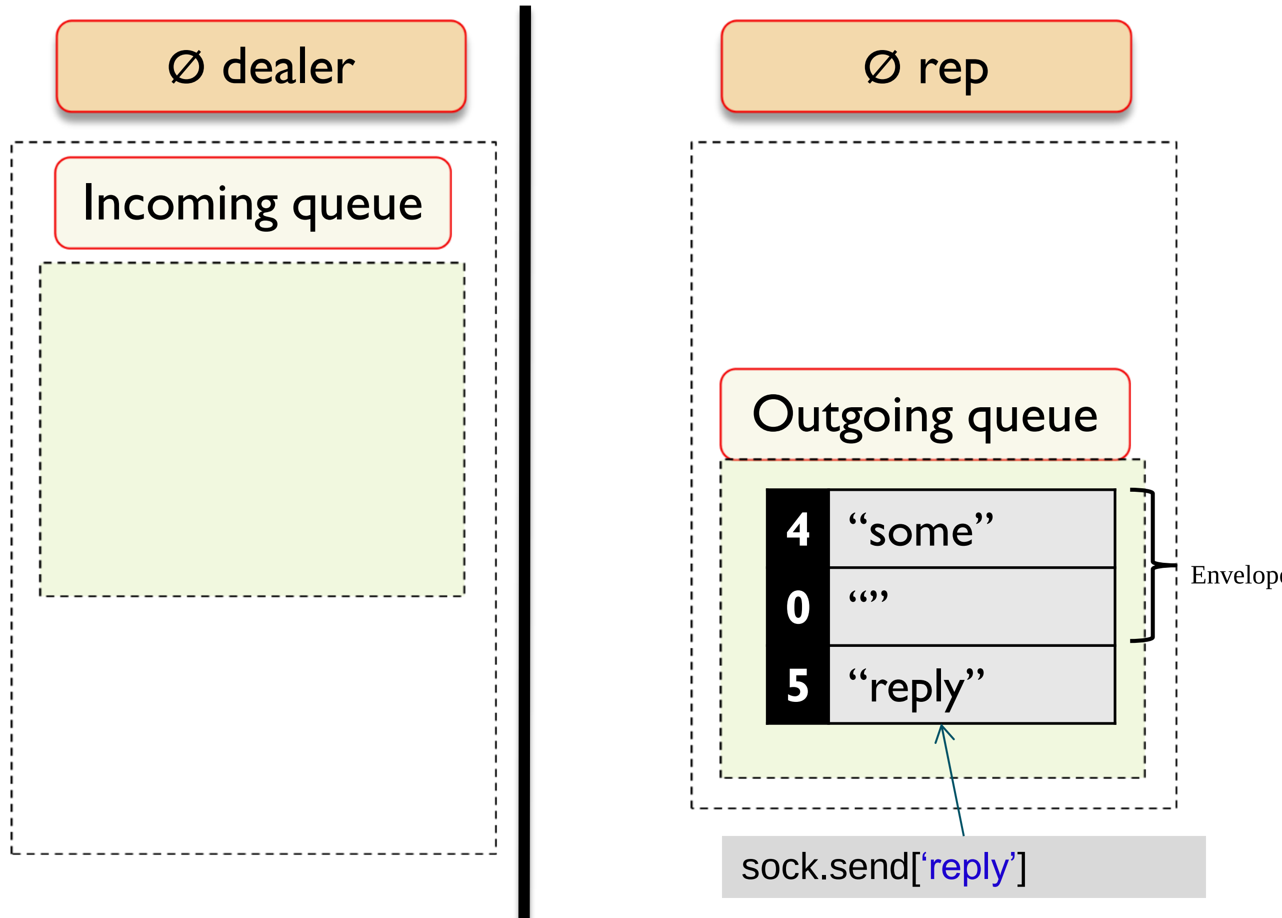
4.4.1. Dealer sockets: Envelopes

- Envelope is more general: All segments up to the first delimiter
  - Envelope is saved by rep…



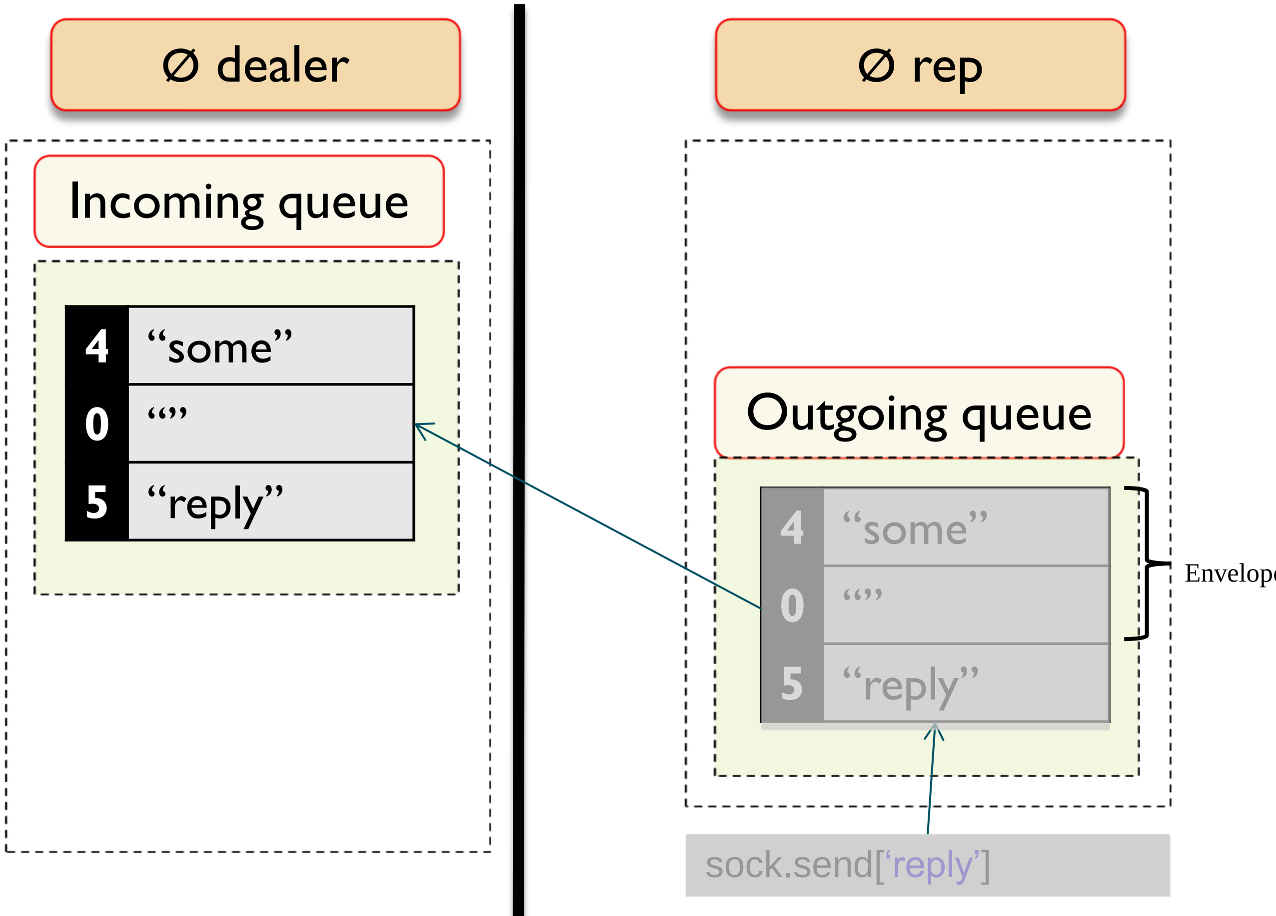
4.4.1. Dealer sockets: Envelopes

- Envelope is more general: All segments up to the first delimiter
  - Envelope is saved by rep… and reinserted to the reply



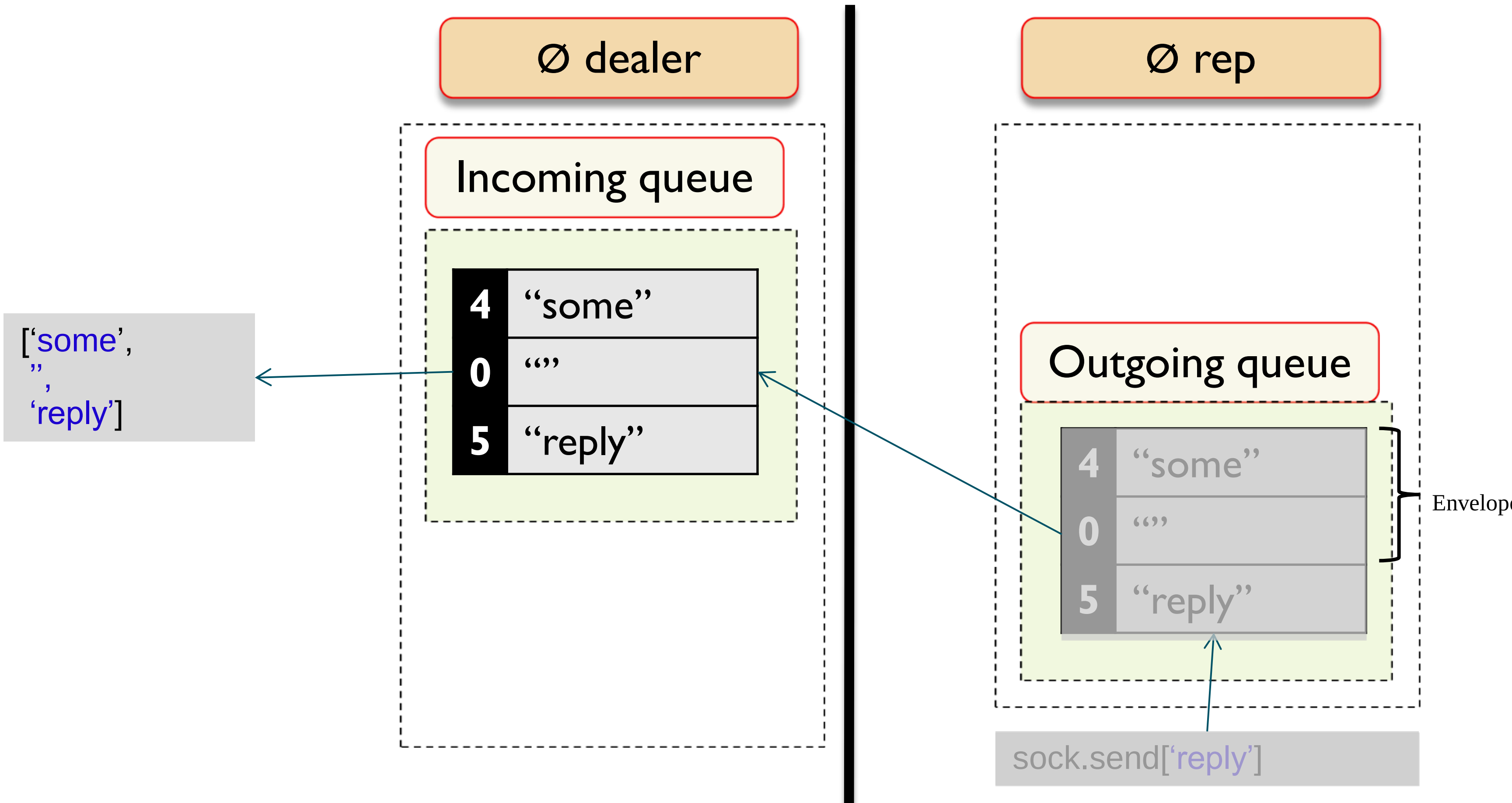
4.4.1. Dealer sockets: Envelopes

- Envelope is more general: All segments up to the first delimiter
  - The composed message is sent back



4.4.1. Dealer sockets: Envelopes

- Envelope is more general: All segments up to the first delimiter
  - And the dealer application gets all of it



4.4.1. Dealer sockets: coding example

```
const zmq  = require('zeromq')
const dealer = zmq.socket('dealer')
let msg = ["", "Hello ", 0]
const host = ”tcp://localhost:888”

dealer.connect(host + 8)
dealer.connect(host + 9)

setInterval(function() {
  dealer.send(msg)
  msg[2]++
}, 1000)

dealer.on('message',
  function(h, seg1, seg2) {
    console.log('Response:’ + seg1 + seg2)
})
```

```
const zmq = require('zeromq')
const rep = zmq.socket('rep')

rep.bindSync('tcp://*:8888')
rep.on('message',
  function (intro, count) {
    rep.send(['World ',
          count])
})
```

```
const zmq = require('zeromq')
const rep = zmq.socket('rep')

rep.bindSync('tcp://*:8889')
rep.on('message',
  function (intro, count) {
    rep.send(['World ',
          count])
})
```

4.4.2. Router sockets

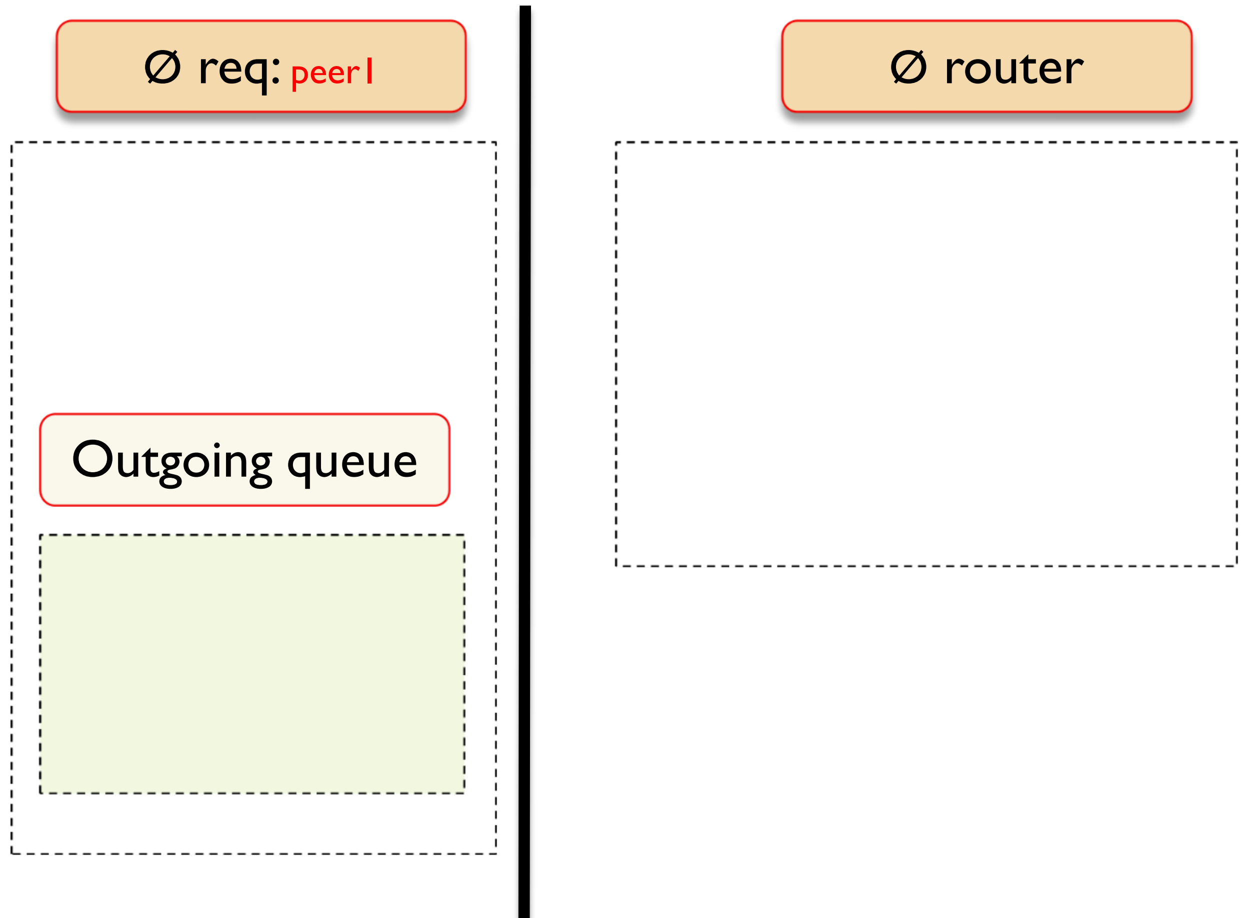
- Async bidirectional sockets
- Allow sending messages to specific peers
  - Assigns an identity to every peer it connects to.
  - The identity is that given to the peer in its program
    - sock.identity = 'my name';
    - When peer has no associated identity socket option
      - Router creates a random identity for the connected peer
      - The created identity lives while the connection is happening
      - When the connection is cut, and re-established the identity changes
    - ID’s are arbitrary binary strings up to 256 bytes long
- When the router socket passes a message to the app
  - It prepends an additional segment with the ID of the sending peer

4.4.2. Router sockets

- When the router socket is sending a message…:
  - It uses its first segment as a connection identity, thus…
    - A router socket maintains a pair of incoming and outgoing message queues **per connection**.
    - Such first segment is used to locate the appropriate connection (i.e., pair of queues). Once it is found…:
      - That first segment is implicitly removed.
        - The programmer does not need to do any thing.
      - The rest of the message is put in the outgoing queue of that connection.
        - This completes the message sending.
  - This allows a trivial router-dealer brokering:
    - The broker process uses a frontend router socket and a backend dealer.
    - Each message received from the router is sent through the dealer.
    - Each message received from the dealer is sent through the router.
    - In both cases, no message segment needs to be modified.

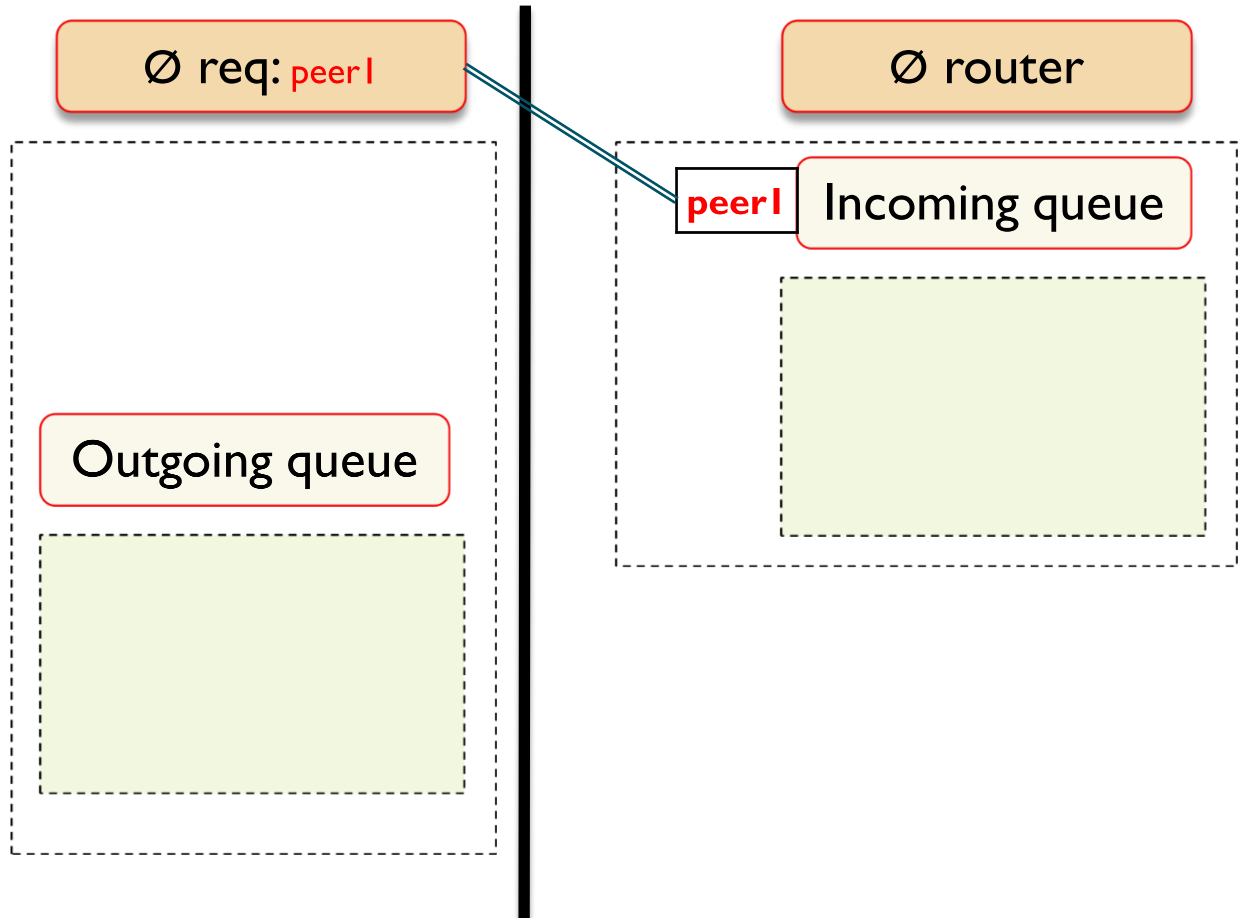
4.4.2. Router sockets: example req peer

- req peer has identity set to "peer1"



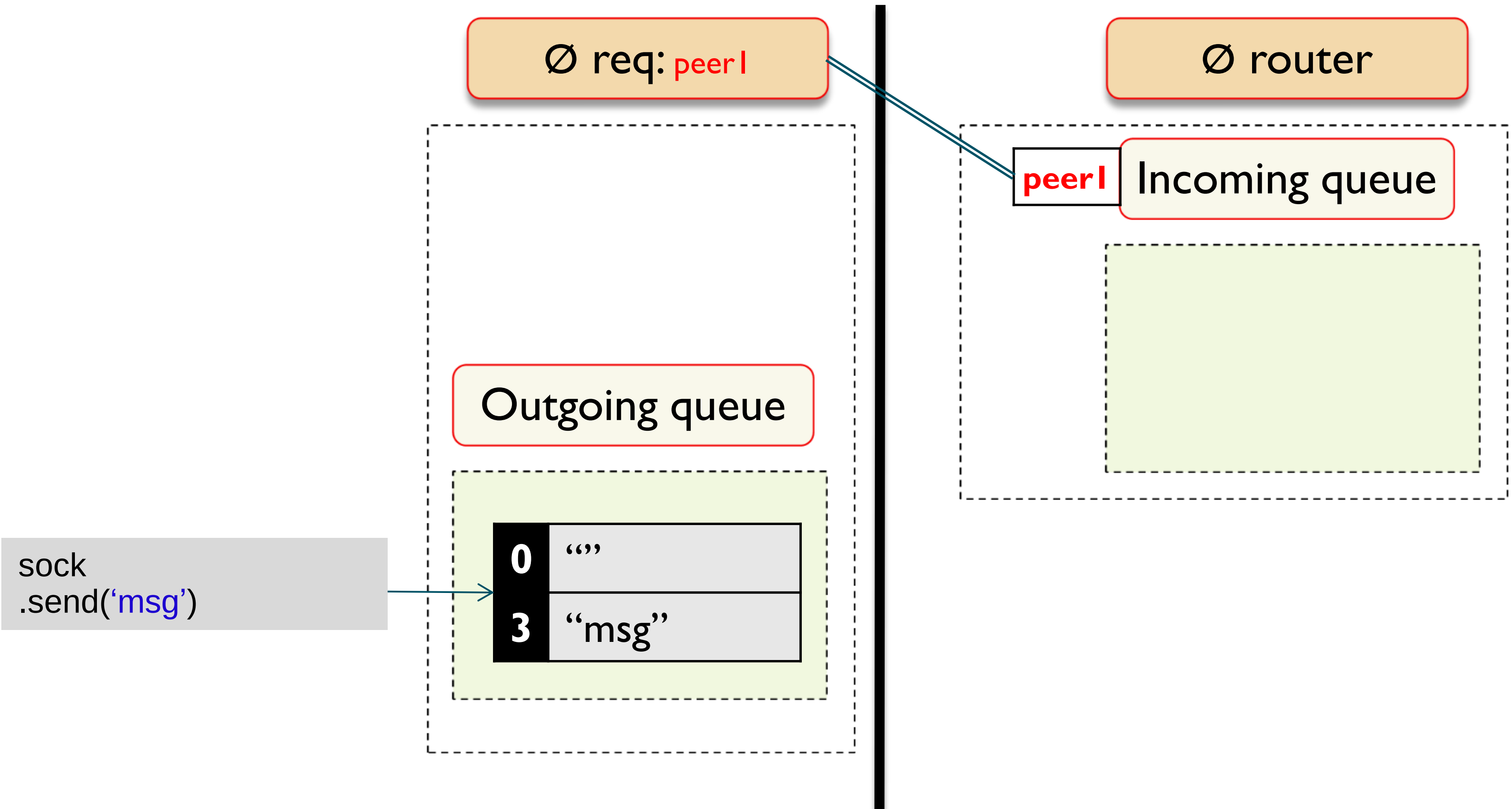
4.4.2. Router sockets: example req peer

- Req peer connects with router
  - Router gets its identity, and stores it, associating in/out queues



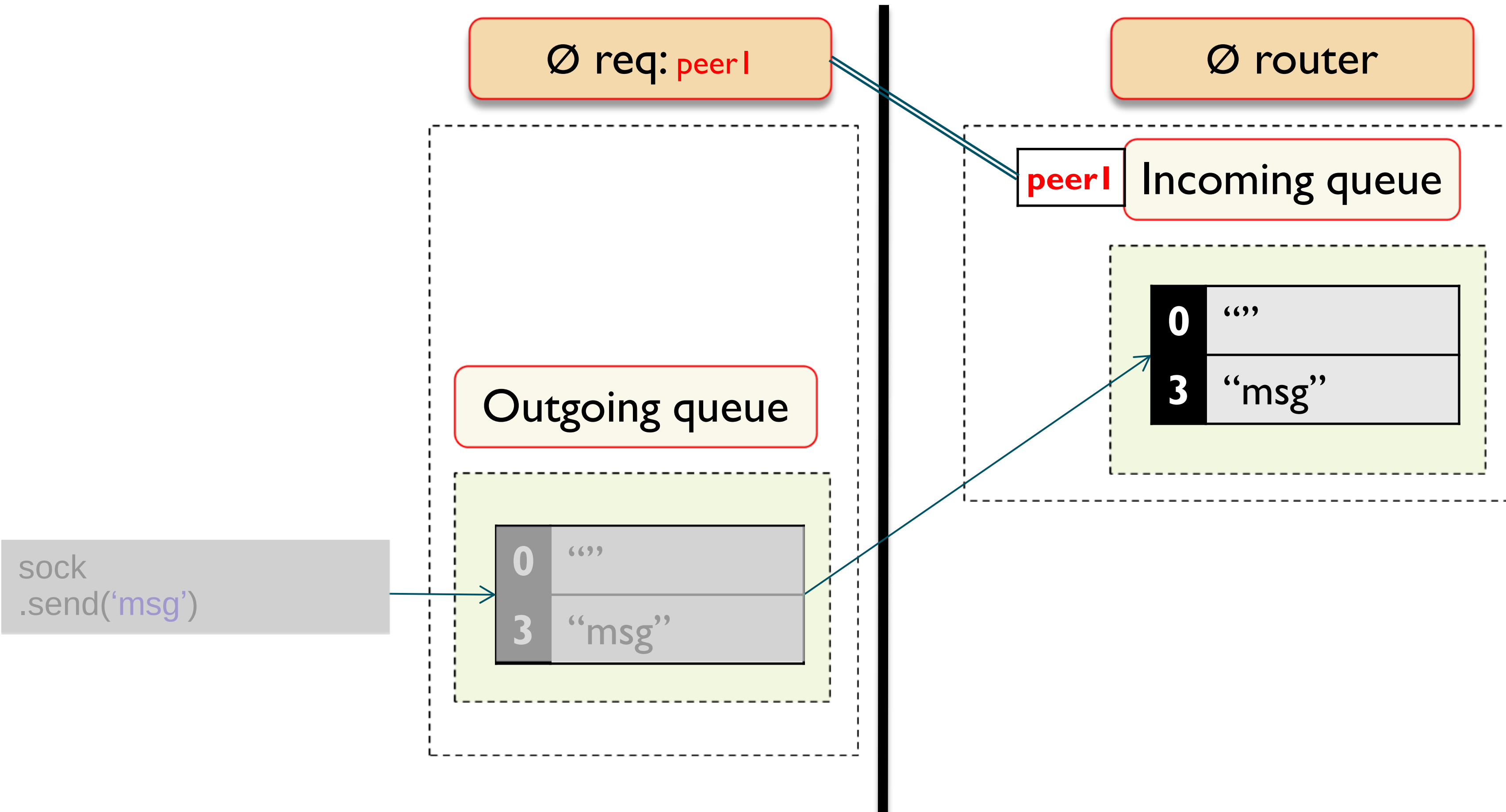
4.4.2. Router sockets: example req peer

- Req app sends a message
  - Req socket adds delimiter…



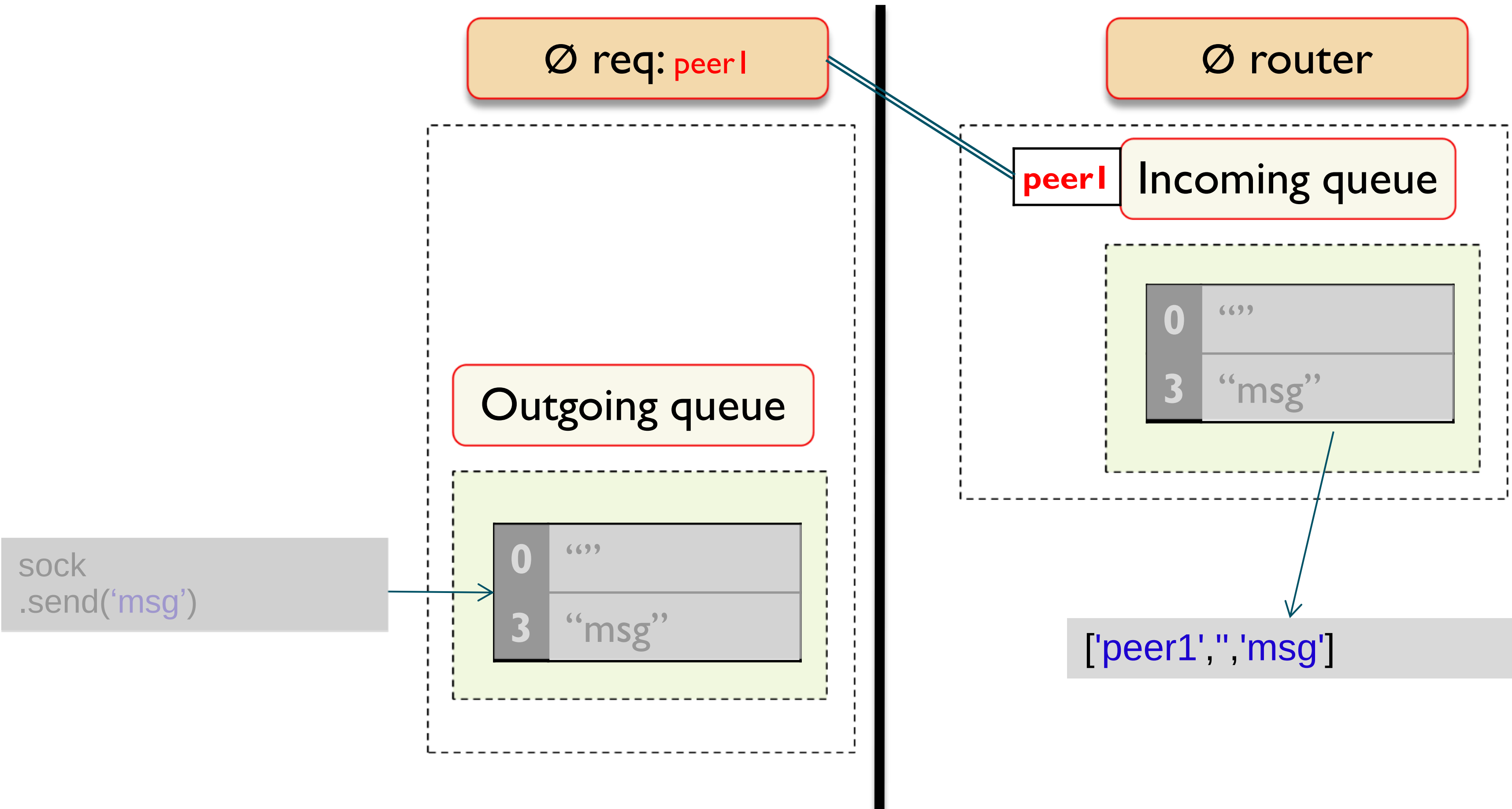
4.4.2. Router sockets: example req peer

- Req app sends a message
  - Req socket adds delimiter… and sends it



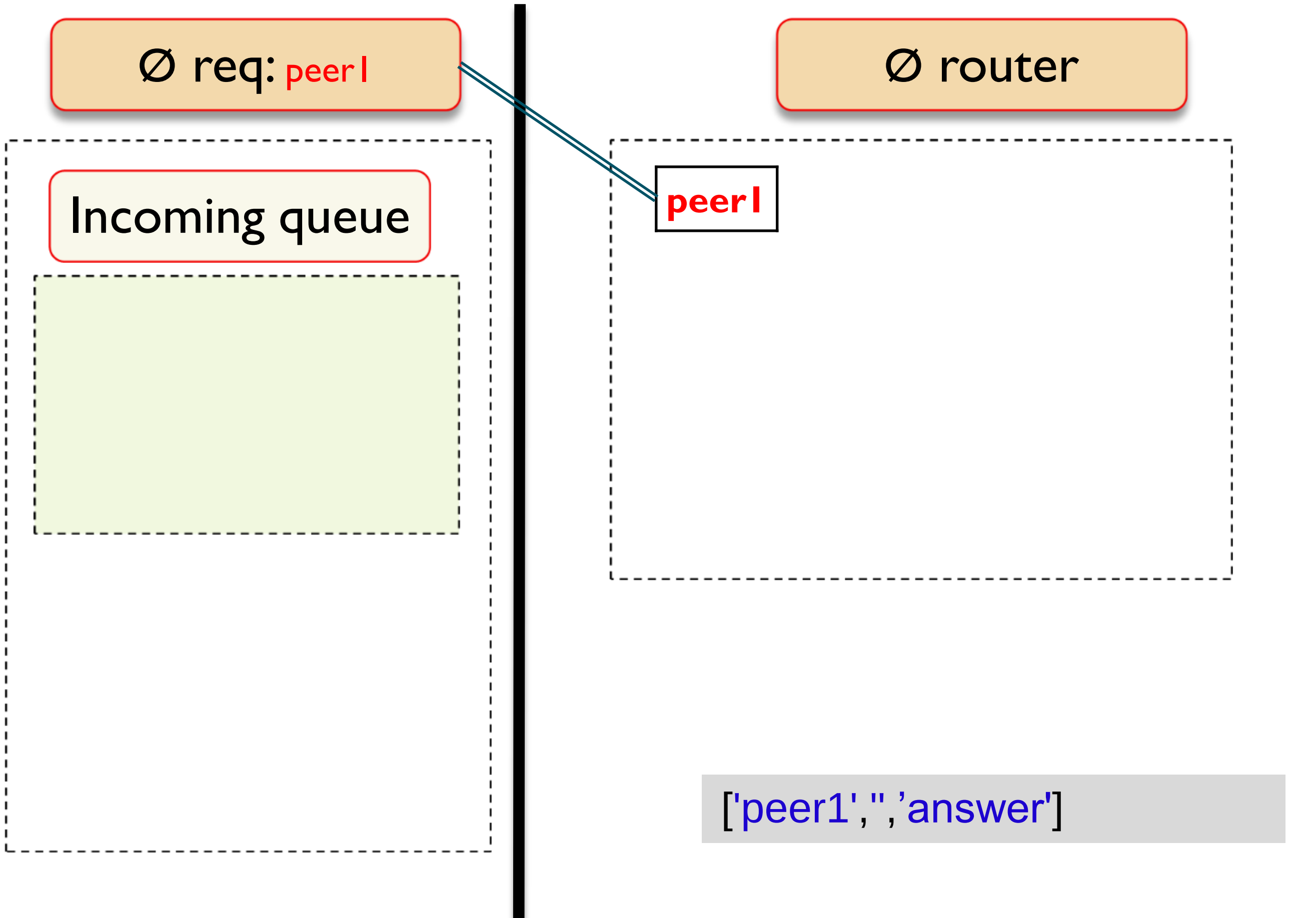
4.4.2. Router sockets: example req peer

- Router socket gives message to its app
  - With the identity of the sender prepended in a segment



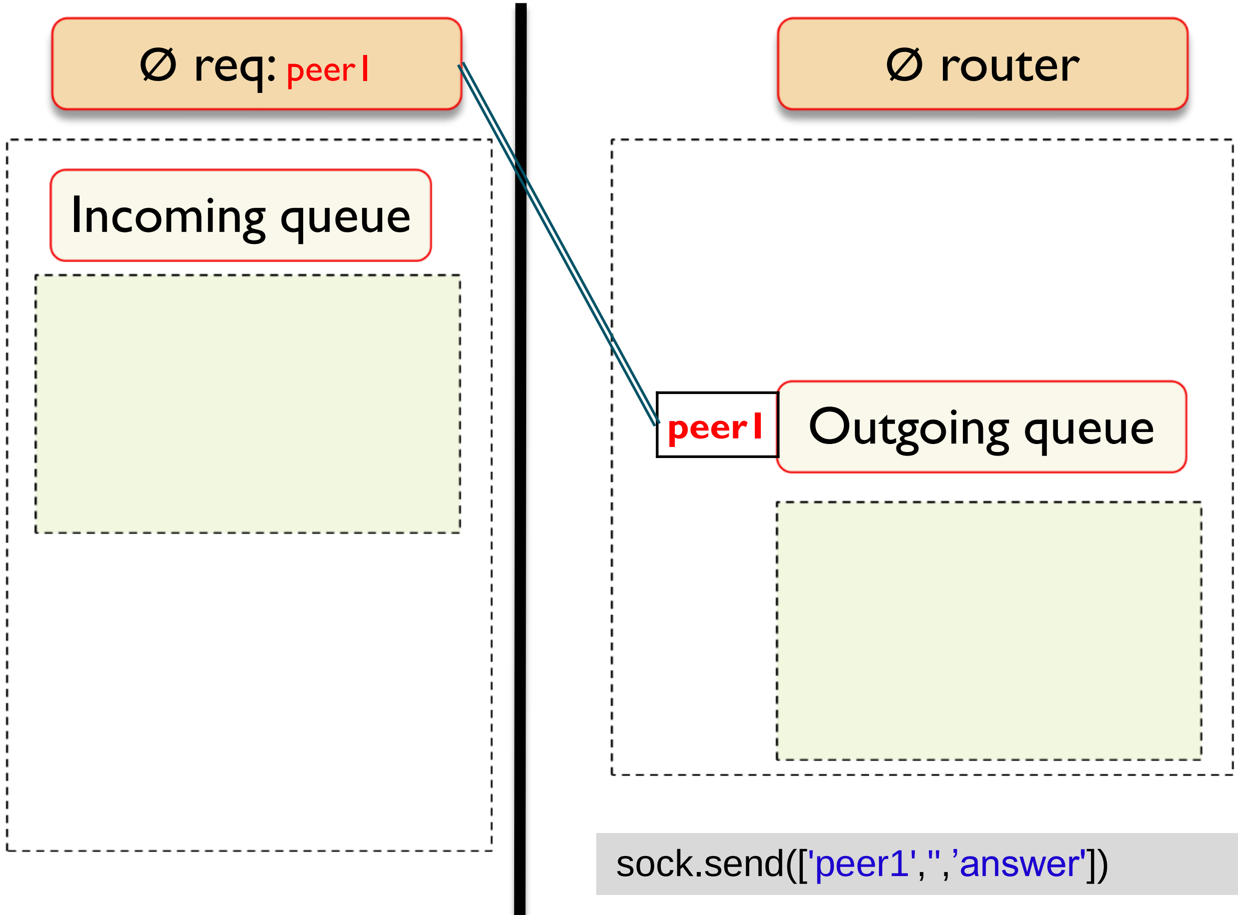
4.4.2. Router sockets: example req peer

- Router app creates an answer, composing the reply message
  - First segment contains identity of peer to receive answer



4.4.2. Router sockets: example req peer

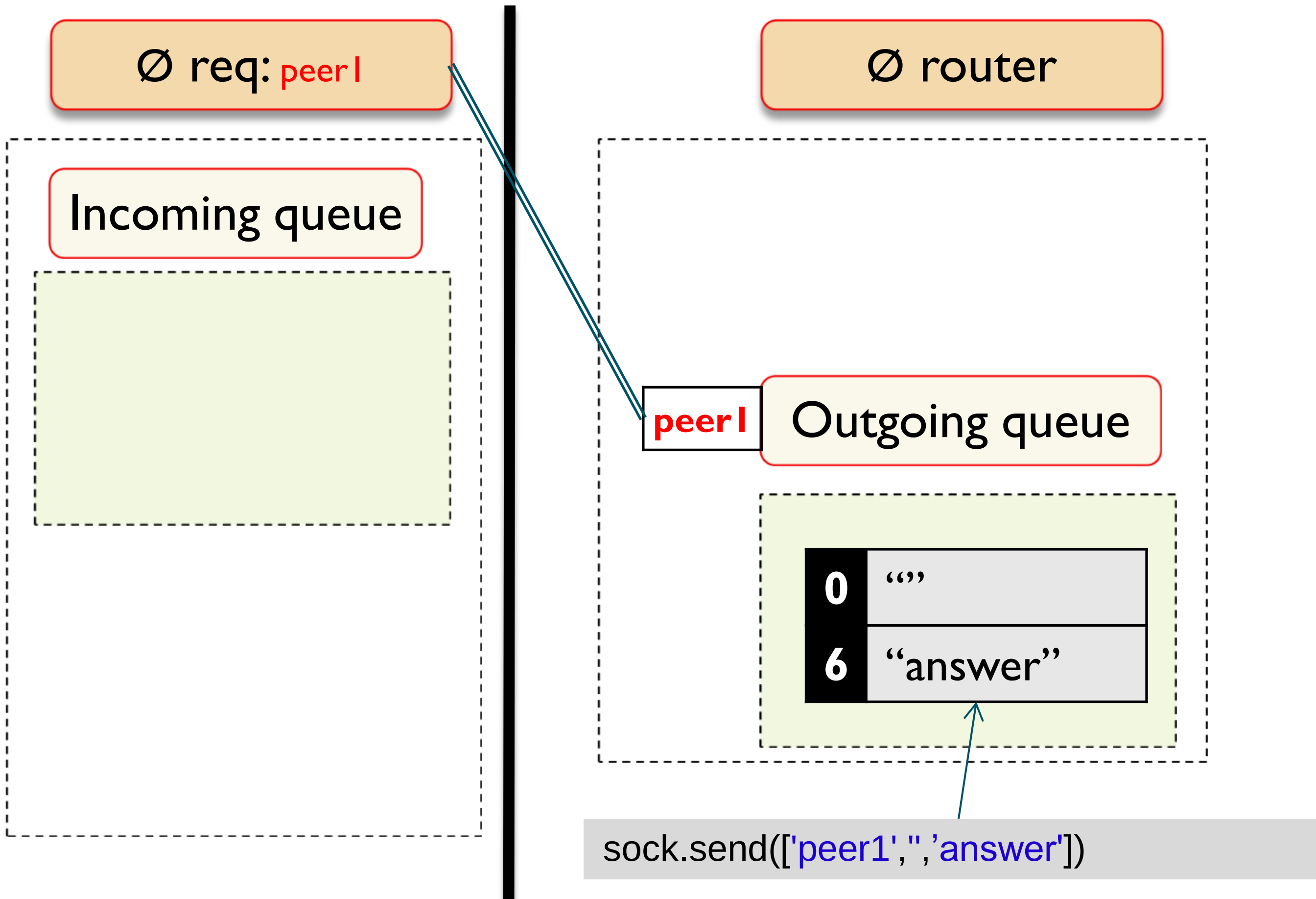
- Router app sends message
  - Router socket selects the output queue based on the identity




```
sock.send(['peer1','','answer'])
```

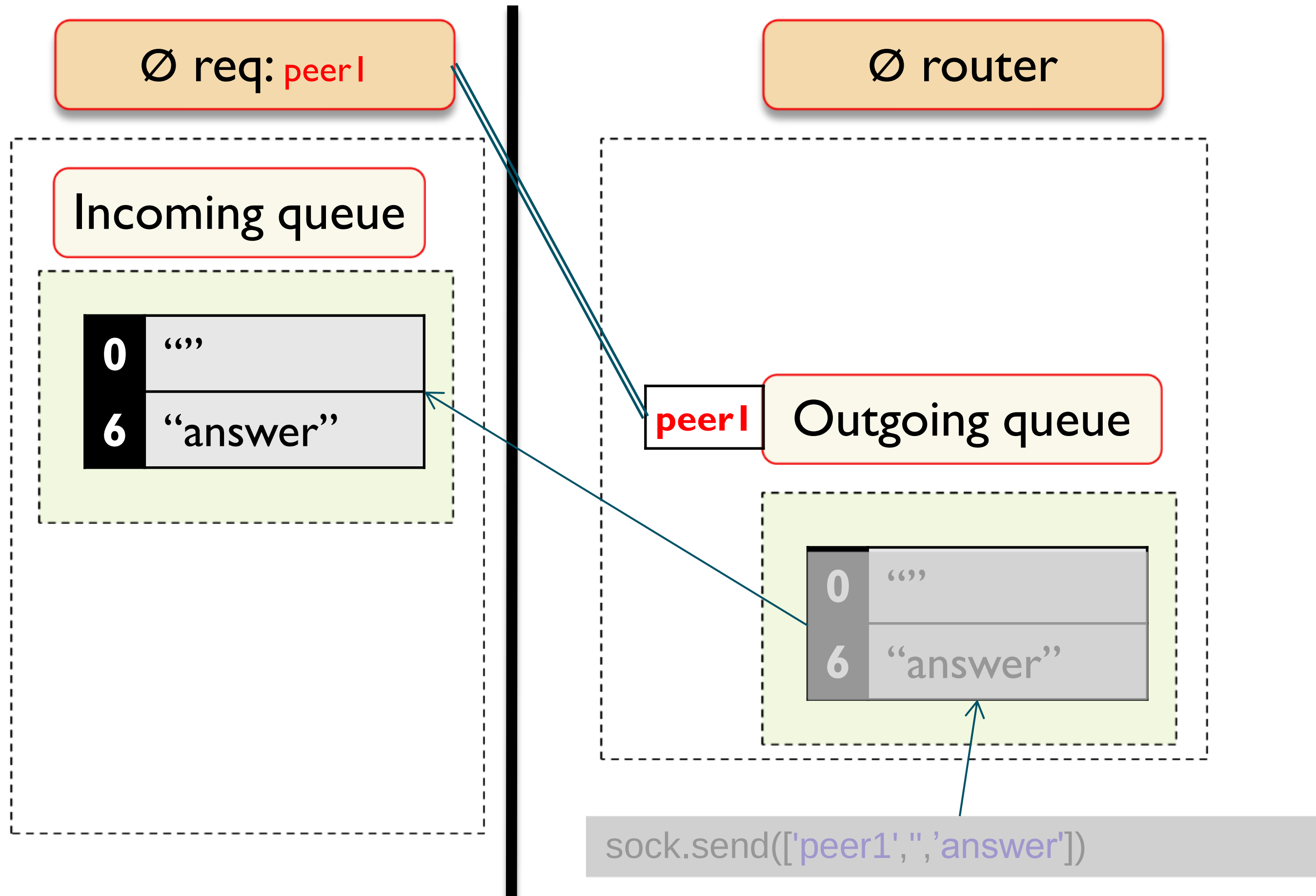
4.4.2. Router sockets: example req peer

- Router socket strips the identity segment
  - Leaves the rest of the message for sending…



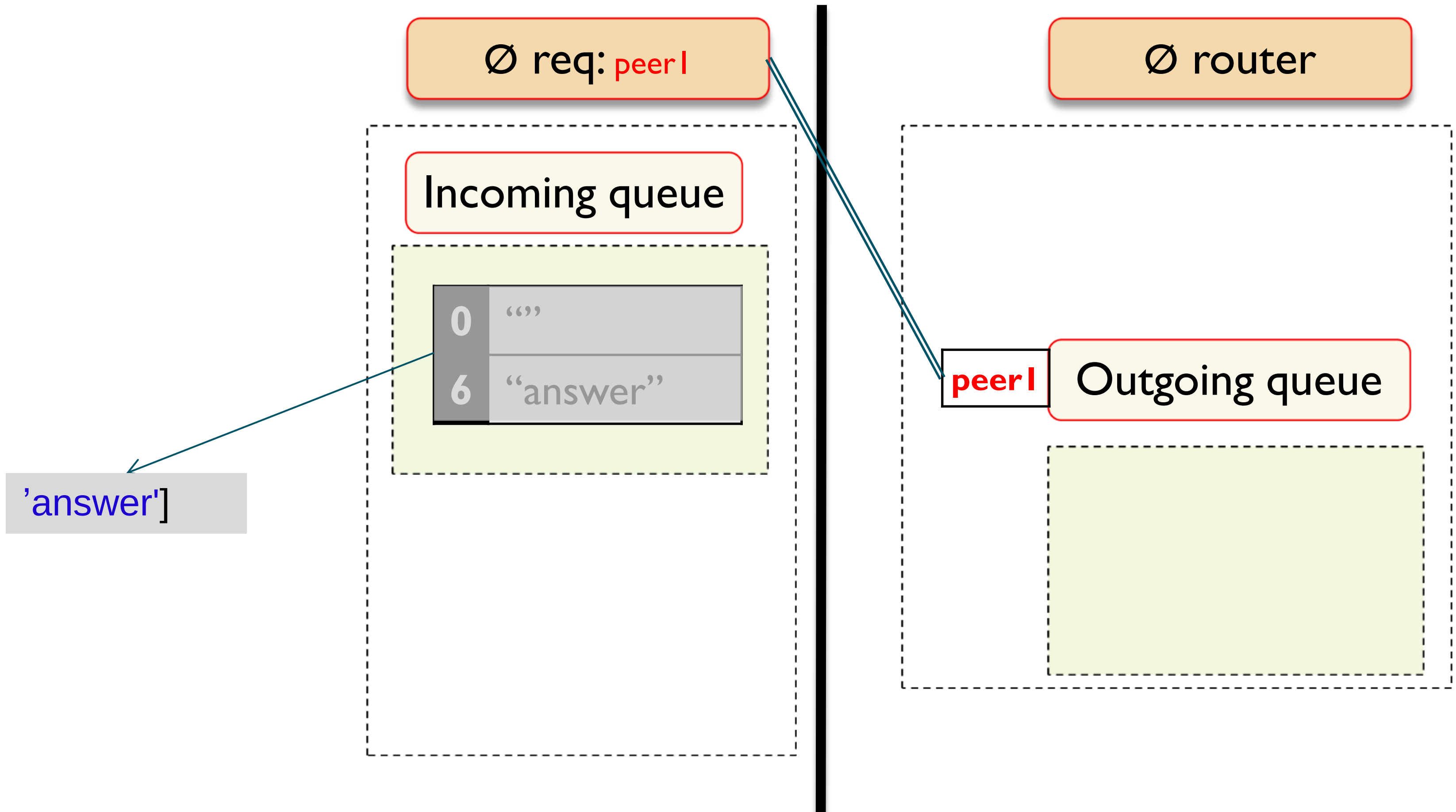
4.4.2. Router sockets: example req peer

- Router socket strips the identity segment
  - Leaves the rest of the message for sending…and sends it



4.4.2. Router sockets: example req peer

- The req socket gives it to its application
  - Eliminating the delimiter segment



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5. Other Middleware

- Event management
  - Often included in messaging systems
    - PUB-SUB pattern
  - E.g. JINI
- Security
  - Authentication
    - A third party warrants the identity of a party
    - E.g. OpenID
  - Authorization
    - A third party authorizes a request
    - E.g. OAuth
  - Integration with other protocols
    - E.g. SSL/TLS and HTTPS
- Transactional support
  - Coordination of distributed atomic state change
    - Fault resilient

Index

6. Conclusions

- DS complexity needs support of code + services
- Standards simplify by making approaches familiar
- Middleware implements common solutions to problems
  - As layers below application code and above communications
- Main middleware target
  - Communication tasks
  - Service request
- Main approaches
  - Messaging
    - Transient/Persistent
    - Broker-based/Brokerless
- Other Middleware
  - Security
  - Transactions

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7. References

- http://zguide.zeromq.org/page:all
  - Can be read online.
  - Has a PDF version
  - The site contains additional information