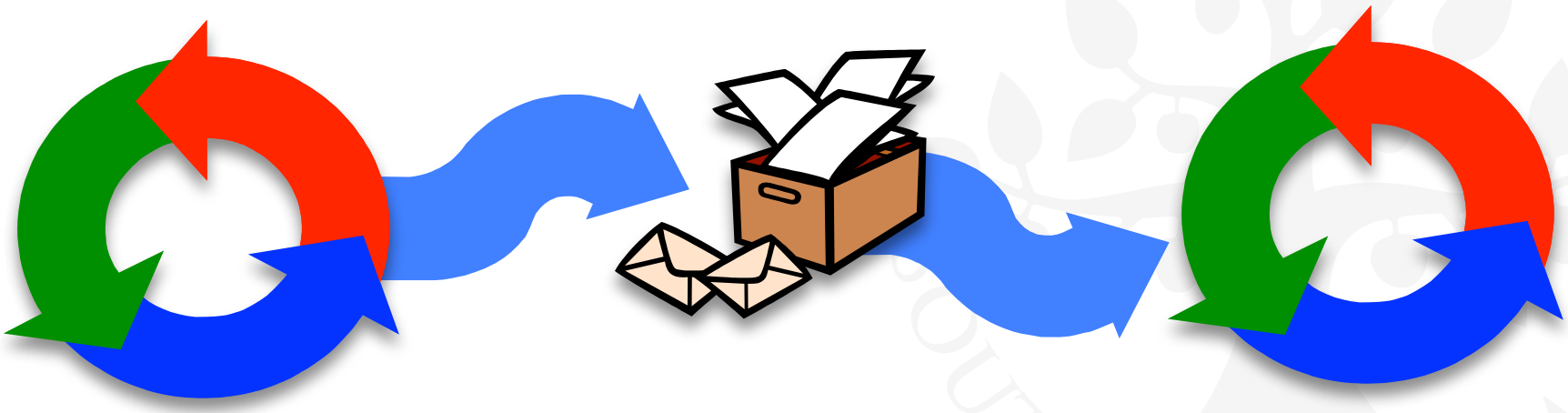
Message Passing



Absence Of Shared Memory

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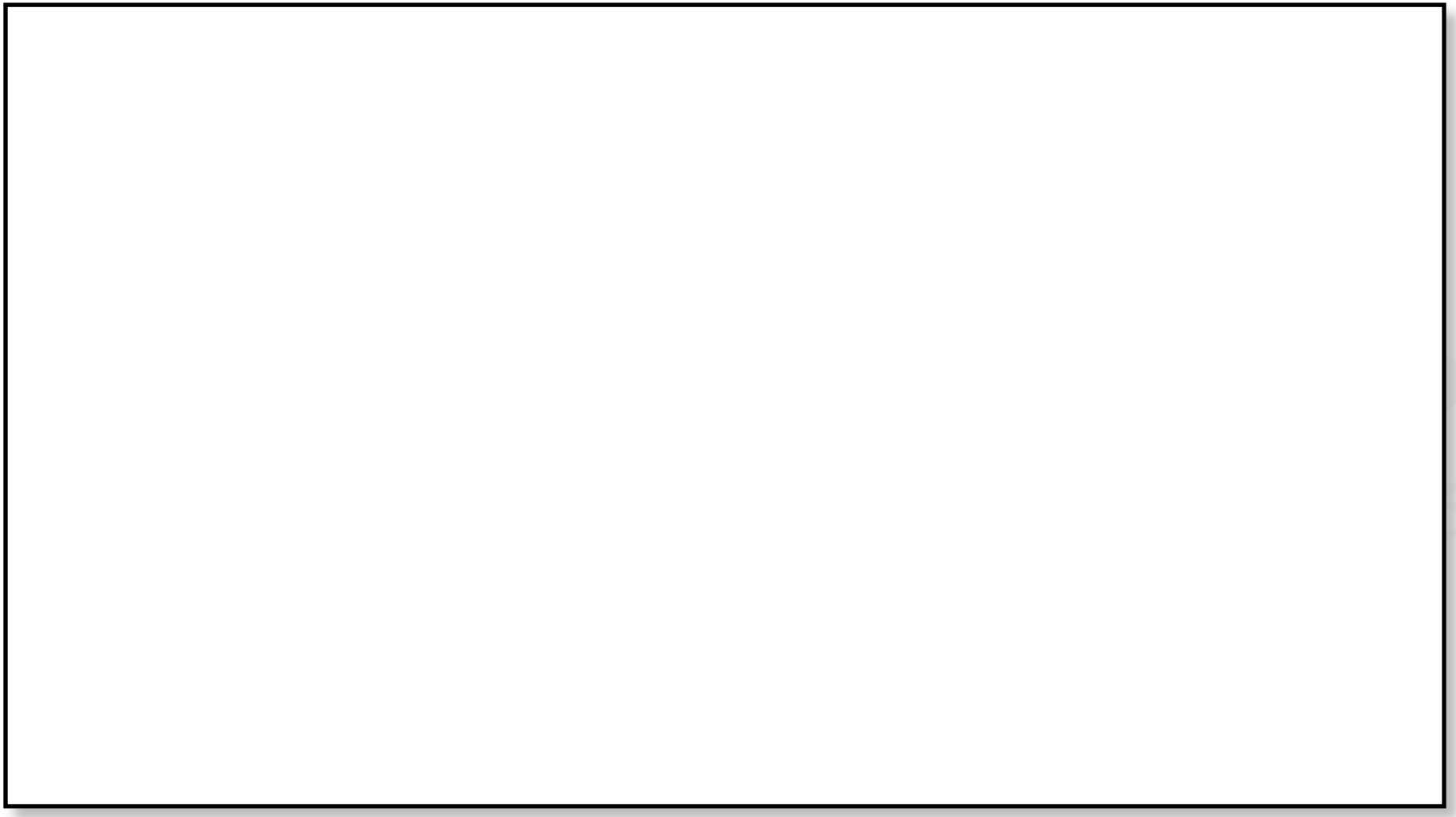
In previous lectures interaction between threads has been via shared memory

- In Java, we refer to shared objects.
- Usually encapsulate shared memory in Monitors.

In a distributed setting there is no shared memory

- Communication is achieved via passing messages between concurrent threads.
- Same message passing abstraction can also be used in non-distributed settings.

Message Passing



Message Passing

Concepts: synchronous message passing - channel

Message Passing

Concepts: synchronous message passing - channel

asynchronous message passing - port

- send and receive / selective receive

Message Passing

Concepts: **synchronous** message passing - **channel**

asynchronous message passing - **port**

- send and receive / selective receive

rendezvous bidirectional comm. - **entry**

- call and accept ... reply

Message Passing

Concepts: **synchronous** message passing - **channel**
asynchronous message passing - **port**
- send and receive / selective receive
rendezvous bidirectional comm. - **entry**
- call and accept ... reply

Models:

channel	: relabelling, choice & guards
port	: message queue, choice & guards
entry	: port & channel

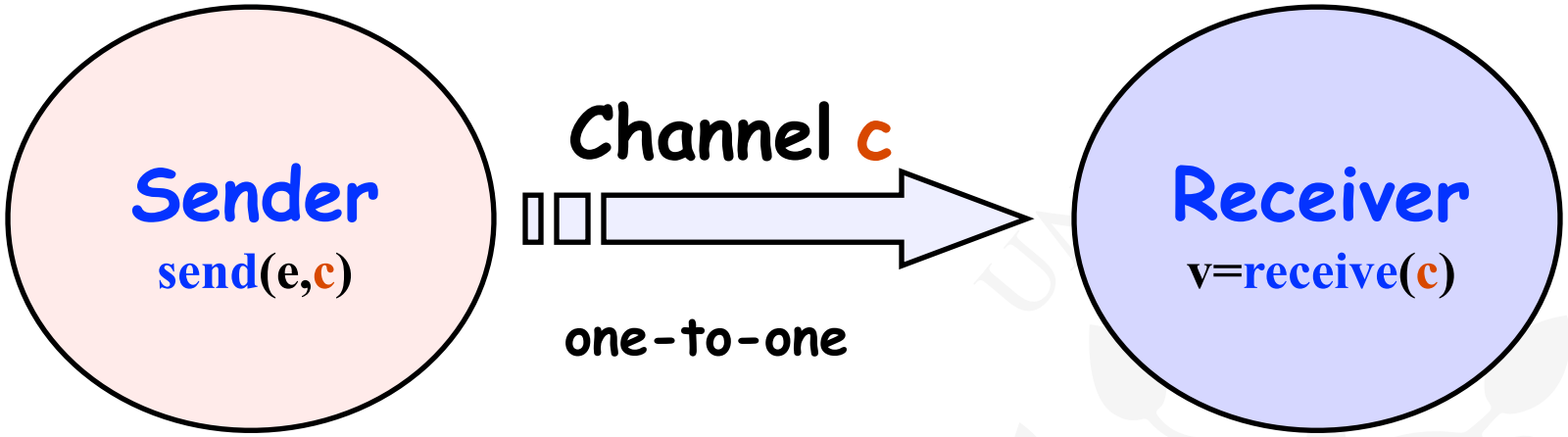
Message Passing

Concepts: **synchronous** message passing - **channel**
asynchronous message passing - **port**
- send and receive / selective receive
rendezvous bidirectional comm. - **entry**
- call and accept ... reply

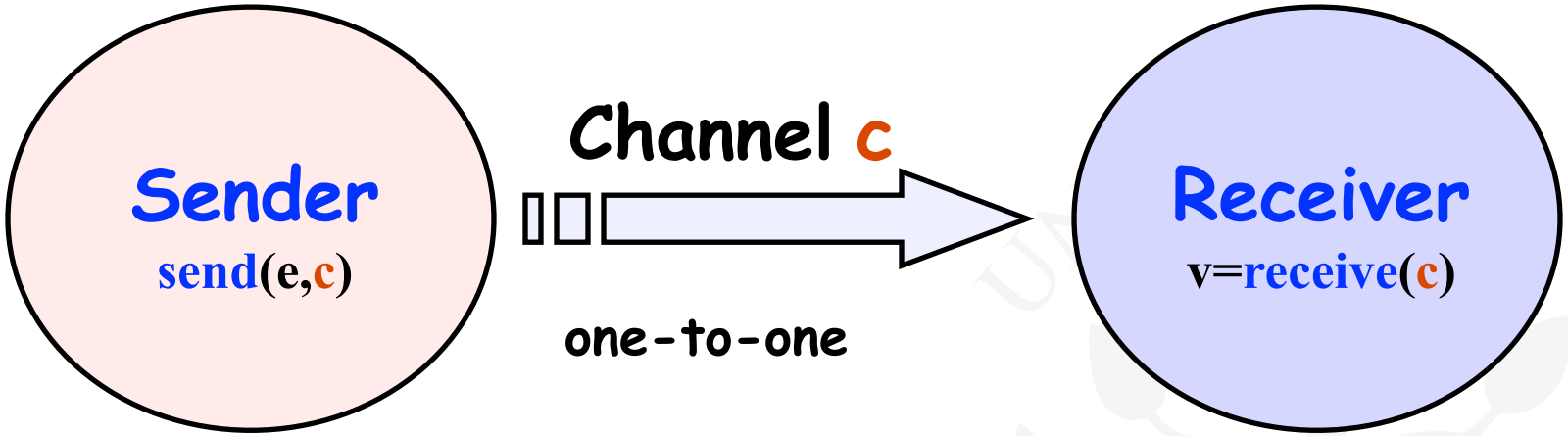
Models:
channel : relabelling, choice & guards
port : message queue, choice & guards
entry : port & channel

Practice: distributed computing (disjoint memory)
threads and monitors (shared memory)

10.1 Synchronous Message Passing - Channel



10.1 Synchronous Message Passing - Channel



- **send(e,c)** - send e to channel c. The sender is **blocked** until the message is received from the channel.

- ***v* = receive(*c*)** - receive a value into local variable v from channel c. The calling process is **blocked** until a message is sent to the channel.

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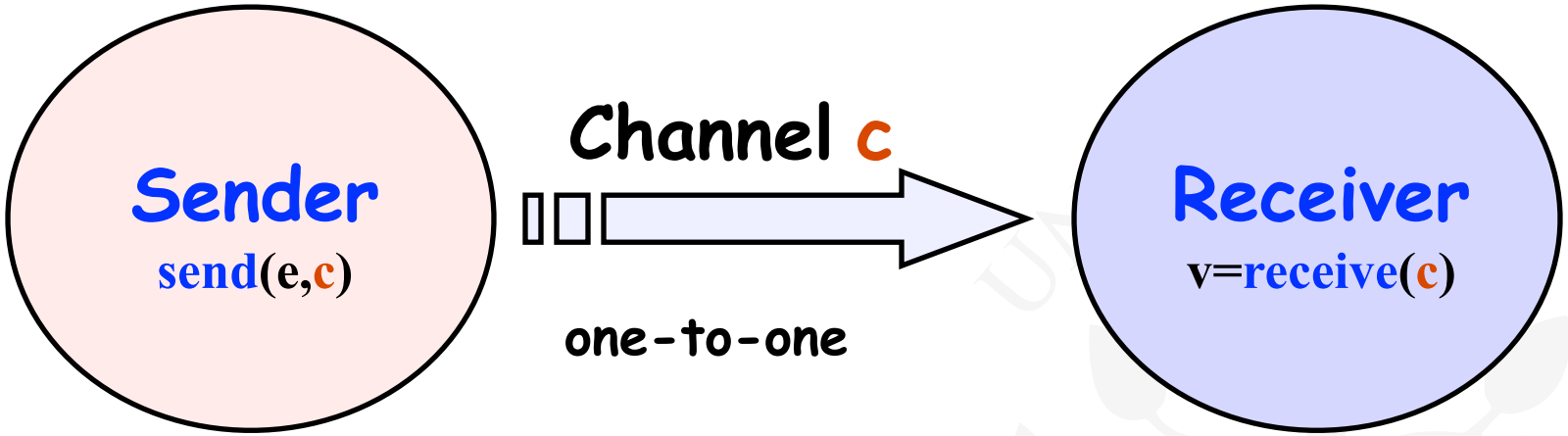


- **send(e,c)** - send e to channel c. The sender is **blocked** until the message is received from the channel.

- ***v* = receive(*c*)** - receive a value into local variable v from channel c. The calling process is **blocked** until a message is sent to the channel.

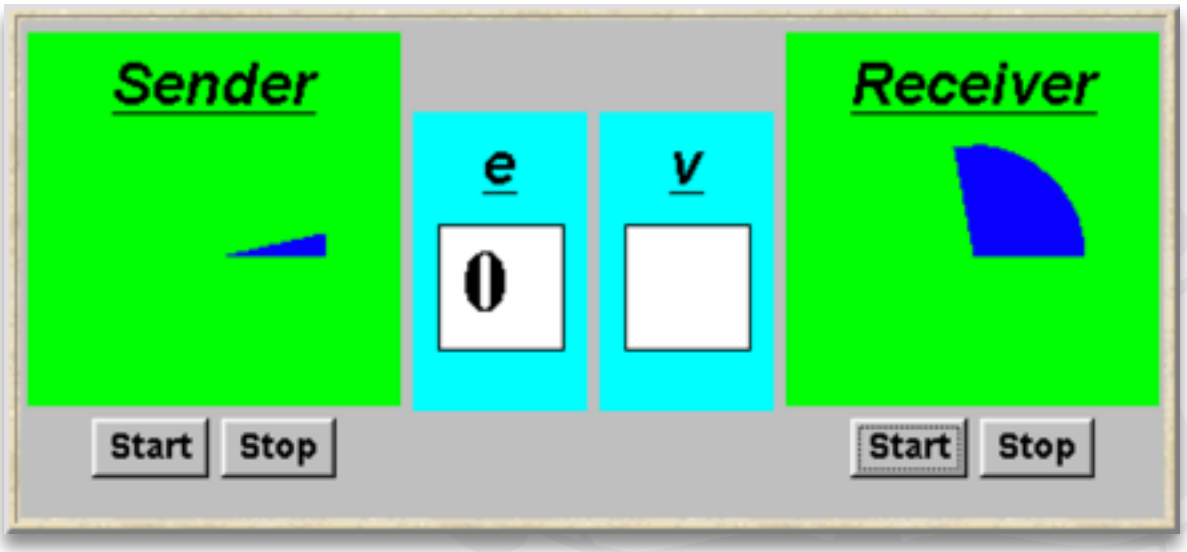
Channel has no buffering

Corresponds to "v = e"

Synchronous Message Passing - Applet

A sender communicates with a receiver using a single channel.

The sender sends a sequence of integer values from 0 to 9 and then restarts at 0 again.



Synchronous Message Passing - Applet

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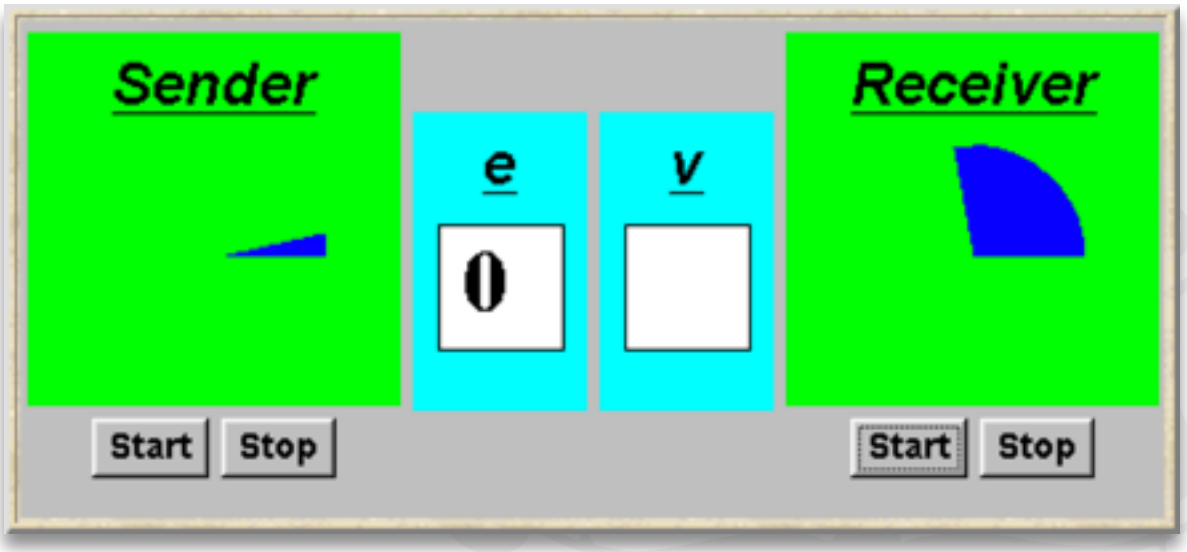


```
Channel<Integer> chan = new Channel<Integer>();
tx.start(new Sender(chan,senddisp));
rx.start(new Receiver(chan,recvdisp));
```

Instances of `ThreadPanel`

Instances of `SlotCanvas`

Synchronous Message Passing In Java

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Java has no built in message passing primitives

- Unlike Occam, Erlang, or Ada.

Can still do message passing in Java, but it's clunky:

- Encapsulate message passing abstractions in monitor Channel:

Synchronous Message Passing In Java

Java has no built in message passing primitives

- Unlike Occam, Erlang, or Ada.

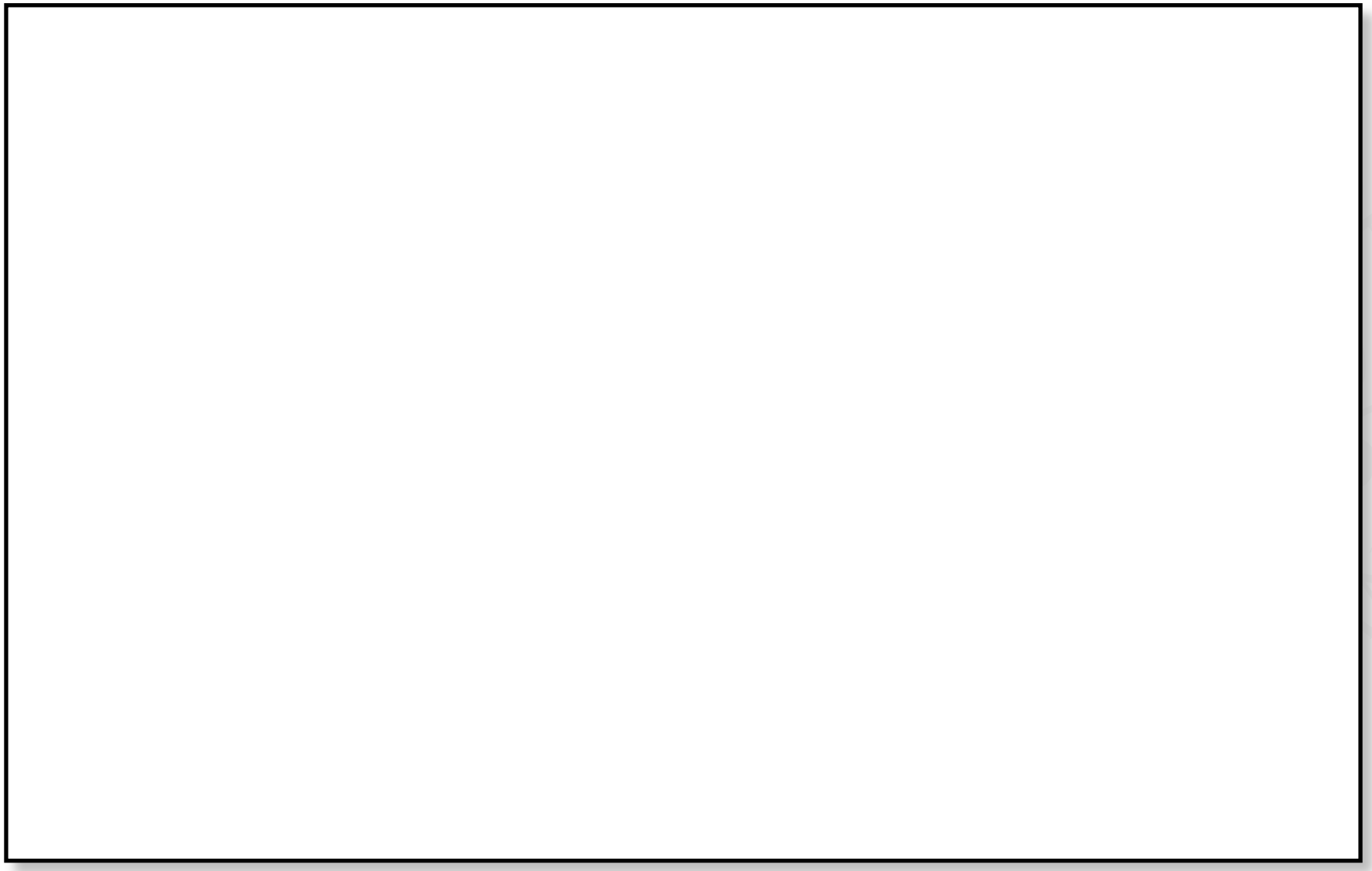
Can still do message passing in Java, but it's clunky:

- Encapsulate message passing abstractions in monitor Channel:

```
class Channel<T> extends Selectable {
   public synchronized void send(T v)
      throws InterruptedException{...}

   public synchronized T receive() {...}
}
```

Java Implementation - Channel



Java Implementation - Channel


```
public class Channel<T> extends Selectable {
 T chan_ = null;
```

Channel is a monitor that has synchronized access methods for send and receive.

Java Implementation - Channel


```
public class Channel<T> extends Selectable {
 T chan_ = null;

   public synchronized void send(T v)
          throws InterruptedException {
     chan_ = v;
     signal();
     while (chan_ != null) wait();
  }
```

Channel is a monitor that has synchronized access methods for send and receive.

Java Implementation - Channel


```
public class Channel<T> extends Selectable {
 T chan_ = null;

   public synchronized void send(T v)
          throws InterruptedException {
     chan_ = v;
     signal();
     while (chan_ != null) wait();
   }

   public synchronized T receive()
          throws InterruptedException {
     block(); clearReady();   // part of Selectable
     T tmp = chan_; chan_ = null;
     notifyAll();             // could be notify()
     return(tmp);
   }
}
```

Channel is a monitor that has synchronized access methods for send and receive.

Selectable is described later.

Java Implementation - Sender


```
class Sender implements Runnable {
  private Channel<Integer> chan;
  private SlotCanvas display;
  Sender(Channel<Integer> c, SlotCanvas d)
    {chan=c; display=d;}

  public void run() {
    try { int ei = 0;
          while(true) {
            display.enter(String.valueOf(ei));
            ThreadPanel.rotate(12);
            chan.send(new Integer(ei));
            display.leave(String.valueOf(ei));
            ei=(ei+1)%10; ThreadPanel.rotate(348);
          }
    } catch (InterruptedException e){}
  }
}
```

Java Implementation - Receiver


```
class Receiver implements Runnable {
  private Channel<Integer> chan;
  private SlotCanvas display;
  Receiver(Channel<Integer> c, SlotCanvas d)
    {chan=c; display=d;}

  public void run() {
    try { Integer v=null;
          while(true) {
            ThreadPanel.rotate(180);
            if (v!=null) display.leave(v.toString());
            v = chan.receive();
            display.enter(v.toString());
            ThreadPanel.rotate(180);
          }
    } catch (InterruptedException e){}
  }
}
```

Model

Model


```
range M = 0..9                  // messages with values up to 9

SENDER = SENDER[0],             // shared channel chan
SENDER[e:M] = (chan.send[e]-> SENDER[(e+1)%10]).

RECEIVER = (chan.receive[v:M]-> RECEIVER).
```

Model


```
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                                // relabeling to model synchronization
||SyncMsg = (SENDER || RECEIVER)
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```

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LTS?

Model


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LTS?

How could this be modeled directly without the need for relabeling?

message operation	FSP model
send(e,chan)	?
v = receive(*chan*)	?

Model


```
range M = 0..9                  // messages with values up to 9

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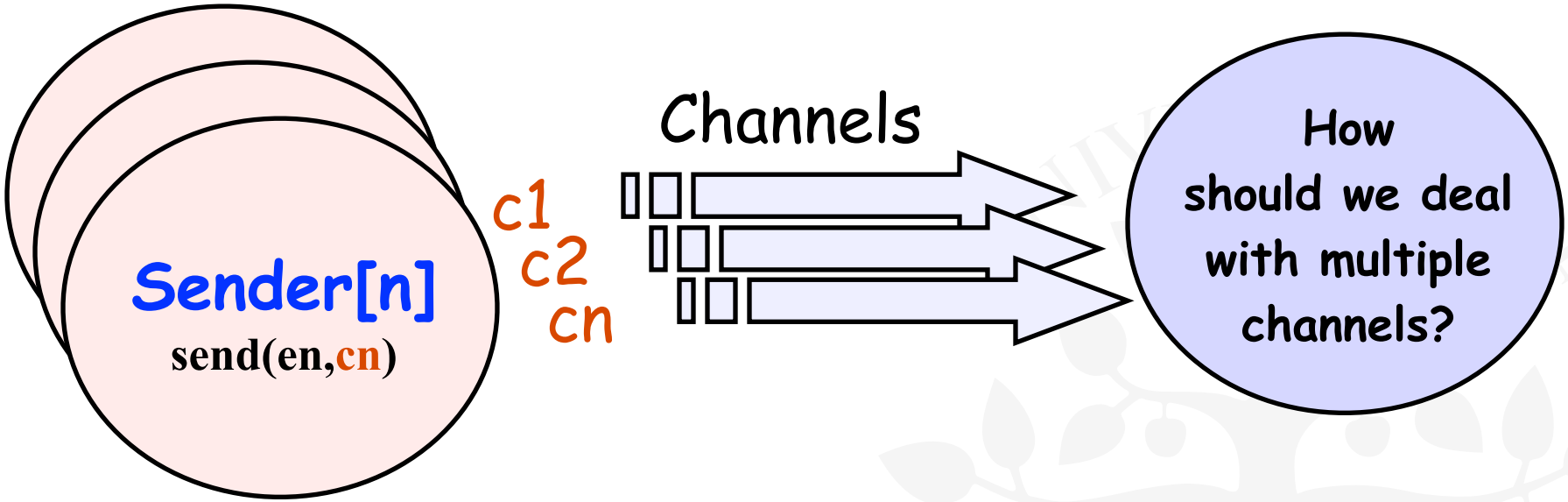
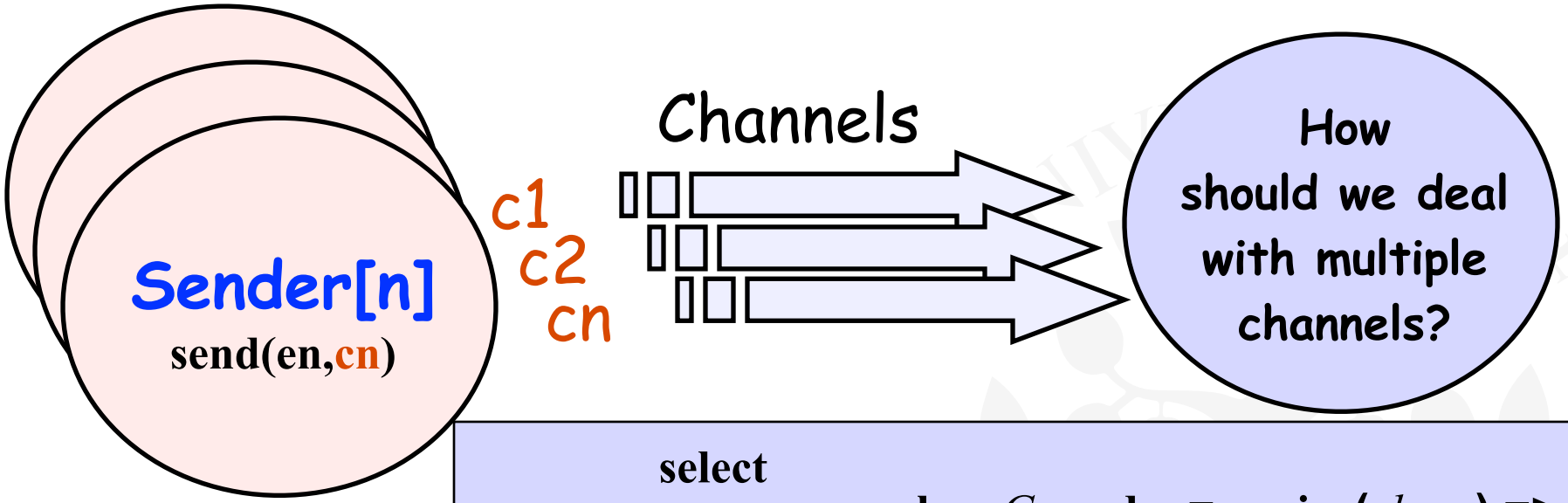
Selective Receive



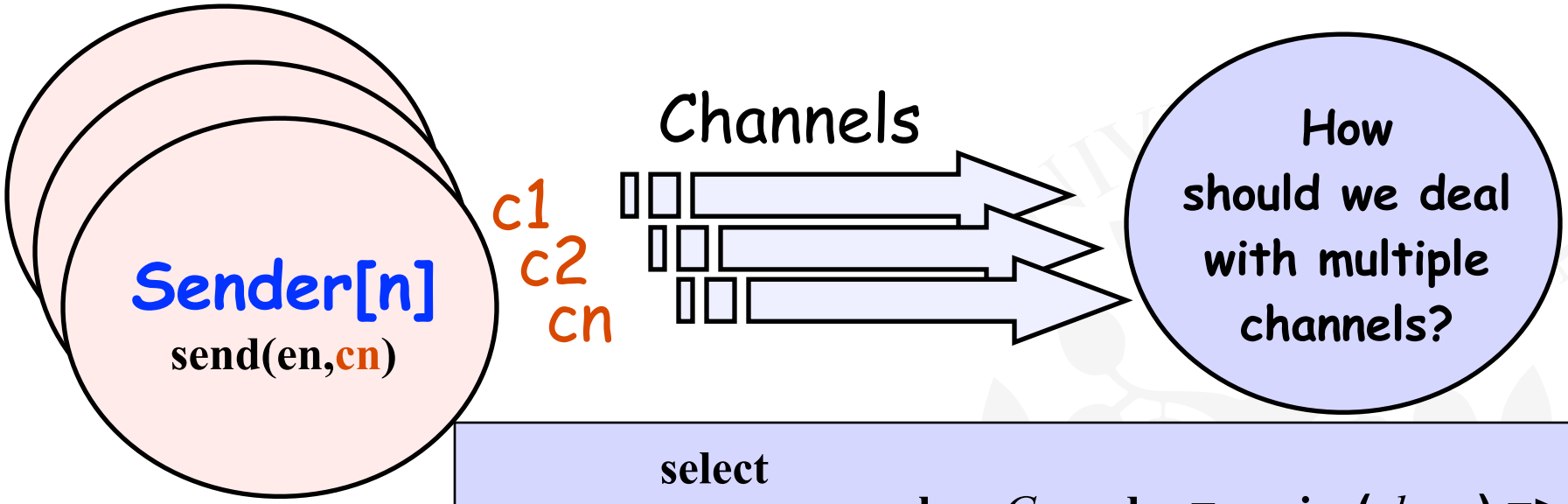
Selective Receive



Select statement...

```
select
        when G1 and v1=receive(chan1) => S1;
  or
        when G2 and v2=receive(chan2) => S2;
  or
        ...
  or
        when Gn and vn=receive(chan_n) => Sn;
  end
```

Selective Receive



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  or
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end
```
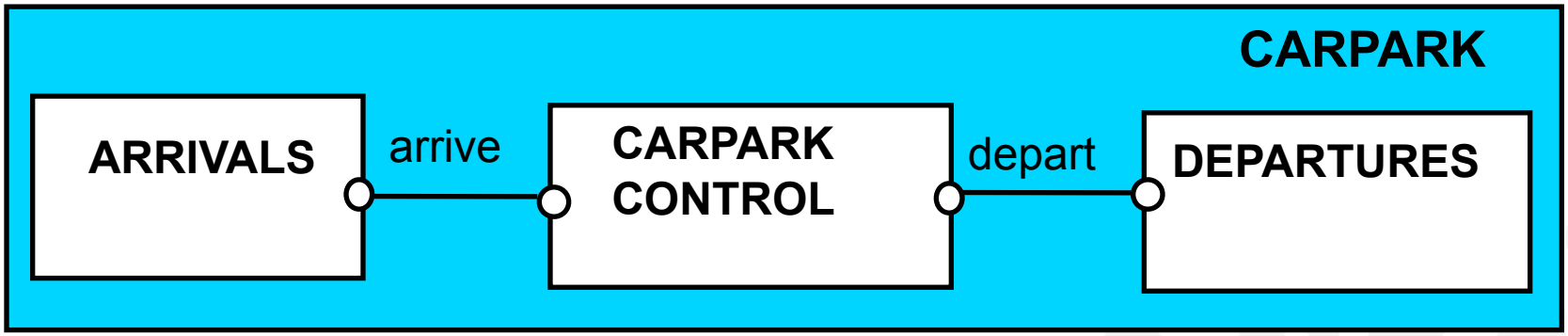
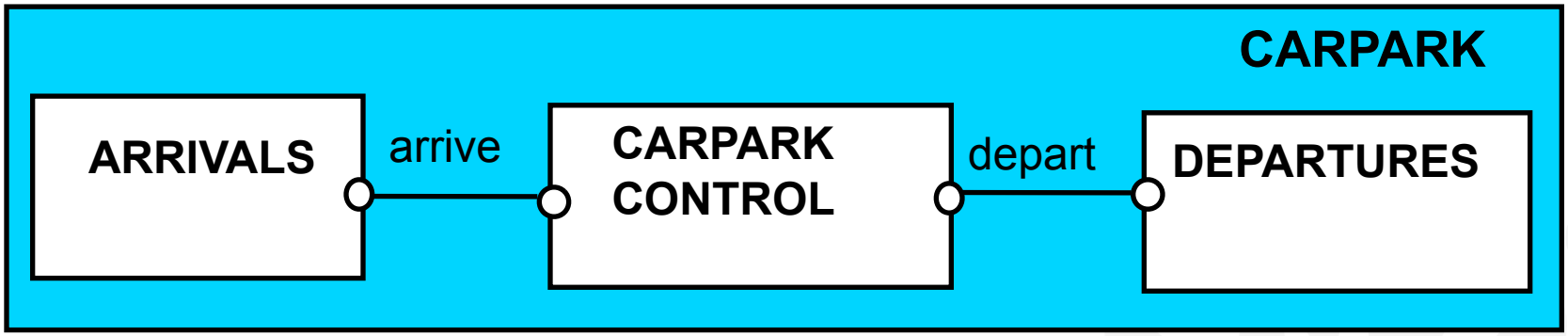

How would we model this in FSP?

Example: Selective Receive




```
CARPARKCONTROL(N=4) = SPACES[N],
SPACES[i:0..N] = (when(i>0) arrive->SPACES[i-1]
                 |when(i<N) depart->SPACES[i+1]
                 ).

ARRIVALS   = (arrive->ARRIVALS).
DEPARTURES = (depart->DEPARTURES).

||CARPARK = (ARRIVALS||CARPARKCONTROL(4)
                      ||DEPARTURES).
```

Example: Selective Receive

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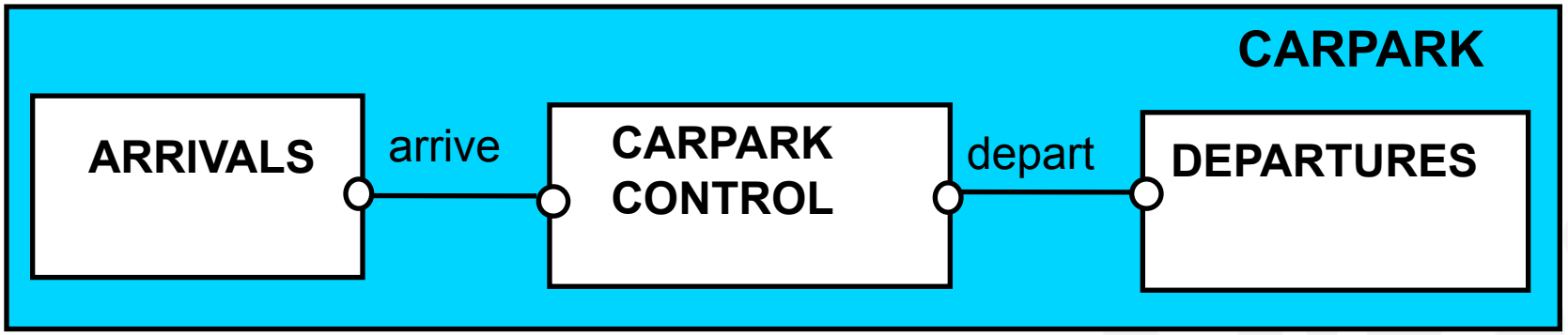
```

Interpret as channels

Example: Selective Receive

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||CARPARK = (ARRIVALS||CARPARKCONTROL(4)
                      ||DEPARTURES).
```

Interpret as channels

Implementation using message passing?

Java Implementation - Selective Receive


```
class MsgCarPark implements Runnable {
  private Channel<Signal> arrive, depart;
  private int spaces, N;
  private StringCanvas disp;

  public MsgCarPark(Channel<Signal> a,
                    Channel<Signal> l,
                   StringCanvas d,int capacity) {
    depart=l; arrive=a; N=spaces=capacity; disp=d;
  }
  …
  public void run() {…}
}
```

Java Implementation - Selective Receive


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class MsgCarPark implements Runnable {
  private Channel<Signal> arrive, depart;
  private int spaces, N;
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  public MsgCarPark(Channel<Signal> a,
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    depart=l; arrive=a; N=spaces=capacity; disp=d;
  }
  …
  public void run() {…}
}
```

Implement CARPARKCONTROL as a thread MsgCarPark which receives signals from channels arrive and depart.

Java Implementation - Selective Receive


```
public void run() {
    try {
      Select sel = new Select();
      sel.add(depart);
      sel.add(arrive);
      while(true) {
        ThreadPanel.rotate(12);
        arrive.guard(spaces>0);
        depart.guard(spaces<N);
        switch (sel.choose()) {
        case 1:depart.receive();display(++spaces);
               break;
        case 2:arrive.receive();display(--spaces);
               break;
        }
      }
    } catch InterrruptedException{}
  }
```

Java Implementation - Selective Receive


```
public void run() {
    try {
      Select sel = new Select();
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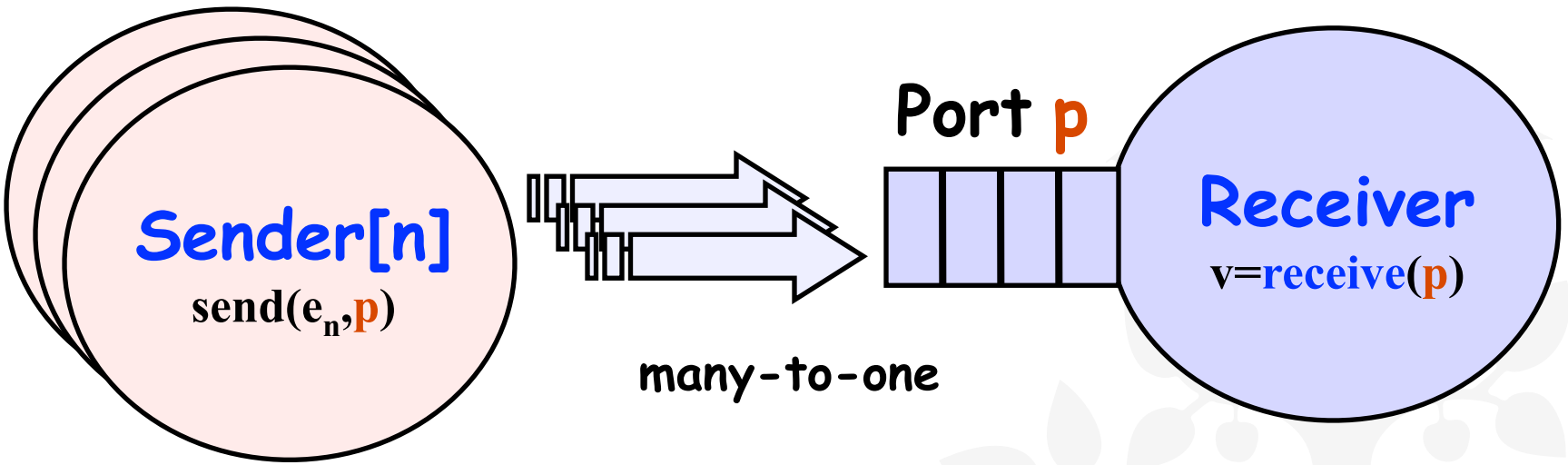
See applet

10.2 Asynchronous Message Passing - Port



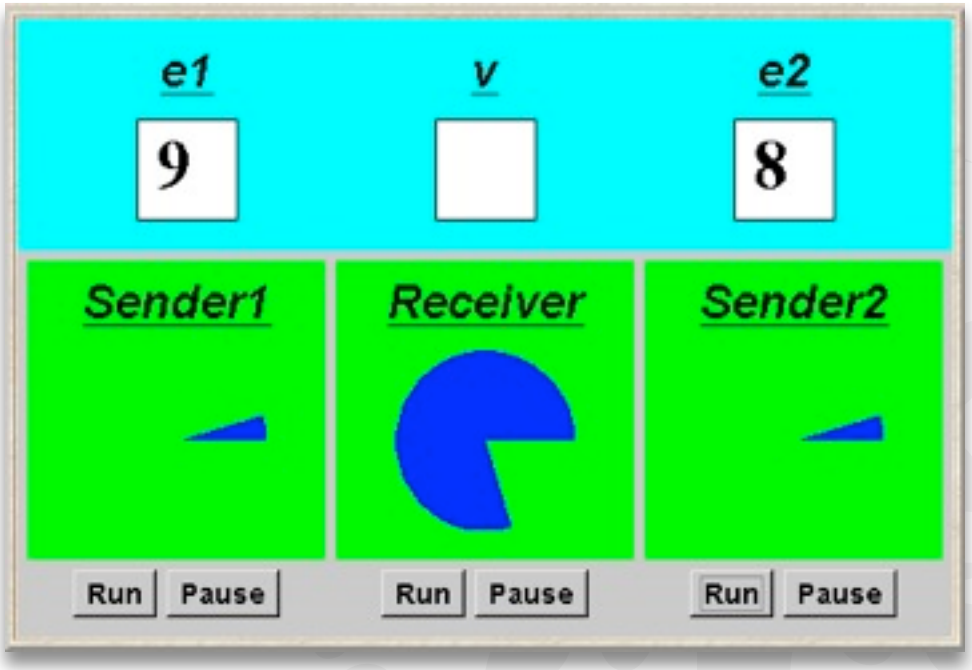
- **send(e,p)** - send e to port p. The calling process is **not blocked**. The message is queued at the port if the receiver is not waiting.

- ***v* = receive(*p*)** - receive a value into local variable v from port p. The calling process is **blocked** if no messages queued to the port.

Asynchronous Message Passing - Applet

Two senders communicate with a receiver via an "unbounded" port.

Each sender sends a sequence of integer values from 0 to 9 and then restarts at 0 again.



Asynchronous Message Passing - Applet

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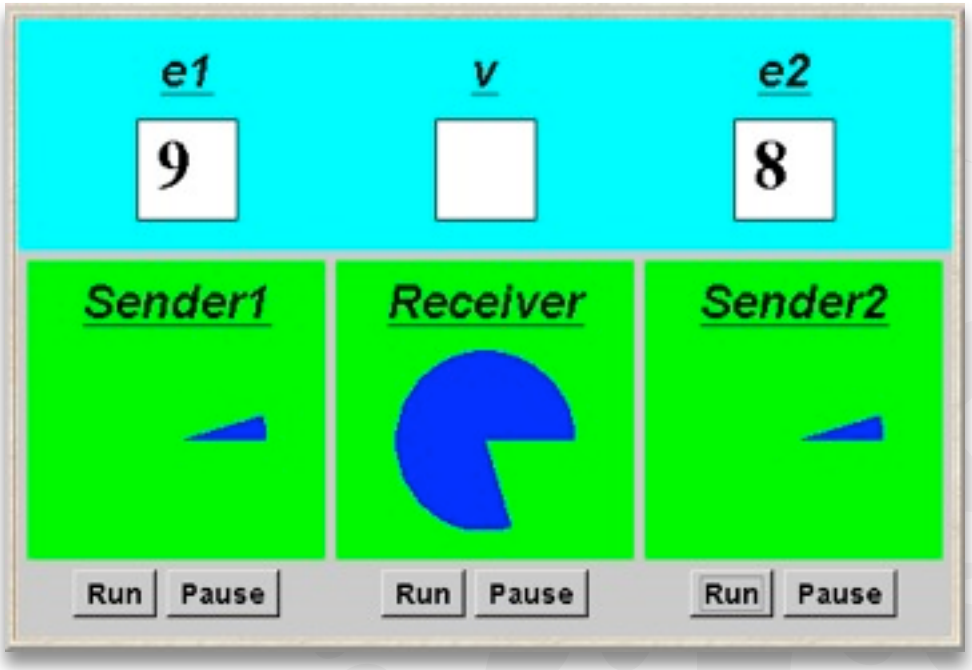
Each sender sends a sequence of integer values from 0 to 9 and then restarts at 0 again.

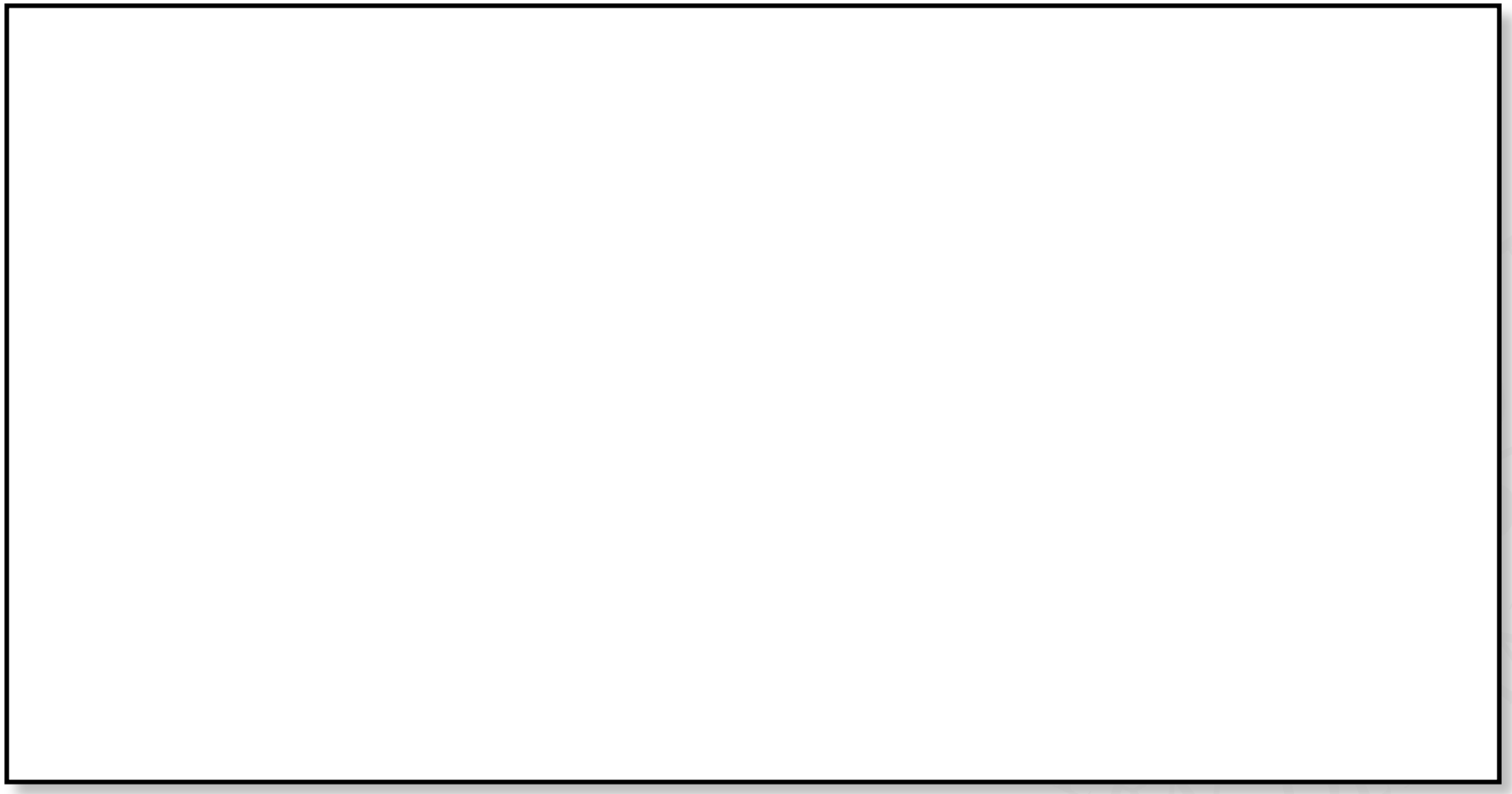



```
Port<Integer> port = new Port<Integer> ();
tx1.start(new Asender(port,send1disp));
tx2.start(new Asender(port,send2disp));
rx.start(new Areceiver(port,recvdisp));
```

Instances of ThreadPanel

Instances of SlotCanvas

Java Implementation - Port



Java Implementation - Port


```
class Port<T> extends Selectable {
```

The implementation of `Port` is a monitor that has synchronized access methods for send and receive.

Java Implementation - Port


```
class Port<T> extends Selectable {

 Queue<T> queue = new LinkedList<T>();
```

The implementation of `Port` is a monitor that has synchronized access methods for send and receive.

Java Implementation - Port


```
class Port<T> extends Selectable {

 Queue<T> queue = new LinkedList<T>();

   public synchronized void send(T v){
      queue.add(v);
      signal();
  }
```

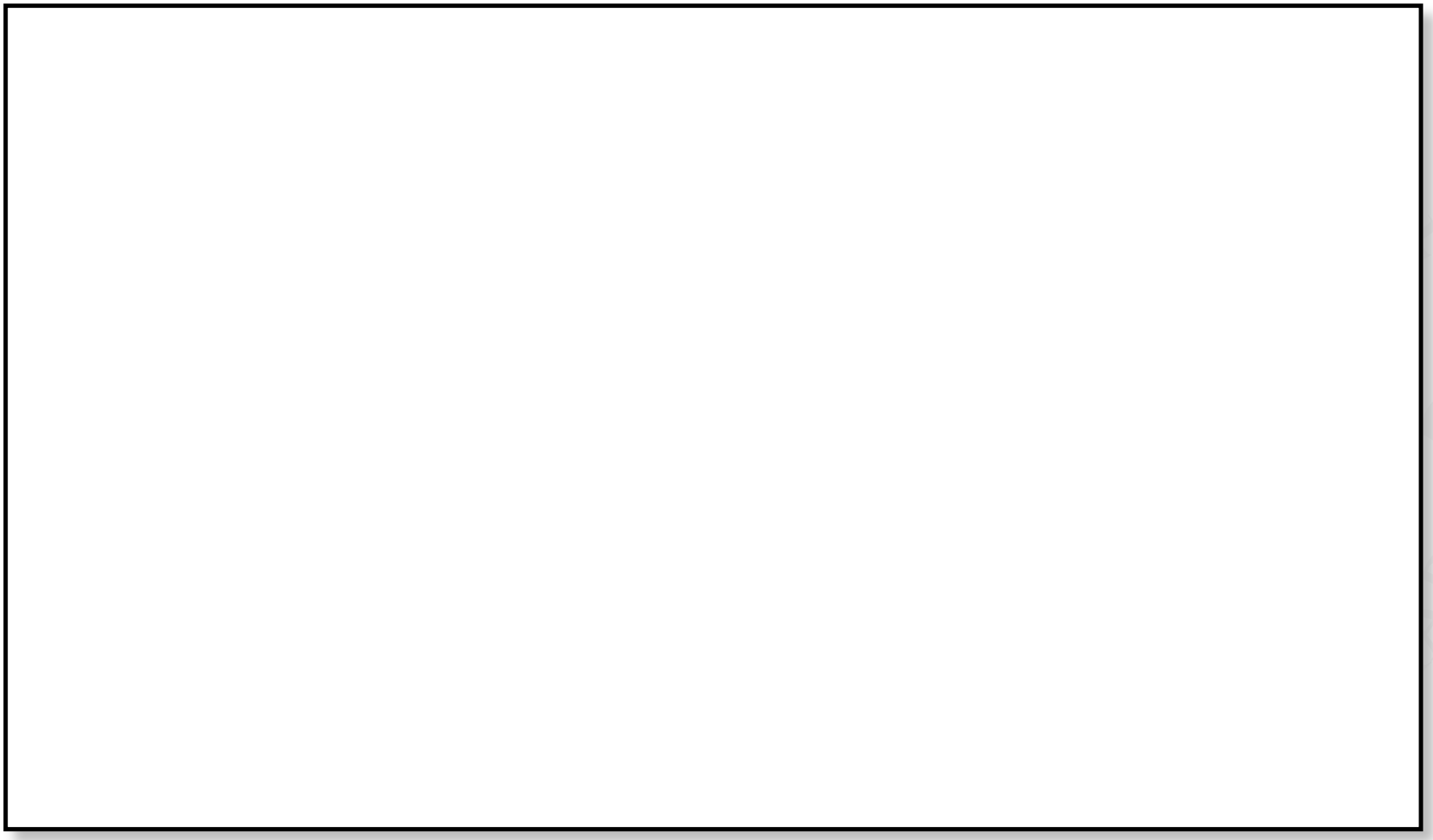
The implementation of `Port` is a monitor that has synchronized access methods for send and receive.

Java Implementation - Port


```
class Port<T> extends Selectable {

 Queue<T> queue = new LinkedList<T>();

   public synchronized void send(T v){
      queue.add(v);
      signal();
   }

   public synchronized T receive()
            throws InterruptedException {
      block(); clearReady();
      return queue.remove();
   }
}
```

The implementation of `Port` is a monitor that has synchronized access methods for send and receive.

Port FSP Model



Port FSP Model


```
range M = 0..9                  // messages with values up to 9
set   S = {[M],[M][M]}          // queue of up to three messages
```

Port FSP Model


```
range M = 0..9                  // messages with values up to 9
set   S = {[M],[M][M]}          // queue of up to three messages

PORT                            // empty state, only send permitted
  = (send[x:M]->PORT[x]),
```

Port FSP Model


```
range M = 0..9                  // messages with values up to 9
set   S = {[M],[M][M]}          // queue of up to three messages

PORT                            // empty state, only send permitted
  = (send[x:M]->PORT[x]),
PORT[h:M]                       // one message queued to port
  = (send[x:M]->PORT[x][h]
    |receive[h]->PORT
    ),
```

Port FSP Model


```
range M = 0..9                  // messages with values up to 9
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    ),
PORT[t:S][h:M]                  // two or more  messages queued to port
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```

Port FSP Model


```
range M = 0..9                  // messages with values up to 9
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    ).

// minimise to see result of abstracting from data values
||APORT = PORT/{send/send[M],receive/receive[M]}.
```

Port FSP Model


```
range M = 0..9                  // messages with values up to 9
set   S = {[M],[M][M]}          // queue of up to three messages

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    ),
PORT[t:S][h:M]                  // two or more  messages queued to port
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    |receive[h]->PORT[t]
    ).

// minimise to see result of abstracting from data values
||APORT = PORT/{send/send[M],receive/receive[M]}.
```
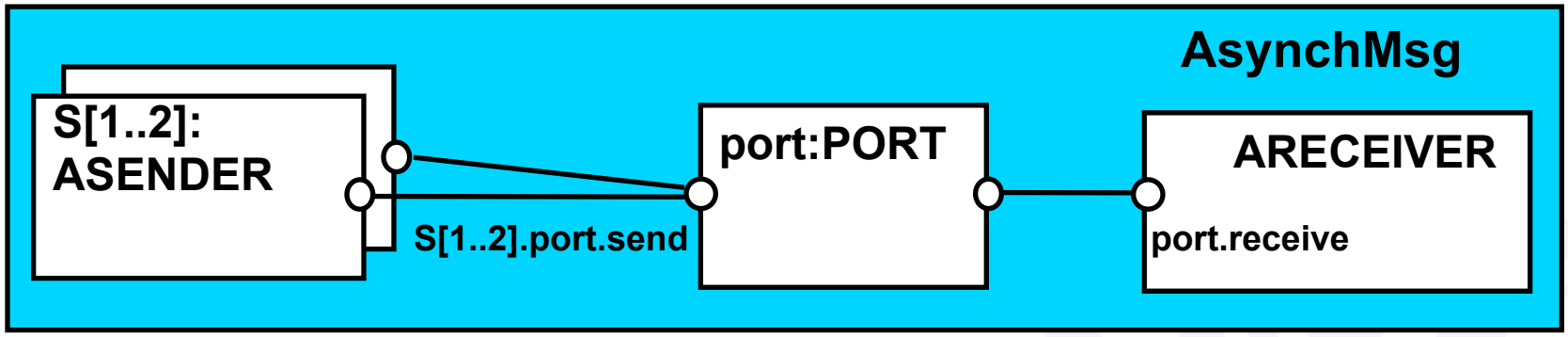

LTS?

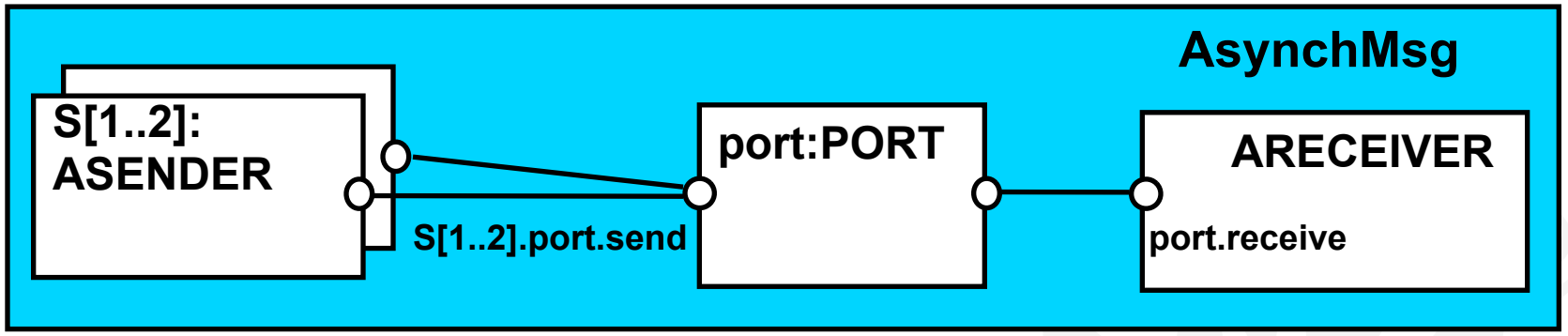
What happens if you send 4 values?

Model Of Applet




```
ASENDER = ASENDER[0],
ASENDER[e:M] = (port.send[e]->ASENDER[(e+1)%10]).

ARECEIVER = (port.receive[v:M]->ARECEIVER).

||AsyncMsg = (s[1..2]:ASENDER || ARECEIVER||port:PORT)
             /{s[1..2].port.send/port.send}.
```

Model Of Applet

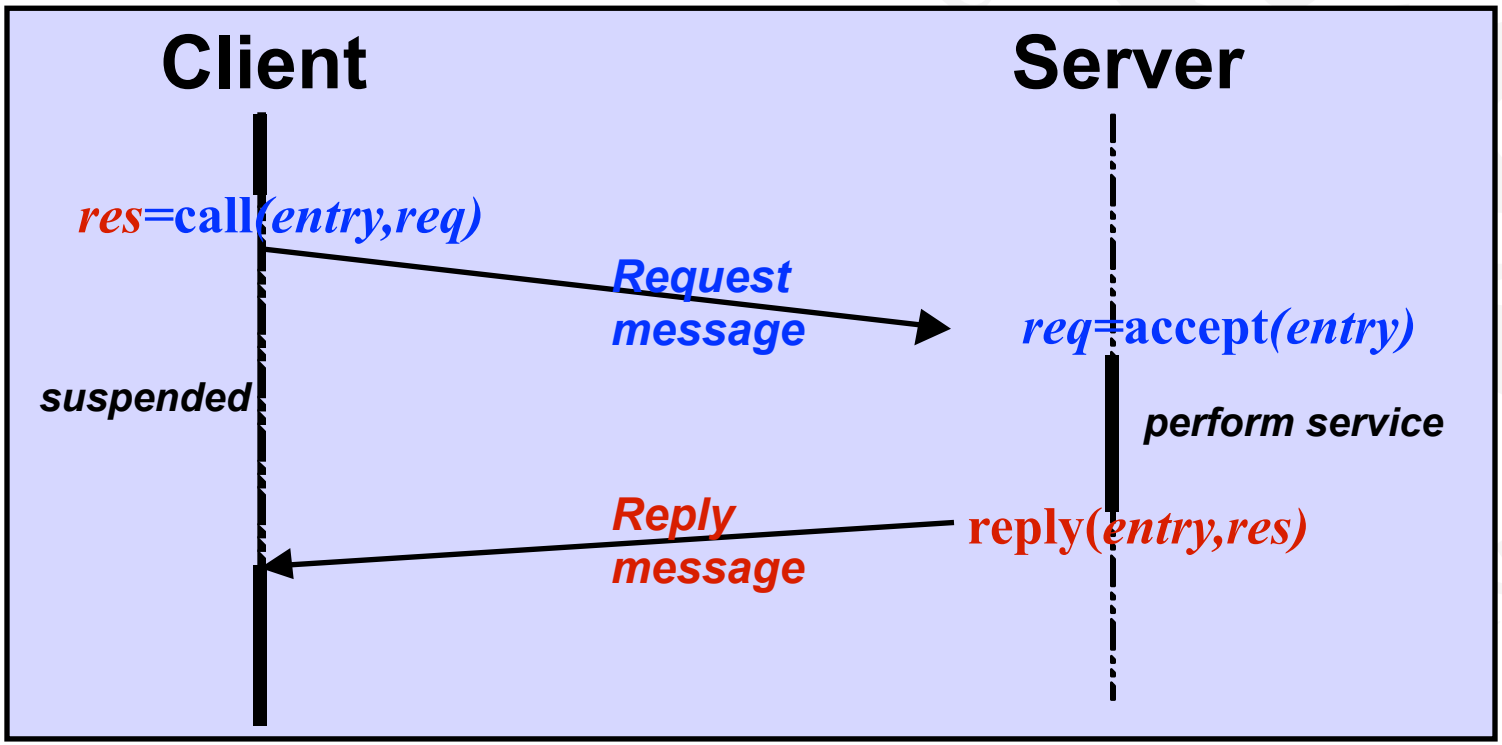



```
ASENDER = ASENDER[0],
ASENDER[e:M] = (port.send[e]->ASENDER[(e+1)%10]).

ARECEIVER = (port.receive[v:M]->ARECEIVER).

||AsyncMsg = (s[1..2]:ASENDER || ARECEIVER||port:PORT)
             /{s[1..2].port.send/port.send}.
```

Safety?

10.3 Rendezvous - Entry

Rendezvous is a form of request-reply to support client server communication. Many clients may request service, but only one is serviced at a time.



Rendezvous

- ***res*=call(*e*,*req*)** - send the value ***req*** as a request message which is queued to the entry ***e***.

- The calling process is **blocked** until a reply message is received into the local variable ***req***.

- ***req*=accept(*e*)** - receive the value of the request message from the entry ***e*** into local variable ***req***. The calling process is **blocked** if there are no messages queued to the entry.

- **reply(*e*,*res*)** - send the value ***res*** as a reply message to entry ***e***.

Rendezvous

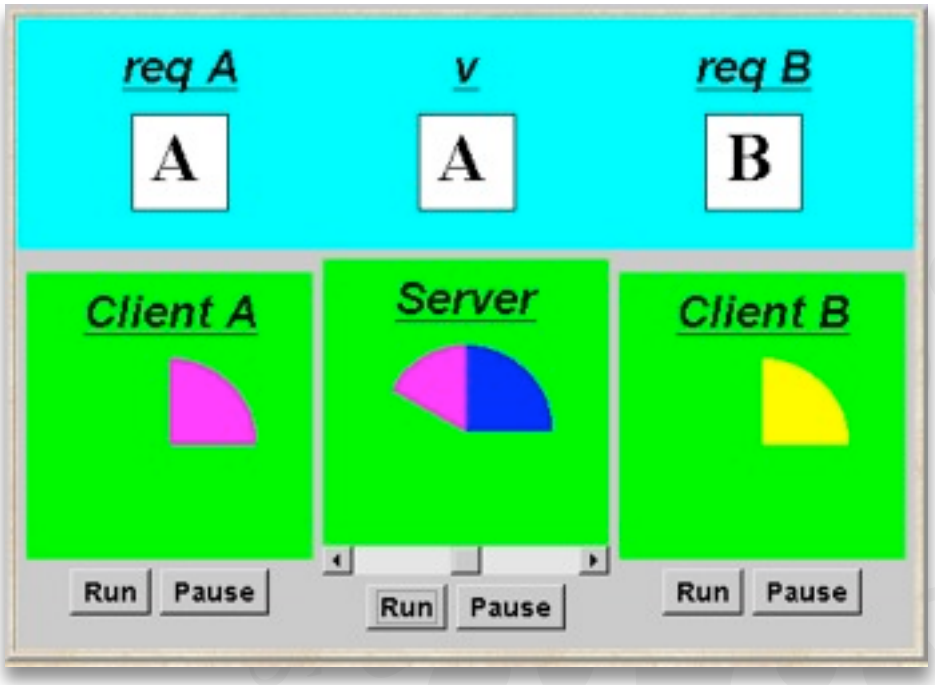
- ***res*=call(*e*,*req*)** - send the value ***req*** as a request message which is queued to the entry ***e***.
- The calling process is **blocked** until a reply message is received into the local variable ***req***.

- ***req*=accept(*e*)** - receive the value of the request message from the entry ***e*** into local variable ***req***. The calling process is **blocked** if there are no messages queued to the entry.
- **reply(*e*,*res*)** - send the value ***res*** as a reply message to entry ***e***.

The model and implementation use a port for one direction and a channel for the other. Which is which?

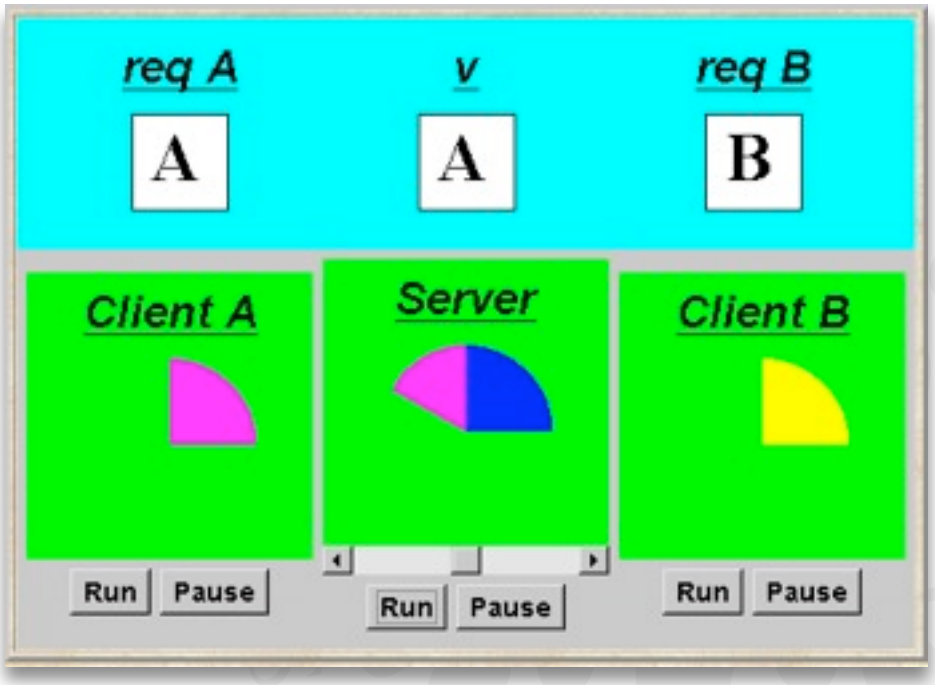
Rendezvous - Applet

Two clients call a server which services a request at a time.



Rendezvous - Applet

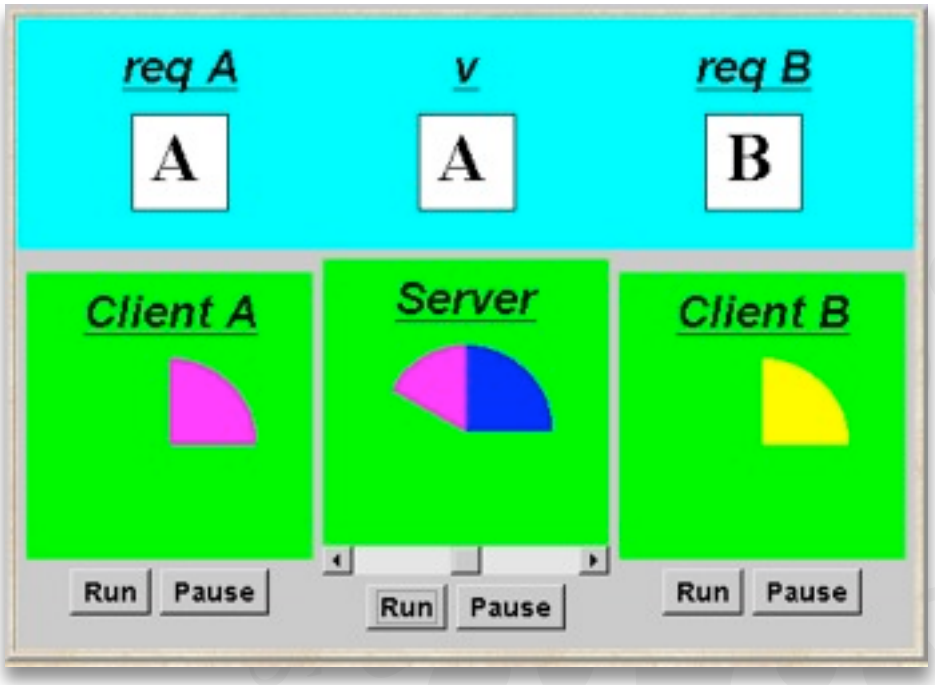
Two clients call a server which services a request at a time.




```
Entry<String,String> entry = new Entry<String,String>();
clA.start(new Client(entry,clientAdisp,"A"));
clB.start(new Client(entry,clientBdisp,"B"));
sv.start(new Server(entry,serverdisp));
```

Rendezvous - Applet

Two clients call a server which services a request at a time.




```
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clA.start(new Client(entry,clientAdisp,"A"));
clB.start(new Client(entry,clientBdisp,"B"));
sv.start(new Server(entry,serverdisp));
```
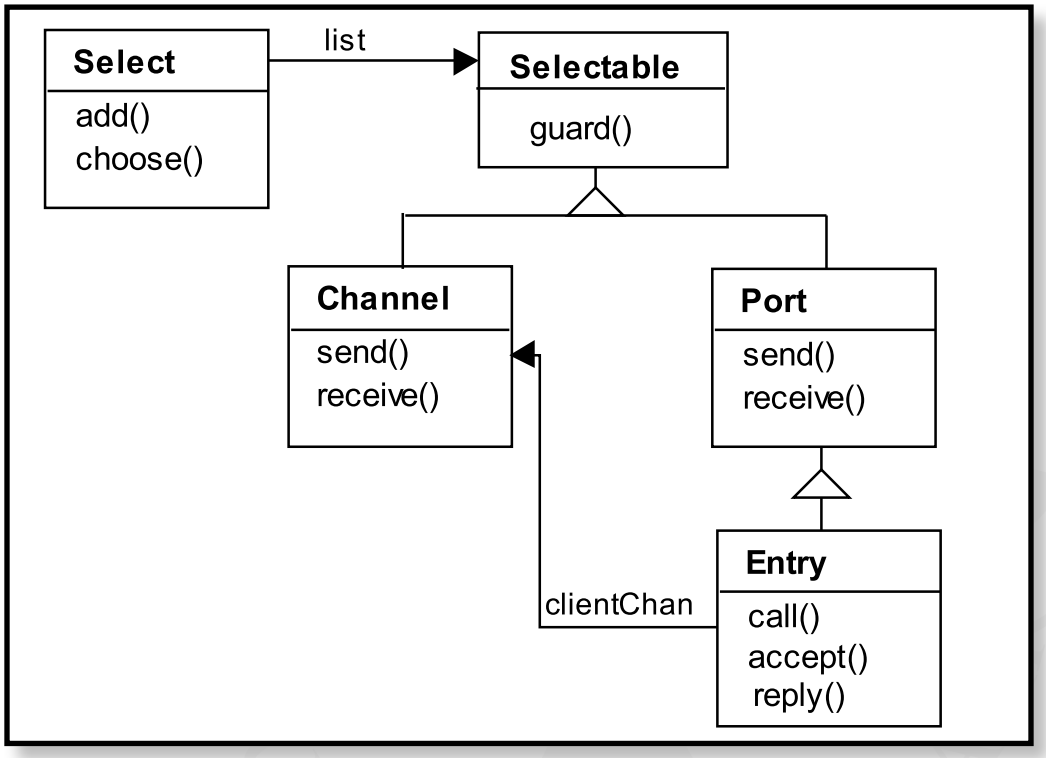

Instances of `ThreadPanel`

Instances of `SlotCanvas`

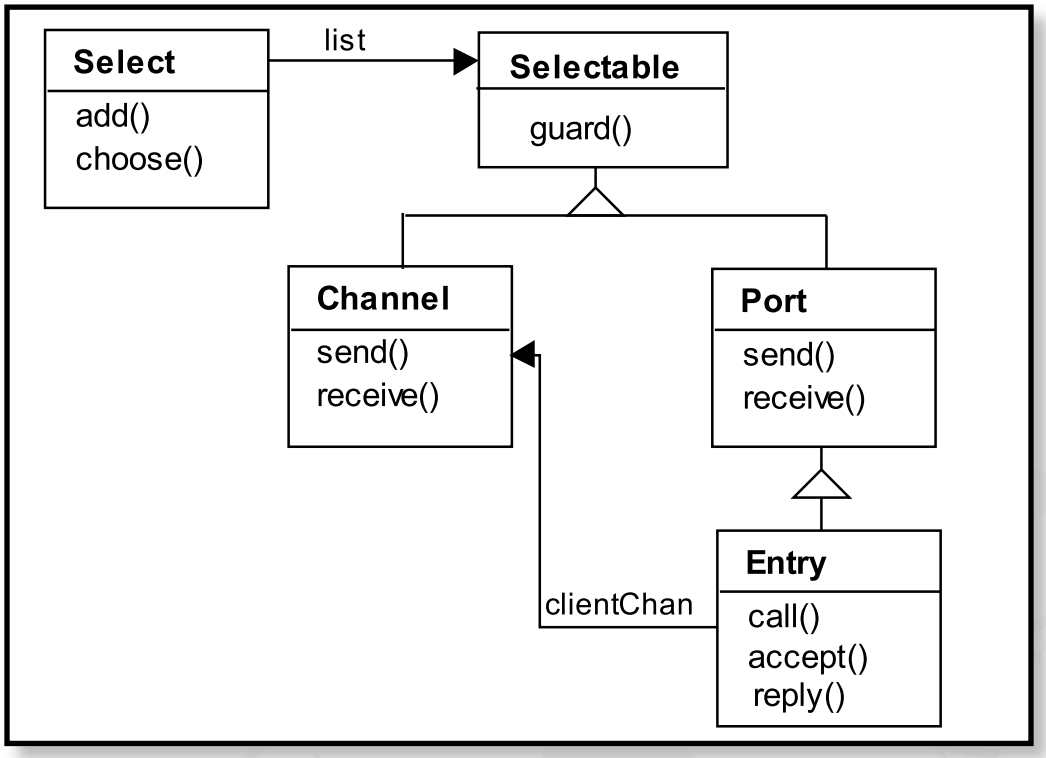
Java Implementation - Entry

Entries: implemented as extensions of ports



Java Implementation - Entry

Entries: implemented as extensions of ports

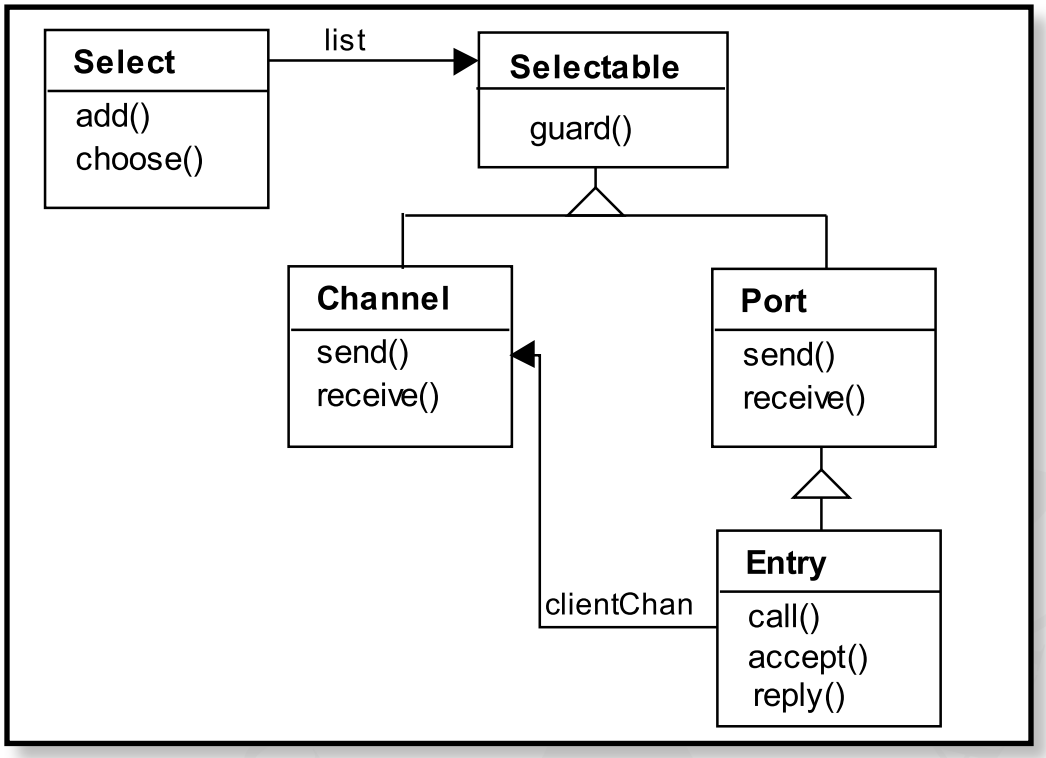


call() creates a channel object on which to receive the reply and passes a references to this in the message to the server.

It then awaits the reply on the channel.

Java Implementation - Entry

Entries: implemented as extensions of ports



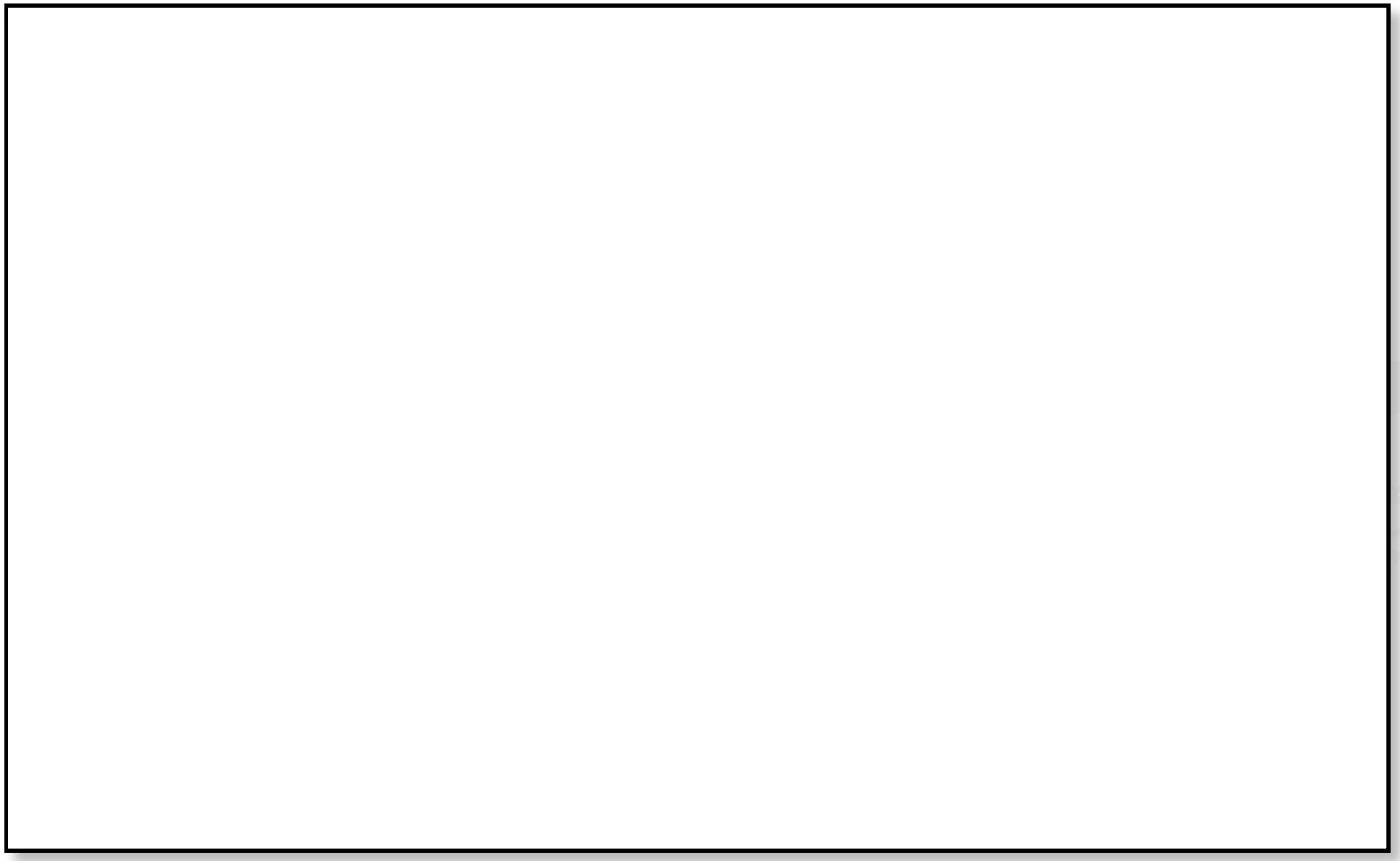
call() creates a channel object on which to receive the reply and passes a references to this in the message to the server.

It then awaits the reply on the channel.

accept() keeps a copy of the channel reference;

reply() sends the reply message to this channel.

Java Implementation - Entry



Java Implementation - Entry


```
class Entry<R,P> extends Port<R>  {
  private CallMsg<R,P> cm;
  private Port<CallMsg<R,P>> cp = new Port<CallMsg<R,P>>();
```

Java Implementation - Entry


```
class Entry<R,P> extends Port<R>  {
  private CallMsg<R,P> cm;
  private Port<CallMsg<R,P>> cp = new Port<CallMsg<R,P>>();
  public P call(R req) throws InterruptedException {
    Channel<P> clientChan = new Channel<P>();
    cp.send(new CallMsg<R,P>(req,clientChan));
    return clientChan.receive();
  }
```

Java Implementation - Entry


```
class Entry<R,P> extends Port<R>  {
  private CallMsg<R,P> cm;
  private Port<CallMsg<R,P>> cp = new Port<CallMsg<R,P>>();
  public P call(R req) throws InterruptedException {
    Channel<P> clientChan = new Channel<P>();
    cp.send(new CallMsg<R,P>(req,clientChan));
    return clientChan.receive();
  }
  public R accept() throws InterruptedException {
    cm = cp.receive();
    return cm.request;
  }
```

Java Implementation - Entry


```
class Entry<R,P> extends Port<R>  {
  private CallMsg<R,P> cm;
  private Port<CallMsg<R,P>> cp = new Port<CallMsg<R,P>>();
  public P call(R req) throws InterruptedException {
    Channel<P> clientChan = new Channel<P>();
    cp.send(new CallMsg<R,P>(req,clientChan));
    return clientChan.receive();
  }
  public R accept() throws InterruptedException {
    cm = cp.receive();
    return cm.request;
  }
  public void reply(P res) throws InterruptedException {
    cm.replychan.send(res);
  }
```

Java Implementation - Entry


```
class Entry<R,P> extends Port<R>  {
  private CallMsg<R,P> cm;
  private Port<CallMsg<R,P>> cp = new Port<CallMsg<R,P>>();
  public P call(R req) throws InterruptedException {
    Channel<P> clientChan = new Channel<P>();
    cp.send(new CallMsg<R,P>(req,clientChan));
    return clientChan.receive();
  }
  public R accept() throws InterruptedException {
    cm = cp.receive();
    return cm.request;
  }
  public void reply(P res) throws InterruptedException {
    cm.replychan.send(res);
  }
  private class CallMsg<R,P> {
    R  request;
    Channel<P> replychan;
    CallMsg(R m, Channel<P> c)
      {request=m; replychan=c;}
  } }
```

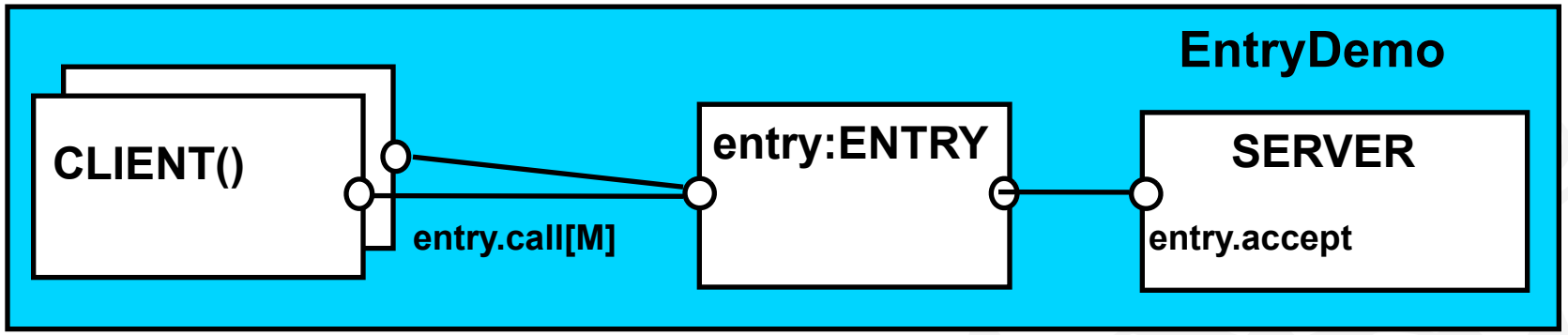
Java Implementation - Entry


```
class Entry<R,P> extends Port<R>  {
  private CallMsg<R,P> cm;
  private Port<CallMsg<R,P>> cp = new Port<CallMsg<R,P>>();
  public P call(R req) throws InterruptedException {
    Channel<P> clientChan = new Channel<P>();
    cp.send(new CallMsg<R,P>(req,clientChan));
    return clientChan.receive();
  }
  public R accept() throws InterruptedException {
    cm = cp.receive();
    return cm.request;
  }
  public void reply(P res) throws InterruptedException {
    cm.replychan.send(res);
  }
  private class CallMsg<R,P> {
    R  request;
    Channel<P> replychan;
    CallMsg(R m, Channel<P> c)
      {request=m; replychan=c;}
  } }
```

Do `call`, `accept` and `reply` need to be synchronized methods?

Model Of Entry And Applet

We reuse the models for ports and channels …




```
set M = {replyA,replyB}          // reply channels
||ENTRY = PORT/{call/send, accept/receive}.
CLIENT(CH='reply) = (entry.call[CH]->[CH]->CLIENT).
SERVER = (entry.accept[ch:M]->[ch]->SERVER).
||EntryDemo = (CLIENT('replyA)||CLIENT('replyB)
                || entry:ENTRY || SERVER  ).
```

Action labels used in expressions or as parameter values must be prefixed with a single quote.

Rendezvous Vs Monitor Method Invocation

What is the difference?

… from the point of view of the client?

… from the point of view of the server?

… mutual exclusion?

Which implementation is more efficient?

… in a local context (client and server in same computer)?

… in a distributed context (in different computers)?

Message Passing

Concepts: **synchronous** message passing - **channel**
asynchronous message passing - **port**
- send and receive / selective receive
rendezvous bidirectional comm. - **entry**
- call and accept ... reply

Models:
channel : relabelling, choice & guards
port : message queue, choice & guards
entry : port & channel

Practice: distributed computing (disjoint memory)
threads and monitors (shared memory)