Chapter 10

Message Passing

Message Passing

Concepts: **synchronous** message passing - **channel**
asynchronous message passing - **port**
- send and receive / selective receive

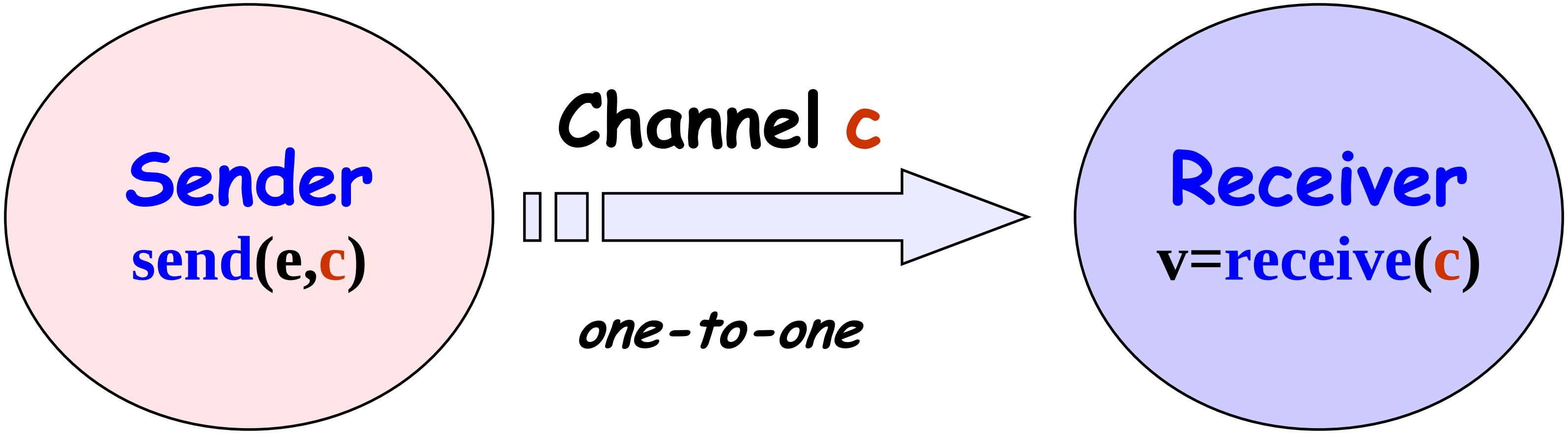
rendezvous bidirectional comms - **entry**
- call and accept ... reply

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



♦ **send(e,c)** - send the value of the expression *e* to channel *c*. The process calling the send operation is ***blocked*** until the message is received from the channel.

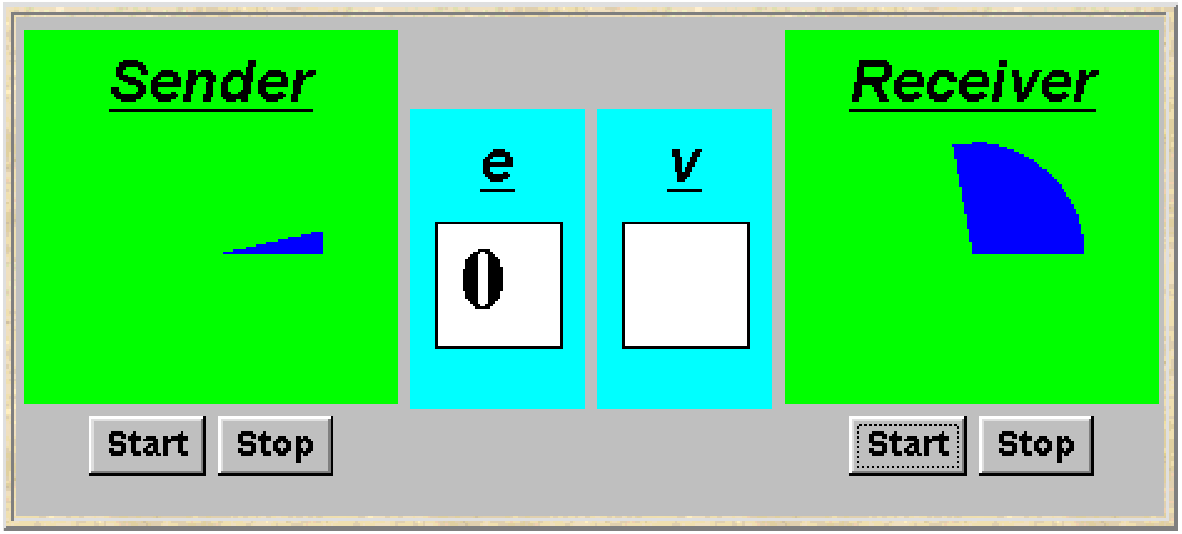
♦ ***v*** = **receive(*c*)** - receive a value into local variable *v* from channel *c*. The process calling the receive operation is ***blocked*** waiting until a message is sent to the channel.

cf. distributed assignment ***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.




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

Instances of `ThreadPanel`

Instances of `SlotCanvas`

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();             //should be notify()
     return(tmp);
   }
}
```

The implementation of `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

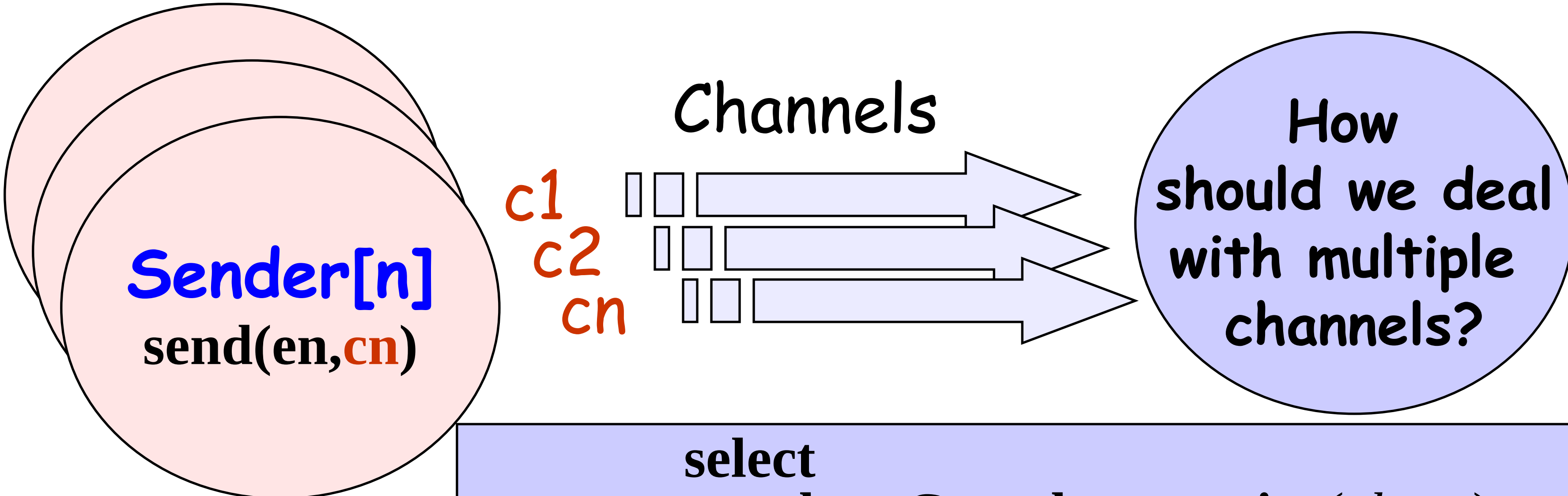
```
range M = 0..9                    // messages with values up to 9

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

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

                                  // relabeling to model synchronization
||SyncMsg = (SENDER || RECEIVER)
            /{chan/chan.{send,receive}}.
```

LTS?

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

message operation	*FSP model*
send(e,chan)	`chan.[e]`
v = receive(*chan*)	`chan.[v:M]`

selective receive

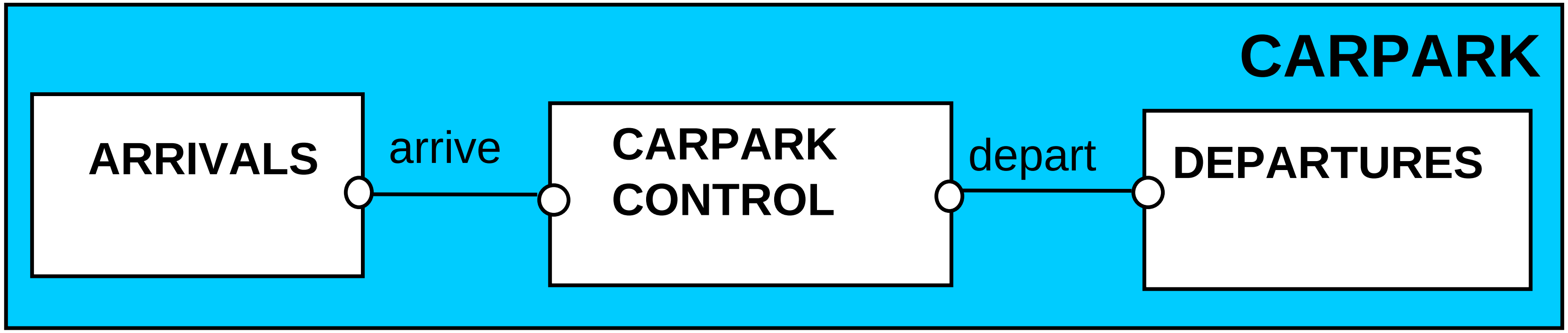


Select statement...

select
  when G_1 **and** v_1=**receive**($chan_1$) => S_1;
or
  when G_2 **and** v_2=**receive**($chan_2$) => S_2;
or
  …
or
  when G_n **and** v_n=**receive**($chan_n$) => S_n;
end

How would we model this in FSP?

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).
```

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() {…}
}
```

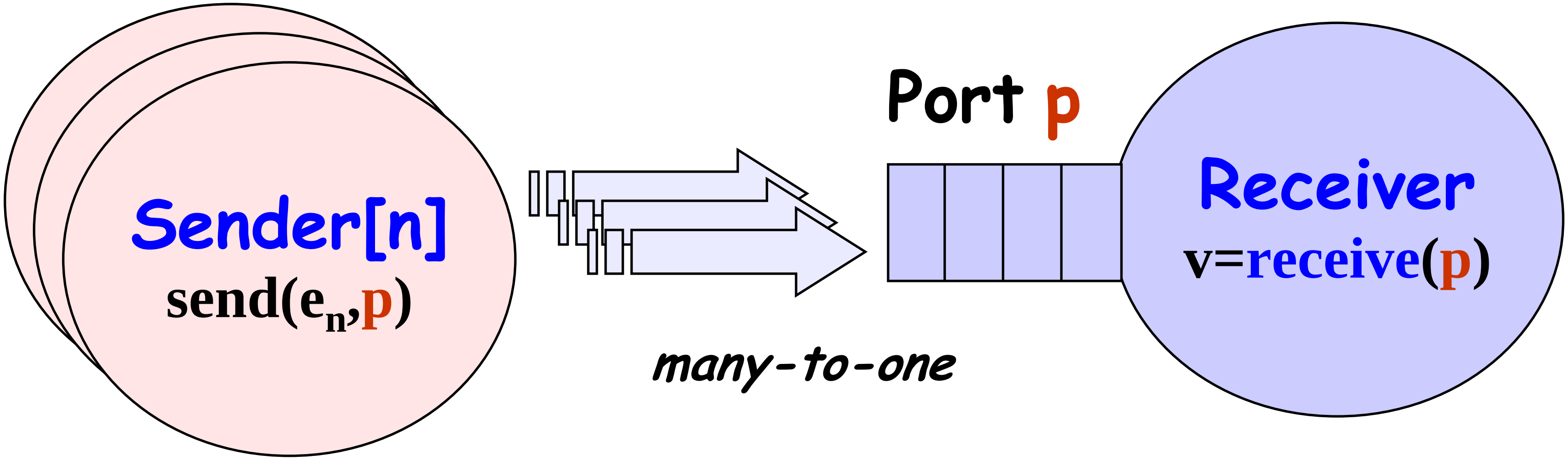
Implement `CARPARKCONTROL` *as a thread* `MsgCarPark` *which receives signals from channels* `arrive` *and* `depart.`

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{}
  }
```

See Applet

10.2 Asynchronous Message Passing - port



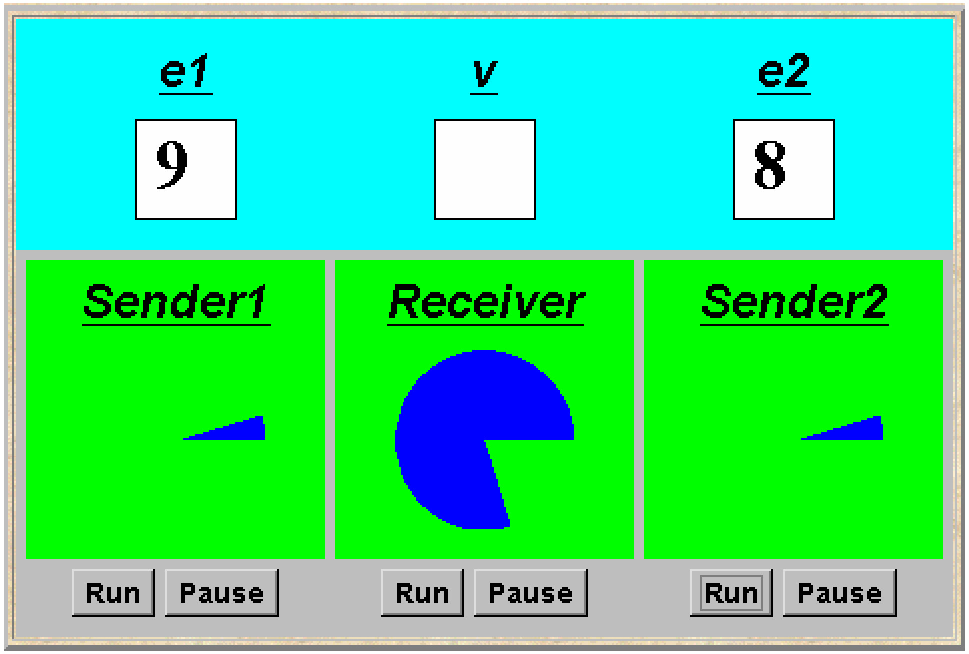
♦ **send(e,p)** - send the value of the expression *e* to port *p*. The process calling the send operation is **not *blocked***. The message is queued at the port if the receiver is not waiting.

♦ *v* = **receive(*p*)** - receive a value into local variable *v* from port *p*. The process calling the receive operation is ***blocked*** if there are 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.




```
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

```
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**.

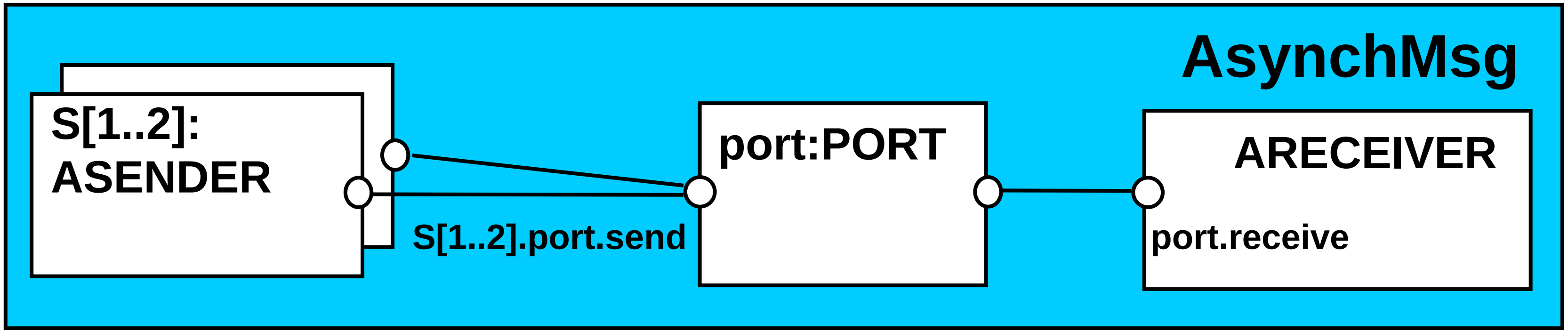
port model

```
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[t:S][h:M]              //two or more  messages queued to port
  = (send[x:M]->PORT[x][t][h]
    |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 send 4 values?

model of applet

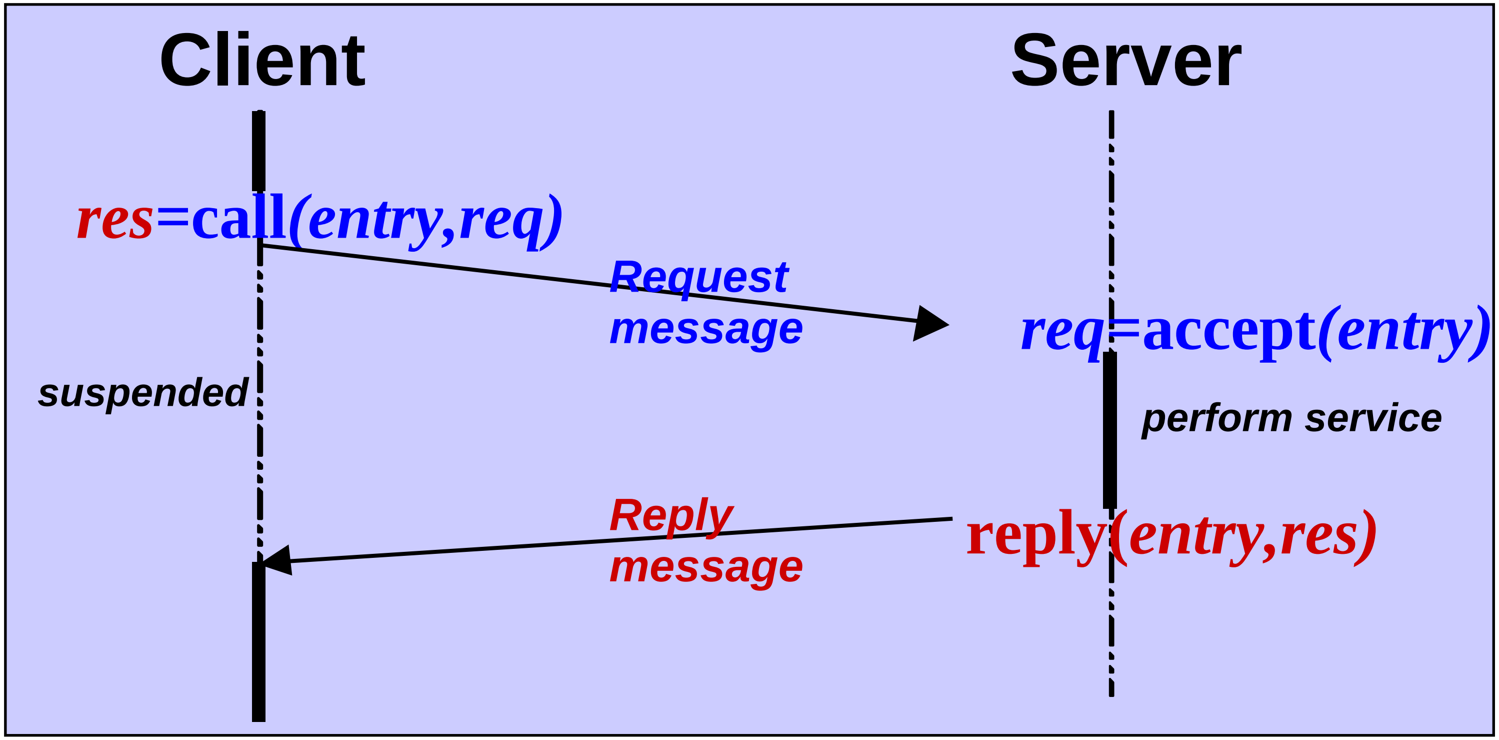



```
ASENDER = ASENDER[0],
ASENDER[e:M] = (port.send[e]->ASENDER[(e+1)%10]).

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

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

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***.

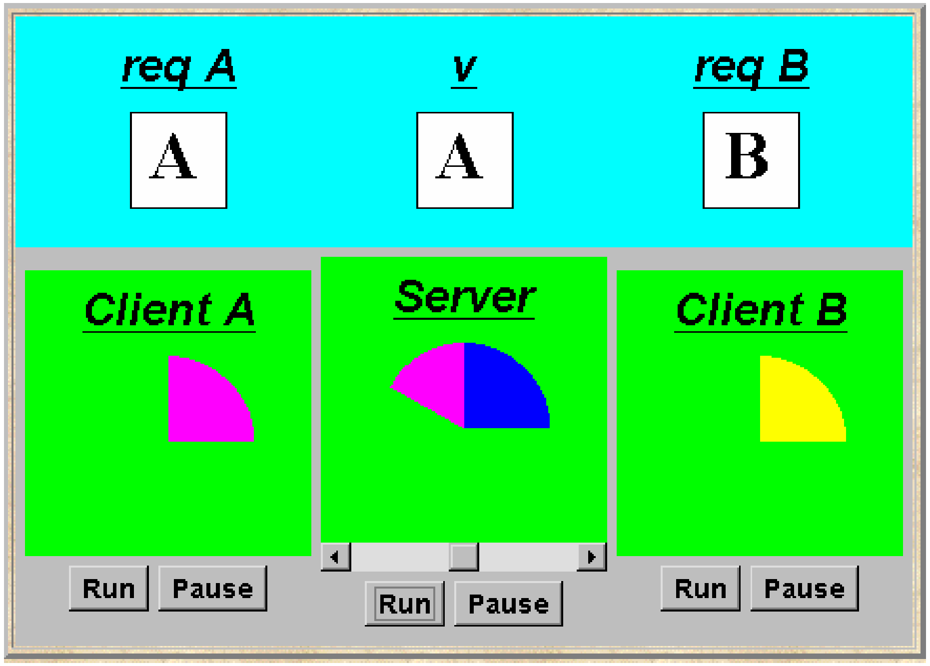
♦ ***req*=accept(*e*)** - receive the value of the request message from the entry ***e*** into local variable ***req***. The calling process is ***blocked*** if there are no messages queued to the entry.

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

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.



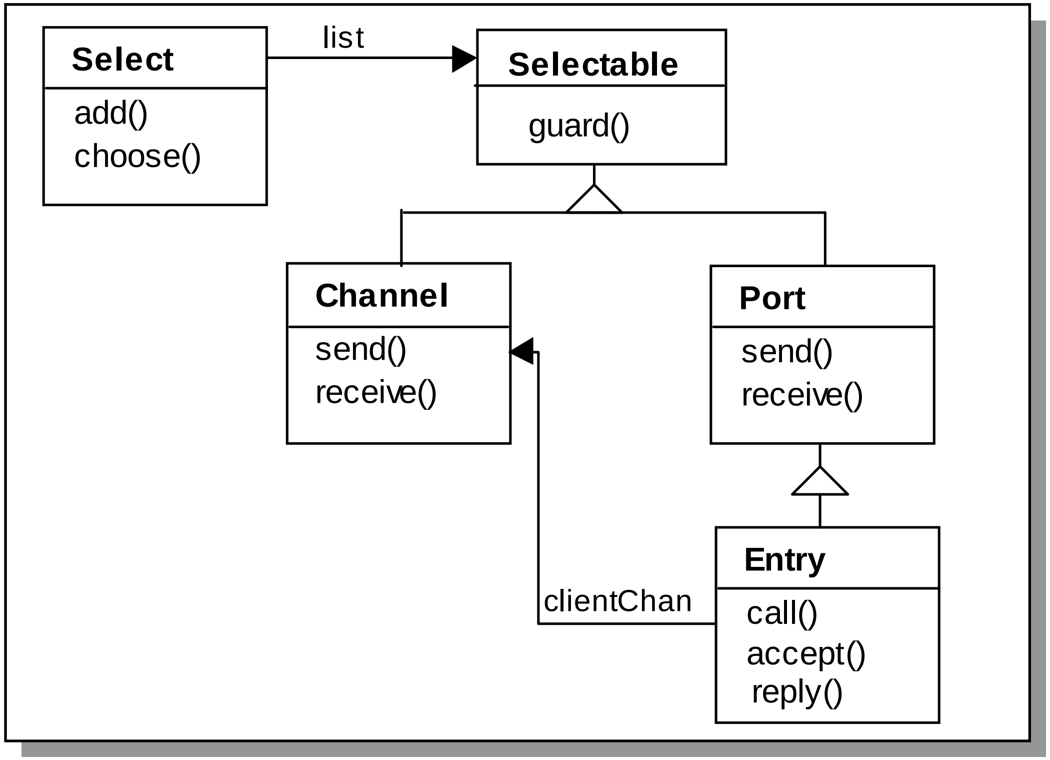

```
Entry<String,String> entry = new Entry<String,String> ();
clA.start(new Client(entry,clientAdisp,"A"));
clB.start(new Client(entry,clientBdisp,"B"));
sv.start(new Server(entry,serverdisp));
```

Instances of `ThreadPanel` Instances of `SlotCanvas`

Java implementation - entry

Entries are implemented as extensions of ports, thereby supporting queuing and selective receipt.

The **call** method creates a channel object on which to receive the reply message. It constructs and sends to the entry a message consisting of a reference to this channel and a reference to the req object. It then awaits the reply on the channel.



The **accept** method keeps a copy of the channel reference; the **reply** method sends the reply message to this channel.

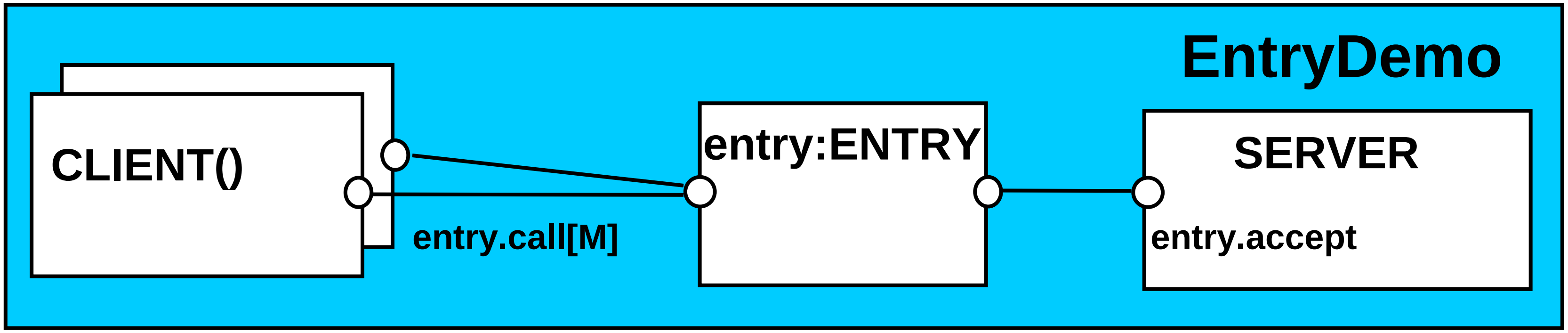
Java implementation - entry

```
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)?

Summary

- Concepts
  - **synchronous** message passing – **channel**
  - **asynchronous** message passing – **port**
    - send and receive / selective receive
  - **rendezvous** bidirectional comms - **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)

Course Outline

- Processes and Threads
- Concurrent Execution
- Shared Objects & Interference
- Monitors & Condition Synchronization
- Deadlock
- Safety and Liveness Properties
- Model-based Design

Concepts

Models

Practice

- Dynamic systems
- Message Passing
- Concurrent Software Architectures
- Timed Systems