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

Sender
send(e,c)

Channel c

one-to-one

Receiver
v=receive(c)

♦ **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.

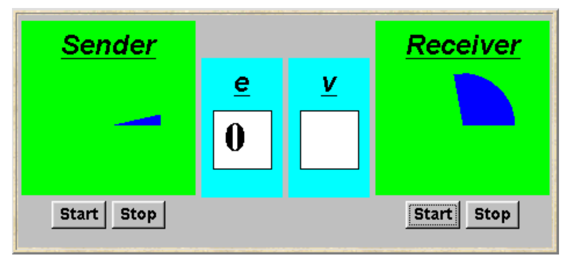
♦ v = **receive(*c*)** - receive a value into local variable *v* from channel *c*. The process calling the receive operation is ***blocked*** waiting until a message is sent to the channel.

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

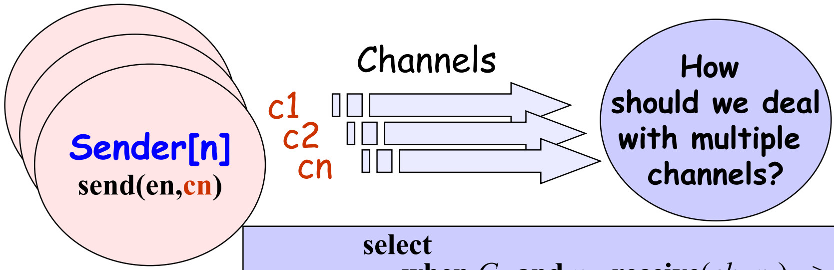
```
range M = 0..9                  // messages with values up to 9

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

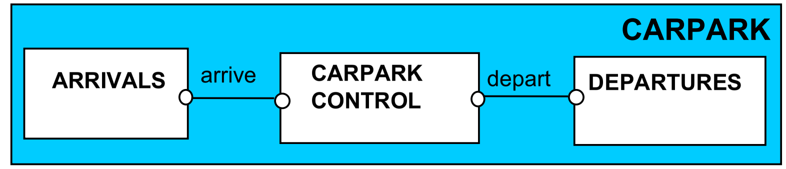


Select statement...

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() {…}
}
```

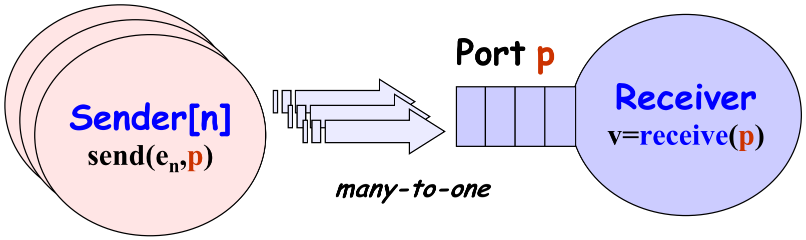
Implement CARPARKCONTROL *as a thread* MsgCarPark *which receives signals from channels* arrive *and* depart.

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



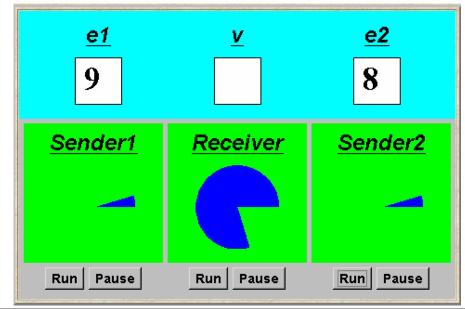
- **send**(e,p) - send the value of the expression *e* to port *p*. The process calling the send operation is **not *blocked***. The message is queued at the port if the receiver is not waiting.

- *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**.

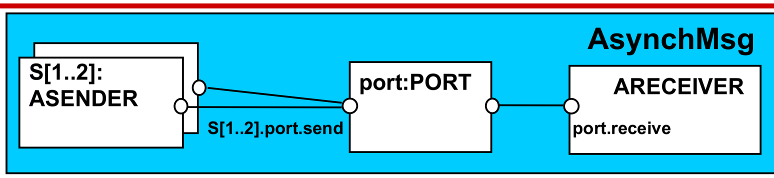
port model

```
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

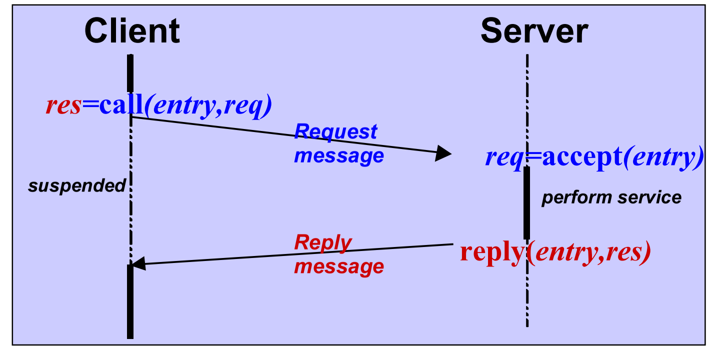



```
ASENDER = ASENDER[0],
ASENDER[e:M] = (port.send[e]->ASENDER[(e+1)%10]).

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

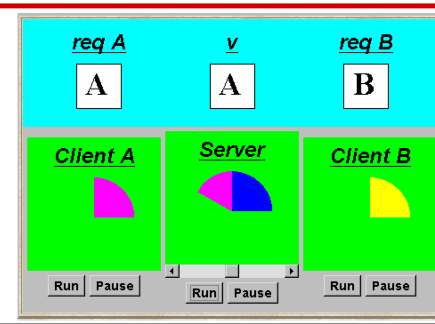
- ***res*=call(*e*,*req*)** - send the value ***req*** as a request message which is queued to the entry ***e***.
- The calling process is ***blocked*** until a reply message is received into the local variable ***req***.

- ***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.



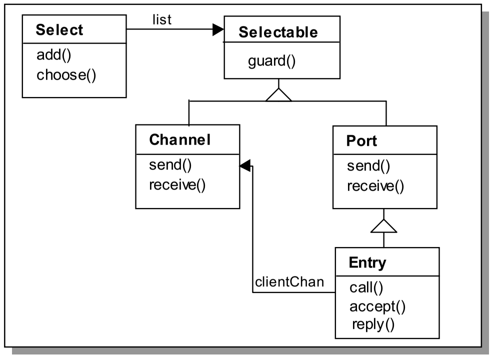

```
Entry<String,String> entry = new Entry<String,String> ();
clA.start(new Client(entry,clientAdisp,"A"));
clB.start(new Client(entry,clientBdisp,"B"));
sv.start(new Server(entry,serverdisp));
```

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.

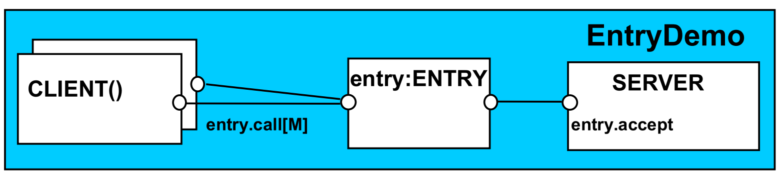
Java implementation - entry

```
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
- Concurrent Software Architectures
- **Message Passing**
- Timed Systems