Part III
Synchronization
Message Passing

The most important property of a program is whether it accomplishes the intention of its user.

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Message Passing: 1/3

- **When processes/threads are interested with one another, two fundamental requirements must be met: synchronization and communication.**
- **Synchronization enforces mutual exclusion.**
- **Communication allows information to be passed to other processes/threads.**
- **Message passing, a form of communication, can be implemented in shared-memory and distributed environment.**

Message Passing: 2/3

- **Mutex locks, semaphores and monitors are shared-memory synchronization mechanisms.**
- **This means all processes and threads use a piece of shared memory to store and manage mutex locks, semaphores and monitors.**
- **In a distributed environment, processes and threads run on different computers without a global shared-memory.**
- **In this case, message passing becomes useful.**

Message Passing: 3/3

- **Communication links can be established between threads/processes. There are three important issues:**
  1. **Naming: How to refer to each other?**
  2. **Synchronization: Shall we wait when participating a message activity?**
  3. **Buffering: Can messages wait in a communication link?**

Naming: Direct Addressing
Symmetric Scheme: 1/3

- **Direct Addressing: Each process that wants to communicate must explicitly name the other party:**
  - `Send(receiver, message);`
  - `Receive(sender, message);`
- **With this scheme:**
  - **Exactly one link exists between each pair of communicating processes.**
  - **These links may be established for processes that need to communicate before they run.**

Naming: Direct Addressing Asymmetric Scheme: 2/3

- **In this scheme, we have**
  - `Send(receiver, message);`
  - `Receive(id, message);`
- **The `Receive()` primitive receives the ID of the sender. Thus, in this scheme, a receiver can receive messages from any process.**

Naming: Direct Addressing Disadvantages: 3/3

- There are disadvantages in the symmetric and asymmetric schemes:
  - Changing the name/ID of a process may require examining all other process definitions.
  - Processes must know the IDs of the other parties to start a communication.

Naming: Indirect Addressing Mailbox: 1/4

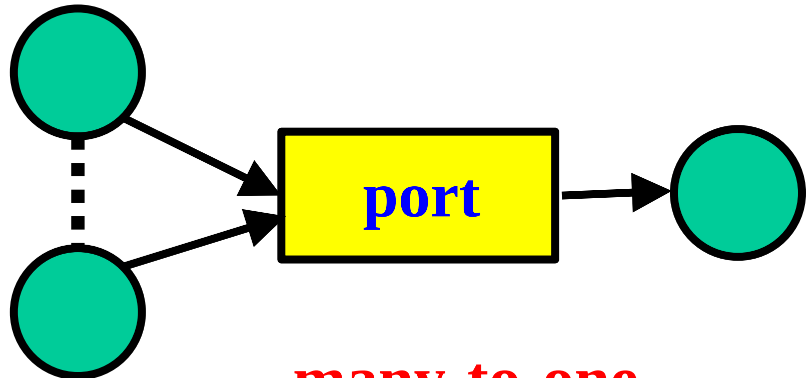
- **With indirect addressing, messages are sent to and received from mailboxes.**
- **Each mailbox has a unique ID.**
- **The primitives are**
  - `Send(mailbox-name, message);`
  - `Receive(mailbox-name,message);`

Naming: Indirect Addressing Communication Links: 2/4

- **There is a link between two processes only if they share a mailbox.**
- **A link may be shared by multiple processes.**
- **Multiple links may exist between each pair of processes, and each link corresponds to a mailbox.**
- **By decoupling the sender and receiver, indirect addressing provides a greater flexibility in the use of messages.**

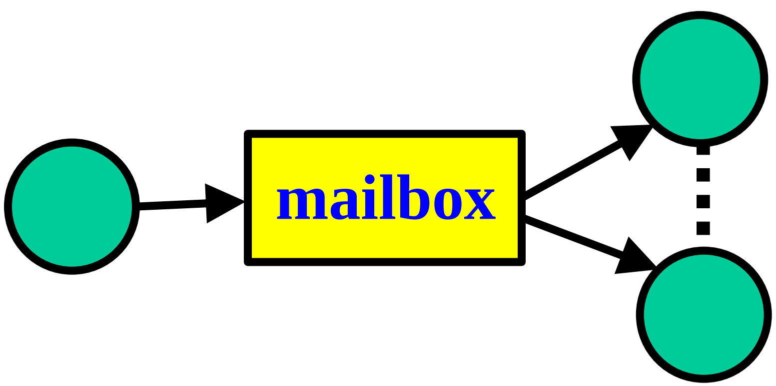
Naming: Indirect Addressing Communication Links: 3/4

one-to-one

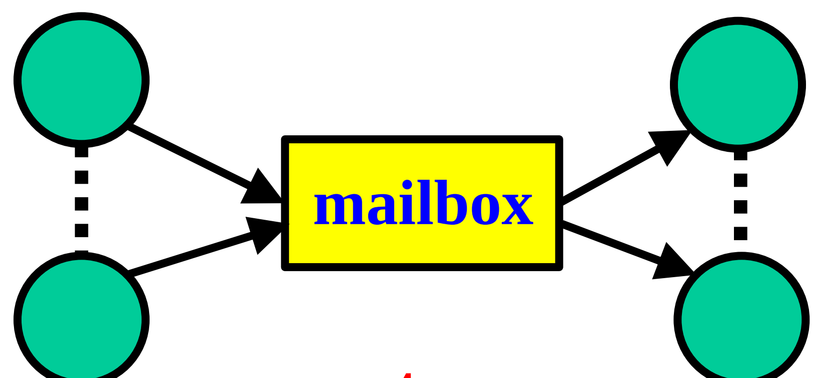


many-to-one

mailbox → port



one-to-many



many-to-many

Naming: Indirect Addressing Communication Links: 4/4

- **What if there is only one message in a mailbox and several processes execute `Receive()`? It depends on the following:**
  - **If there is only one link between at most two processes, this situation will not happen.**
  - **Allow at most one process to receive at a time.**
  - **Allow the system to select an arbitrary order.**

Synchronization

- The sender and/or receiver may be blocked:
  - ❖ **Blocking Send**: the sender blocks until its message is received
  - ❖ **Nonblocking Send**: the sender sends and resumes its execution immediately
  - ❖ **Blocking Receive**: the receiver blocks until a message is available
  - ❖ **Nonblocking Receive**: the receive receives a message or a null.
- When both send and receive are blocking, we have a **rendezvous** between the sender and receiver.

Synchronous vs. Asynchronous

- **Blocking** and **non-blocking** are known as **synchronous** and **asynchronous**.
  - ❖ If the sender and receiver must **synchronize** their activities, use synchronous communication.
  - ❖ Because of the **uncertainty in the order of events**, asynchronous communication is more difficult to program.
  - ❖ On the other hand, asynchronous algorithms are **general** and **portable**, because they are guaranteed to run correctly on networks with arbitrary timing behavior.

Capacity

- The **capacity** of a link is its buffer size:
  - **Zero Capacity**: Since no message can be waiting in the link, it is synchronous. Sender blocks.
  - **Unbounded Capacity**: Messages can wait in the link. Sender never blocks and the link is asynchronous. **The order of messages being received does not have to be FIFO**.
  - **Bounded Capacity**: Buffered Message Passing. Sender blocks if the buffer is full, and the link is asynchronous. Isn't it a bounded buffer if the order is FIFO?

Message Passing in Unix

- **Unix systems provide at least two message passing mechanisms: pipes and message queues.**
- **A pipe is a generalization of the pipe in `A | B`.**
- **Function `pipe(int pfd[2])` creates a communication link and returns two file descriptors. Writing to `pfd[1]` puts data in the pipe; reading from `pfd[0]` gets the data out. Data items in a pipe are FIFO just like `A | B`.**
- **Message queues are mailboxes. Use `msgget()` to obtain a message queue, and use `msgsnd()` and `msgrcv()` to send and receive messages.**

Message Passing with
ThreadMentor

Channels

- A **channel** is a *bi-directional* communication link between two specific threads.
- A channel can be synchronous or asynchronous.
- Channels use user-defined thread IDs for identification purpose. A use-defined thread ID is a unique non-negative integer selected by the user.
- The user-defined thread ID must be set in the thread constructor:

```
UserDefinedThreadID = 10;
```

Declaring a Channel

- **Two classes `SynOneToOneChannel` (blocking send and receive) and `AsynOneToOneChannel` (non-blocking send and receive) are available:**

```
SynOneToOneChannel  X(“chan-2-3”, 15, 3);
AsynOneToOneChannel Y(“chan-4-5”, 15, 3);
```

channel names

user-defined thread IDs

channels `X` and `Y` are built between threads 15 and 3

Sending and Receiving: 1/2

- **Use methods `Send()` and `Receive()` to send and receive a message to and from a channel:**

```
X.Send(*pointer-to-message,size);
Y.Receive(*pointer-to-message,size);
```

- **Send an `int` message to channel `X`:**

```
AsynOneToOneChannel  X;
int  Msg;
X.Send(&Msg, sizeof(int));
```

Sending and Receiving: 2/2

- **Receive a message of four doubles from channel `Y`:**

```
AsynOneToOneChannel  Y;
double  Msg[4];
Y.Receive(Msg, 4*sizeof(double));
```

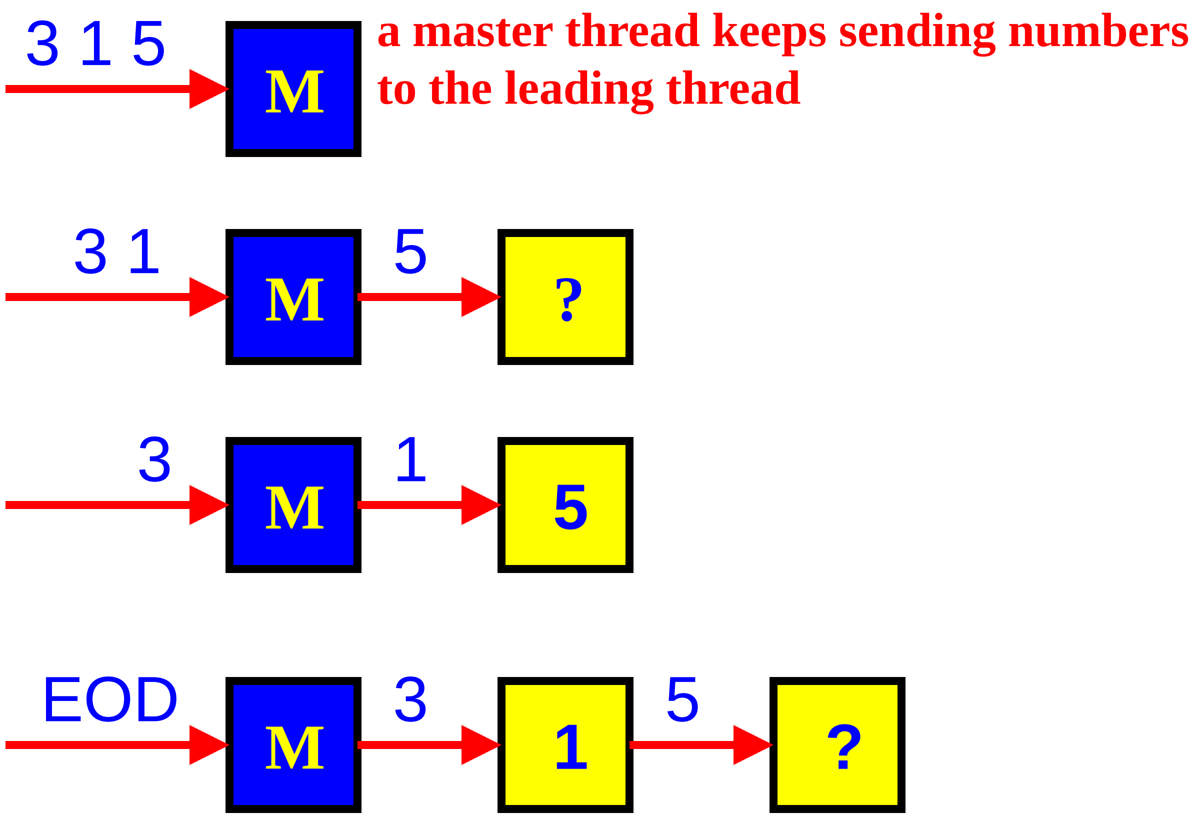
- **Send a message of `struct Data` to channel `Z`;**

```
struct Data
   {double x; int y; char z[100];}
      Msg;
SynOneToOneChannel  Z;
Z.Send(&Msg, sizeof(Data));
```

Linear Array Sorting: 1/9

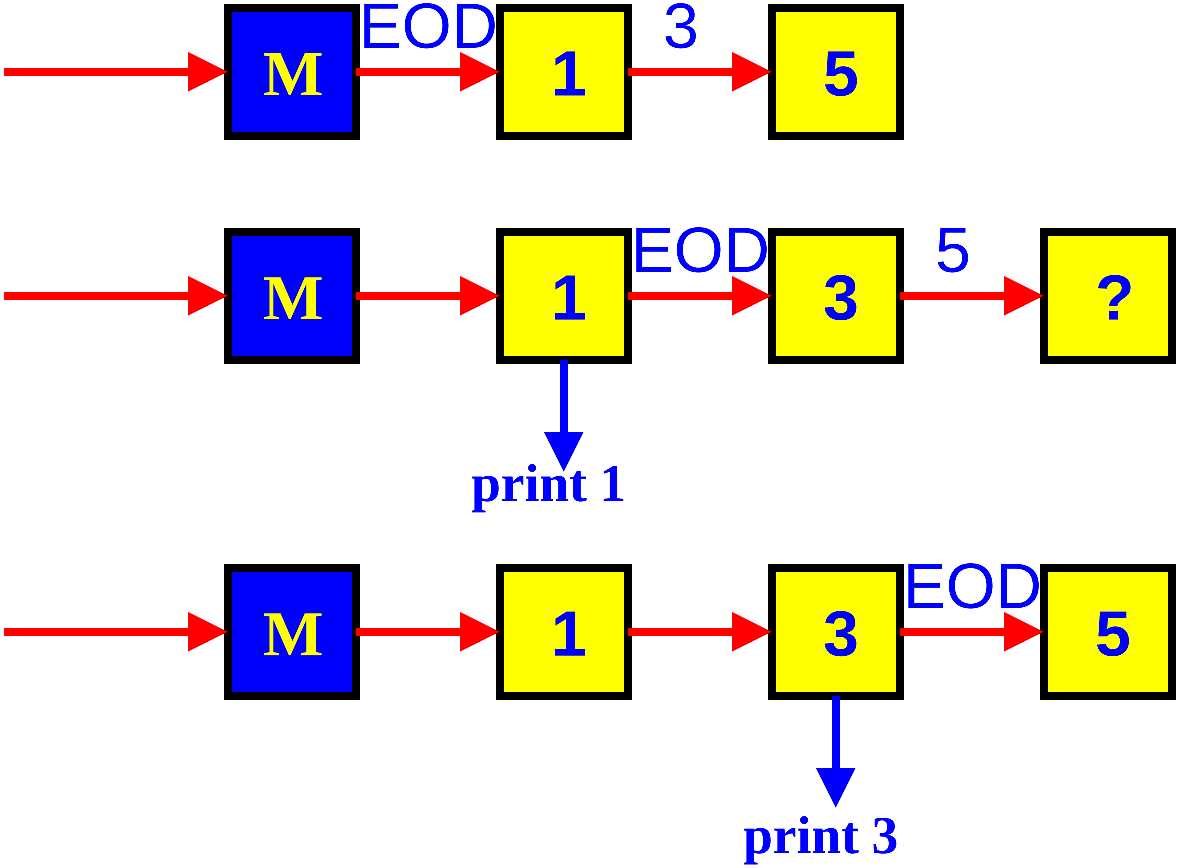
- **Each thread has an input channel from its predecessor and an output channel to its successor.**
- **The first time a thread receives a positive integer, it is memorized as N.**
- **For a subsequent received positive integer X:**
  - **If $X < N$, this thread sends N to its successor and memorizes X as N.**
  - **Otherwise, X is sent to its successor.**
  - **If there is no successor, this thread creates a thread, builds a channel to it, and sends the number.**

Linear Array Sorting: 2/9



sort positive integers with `-1` as `end-of-data`

Linear Array Sorting: 3/9



What type of channels (i.e., sync or async) should be used?

Linear Array Sorting: 4/9

```
const int NOT_DEFINED = -2;
const int END_OF_DATA = -1; // end of input flag
class SortThread : public Thread
{
   public:
      SortThread(int index, int threadID);
      ~SortThread(); // destructor
      SynOneToOneChannel *channel;
   private:
      void ThreadFunc();
      int Index;     // index of the sort thread
      int Number;    // number memorized
      SortThread *neighbor; // next sort thread
};
class MasterThread : public Thread
{
   public: MasterThread(int threadID);
   private: void ThreadFunc();
};
```

used to construct thread name

class definition

Linear Array Sorting: 5/9

can an async. channel be used here?

```
SortThread::SortThread(int index, int threadID)
{
   Index = index;
   UserDefinedThreadID = threadID;
   neighbor = NULL; // initially no neighbor
   Number = NOT_DEFINED; // no memorized number
   ChannelName = … // give this channel a name
   channel = new SynOneToOneChannel(ChannelName,
                        threadID-1, threadID);
}
```

async channel between them

```
SortThread::~SortThread() // this is a destructor
{ delete channel; }
```

constructor and destructor

SortThread body 1/2

GetID() returns the ID of a thread

```
void SortThread::ThreadFunc()
{
   Thread::ThreadFunc();
   int number, tmpNum;
   Thread_t self = GetID();
   while(true) {
      channel->Receive(&number, sizeof(int)); // receive a number
      if (number == END_OF_DATA)
         break;
      if (Number == NOT_DEFINED)
         Number = number;                  // first number.  Memorize it
      else {                               // other numbers
         if (number >= Number)             // larger than mine
            tmpNum = number;               //    save it in temporarily
         else {
            tmpNum = Number;               // no. save mine in temporarily
            Number = number;               //    but, also memorize it
         }
         if (neighbor == NULL)              // no neighbor? create one
            neighbor = new SortThread(Index+1,UserDefinedThreadID+1);
            neighbor->Begin();              // run it!
         }
         neighbor->channel->Send(&tmpNum,sizeof(int)); // send number
      }
   }  // end of data reached.  see next slide
```

Linear Array Sorting: 7/9

SortThread body **2/2**

```
void SortThread::ThreadFunc()
{
   while (true) {
     // other stuffs on the previous slide
     // end of data received
   }
   if (neighbor != NULL) { // if I am not the last one
                           // I should pass the EOD
      neighbor->channel->Send(&number, sizeof(int));
      neighbor->Join();    // wait for neighbor to complete
   }
   Exit();
}
```

MasterThread constructor and body

```
MasterThread::MasterThread(int threadID)
{
   UserDefinedThreadID = threadID;
   ThreadName = …; // a thread name
}

void MasterThread::ThreadFunc()
{
   Thread::ThreadFunc();
   int input;
   do {
      cin >> input;           // read an integer or END_OF_DATA
      if (input == END_OF_DATA)
         break;
      else
         firstSortThread->channel->Send(&input,sizeof(int));
   } while (input != END_OF_DATA);
   firstSortThread->channel->Send(&input, sizeof(int));
   Exit();
}
```

send END_OF_DATA to the first thread

Linear Array Sorting: 9/9

```
SortThread *firstSortThread; // first sorting thread
void main(void)
{
   MasterThread *masterThread;
   firstSortThread = new SortThread(1,2);
   firstSortThread->Begin();
   masterThread = new MasterThread(1);
   masterThread->Begin();
   masterThread->Join();
   firstSortThread->Join();
   Exit();
}
```

sorting thread #1
threadID 2

threadID 1

main program

The End