Chapter IV
INTERPROCESS COMMUNICATION

Jehan-François Pâris
jfparis@uh.edu

CS@UH

Chapter overview

- *Types of IPC*
  - Message passing
  - Shared memory
- *Message passing*
  - Blocking/non-blocking, …
  - Datagrams, virtual circuits, streams
  - Remote procedure calls

Message passing (I)

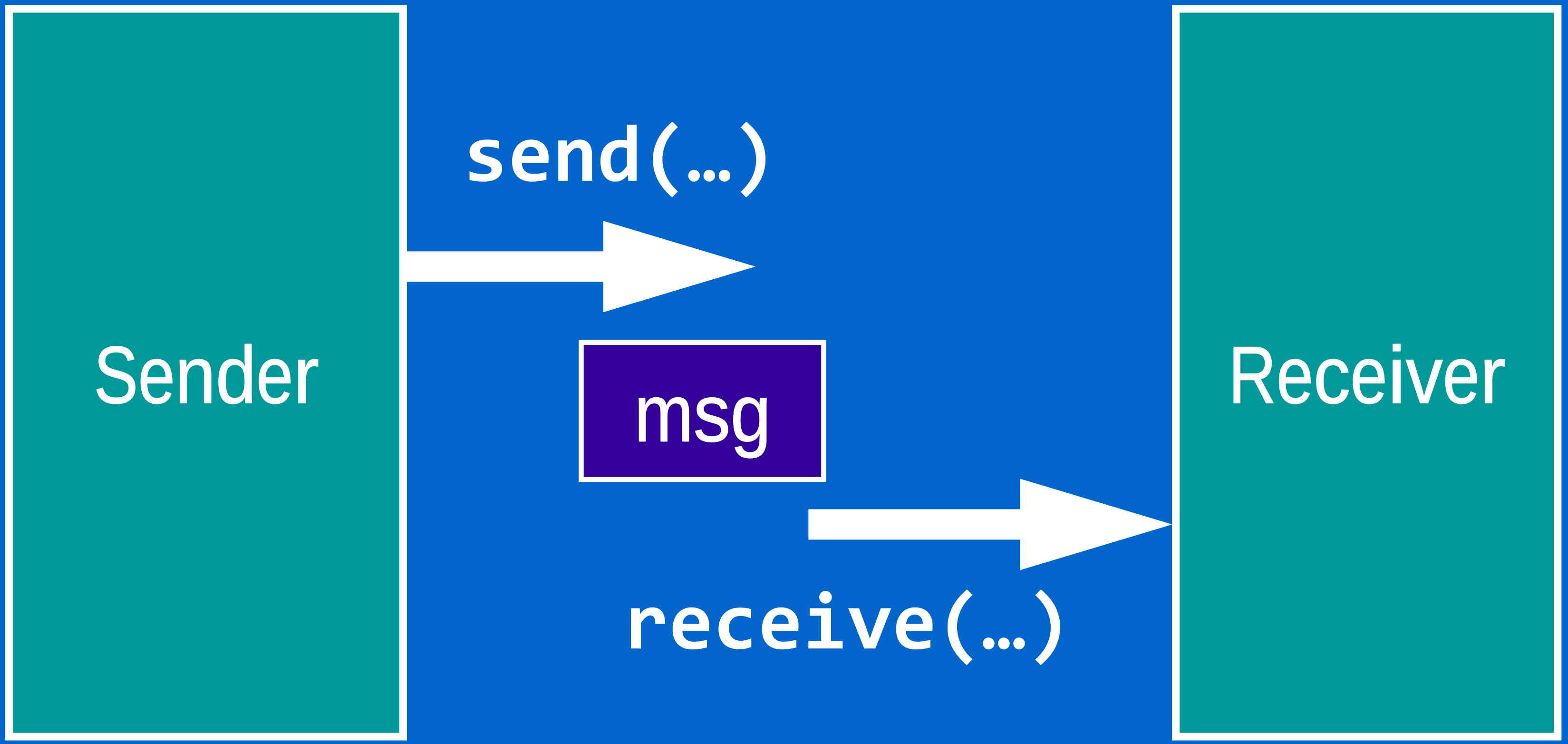
- Processes that want to exchange data send and receive *messages*
- Any *message exchange* requires
  - *One send*

    ```
    send(addr, msg, length);
    ```

  - *One receive*

    ```
    receive(addr, msg, length);
    ```

Message passing (II)



send(…)

Sender

msg

Receiver

receive(…)

Advantages

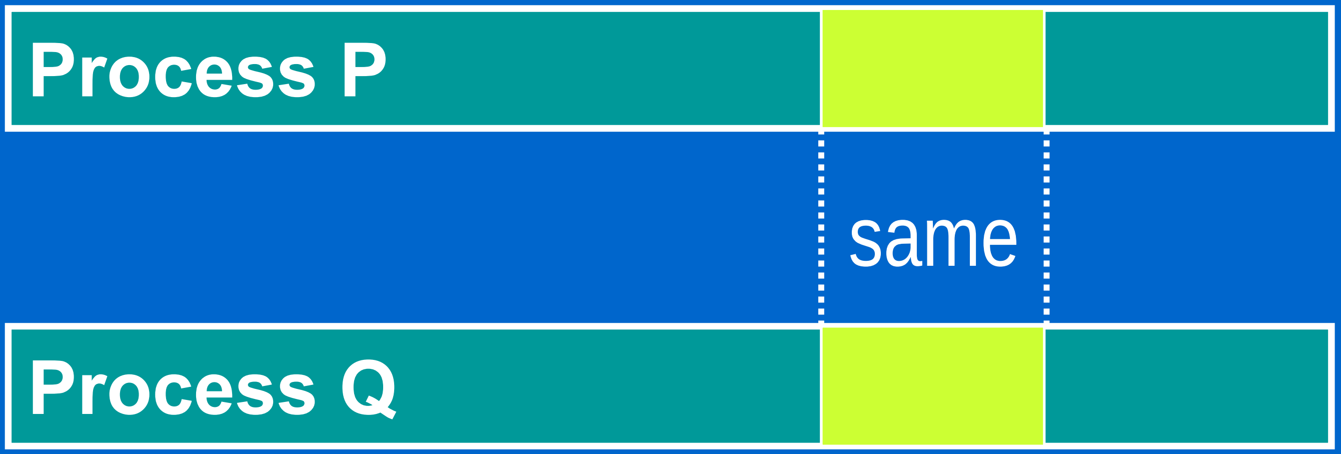
- *Very general*
  - – Sender and receivers can be on different machines
- *Relatively secure*
  - – Receiver can inspect the messages it has received before processing them

Disadvantages

- *Hard to use*
  - Every data transfer requires a **`send()`** and a **`receive()`**
  - Receiving process must *expect* the **`send()`**
    - Might require forking a special thread

Shared Memory

- Name says it
  - Two or more processes share a part of their address space



Advantages

- *Fast and easy to use*
  - The data are there

but

  - Some concurrent accesses to the shared data can result into small disasters
  - Must synchronize access to shared data
    - Topic will be covered in next chapter

Disadvantages

- *Not a general solution*
  - Sender and receivers must be on the *same machine*
- *Less secure*
  - Processes can directly access a part of the address space of other processes

MESSAGE PASSING

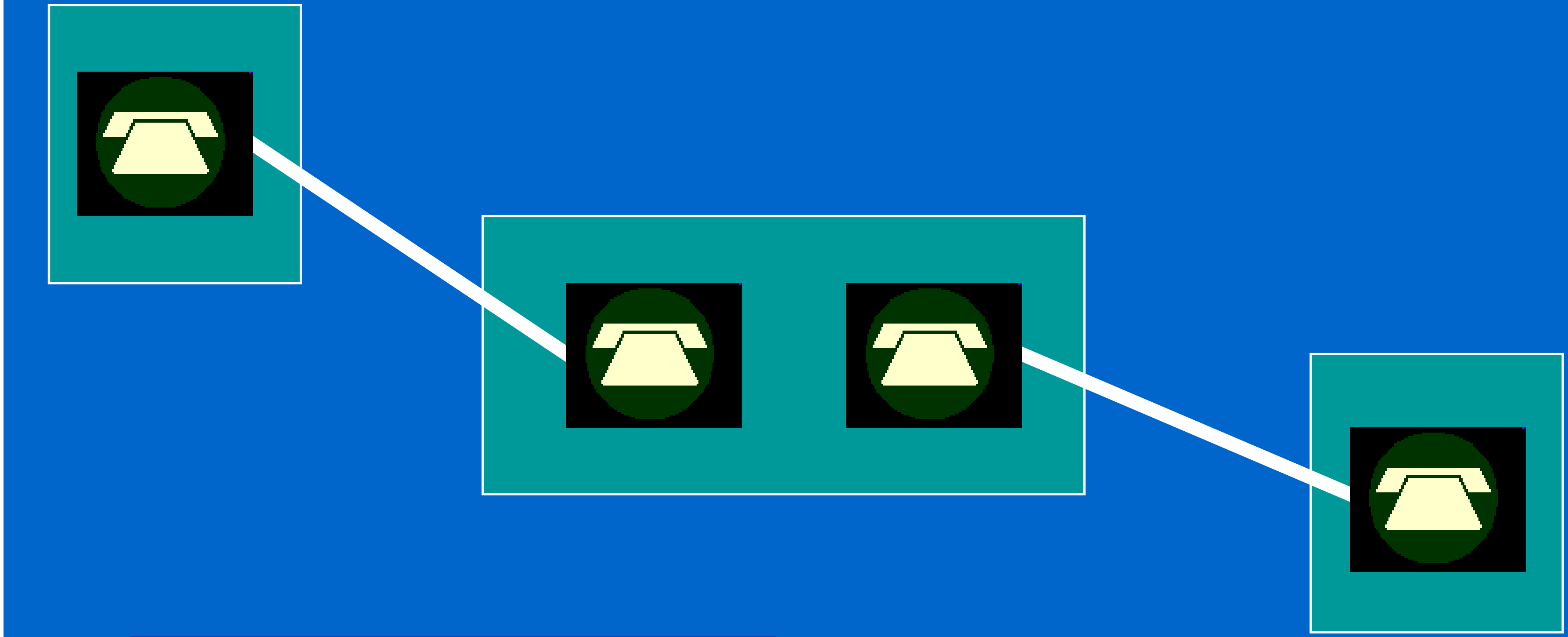
- *Defining issues*
  - Direct/Indirect communication
  - Blocking/Non-blocking primitives
  - Exception handling
  - Quality of service
    - Unreliable/reliable datagrams
    - Virtual circuits, streams

Direct communication (I)

- Send and receive system calls always specify processes as destination or source:
  - `send(process, msg, length);`
  - `receive(process, msg, &length);`
- Most basic solution because there is
  - No intermediary between sender and receiver

An analogy

- Phones without switchboard
  - Each phone is hardwired to another phone



Direct communication (II)

- Process executing the receive call must know the identity of all processes likely to send messages
  - Very bad solution for *servers*
    - *Servers have to answer requests from arbitrary processes*

Indirect communication (I)

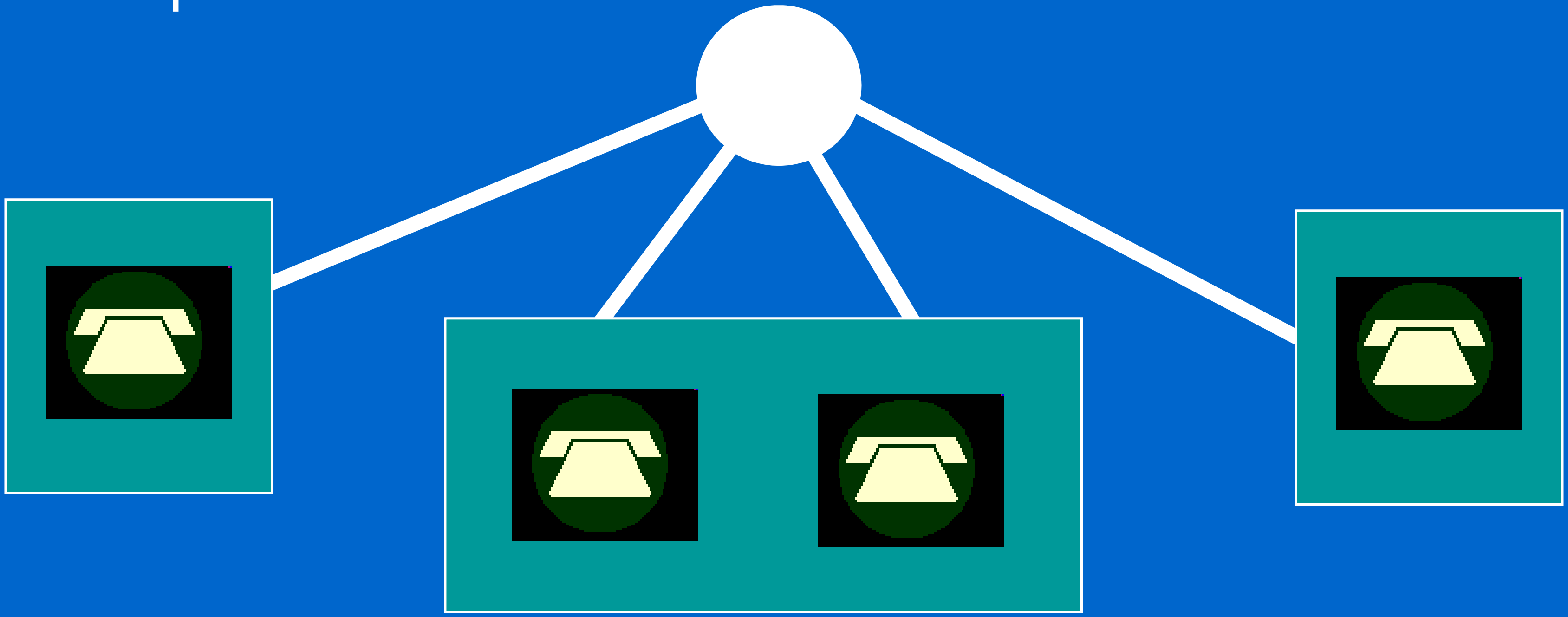
- Send and receive primitives now specify an *intermediary entity* as destination or source: the *mailbox*

  ```
  send(mailbox, msg, size);
  receive(mailbox, msg, &size);
  ```

- Mailbox is a system object created by the kernel at the request of a user process

An analogy (I)

- Phones with a switchboard
  - Each phone can receive calls from any other phone



An analogy (II)

- Each phone has now a *phone number*
  - – Callers dial that number, not a person’s name
- Taking our phone with us allows us to receive phone calls *from everybody*

Indirect communication (II)

- Different processes can send messages to the same mailbox
  - A process can receive messages from processes it does not know anything about
  - A process can wait for messages coming from different senders
    - Will answer the first message it receives

Mailboxes

- Mailboxes can be
  - *Private*
    - Attached to a specific process
      - *Think of your cell phone*
  - *Public*
    - System objects
      - *Think of a house phone*

Private mailboxes

- Process that requested its creation and its children are the only processes that can receive messages through the mailbox are that process and its children
- Cease to exist when the process that requested its creation (and all its children) terminates.
- Often called ports
- *Example*: BSD *sockets*

Public mailboxes

- Owned by the system
- Shared by all the processes having the right to receive messages through it
- Survive the termination of the process that requested their creation
- Work best when all processes are on the same machine
- *Example:* System V UNIX *message queues*

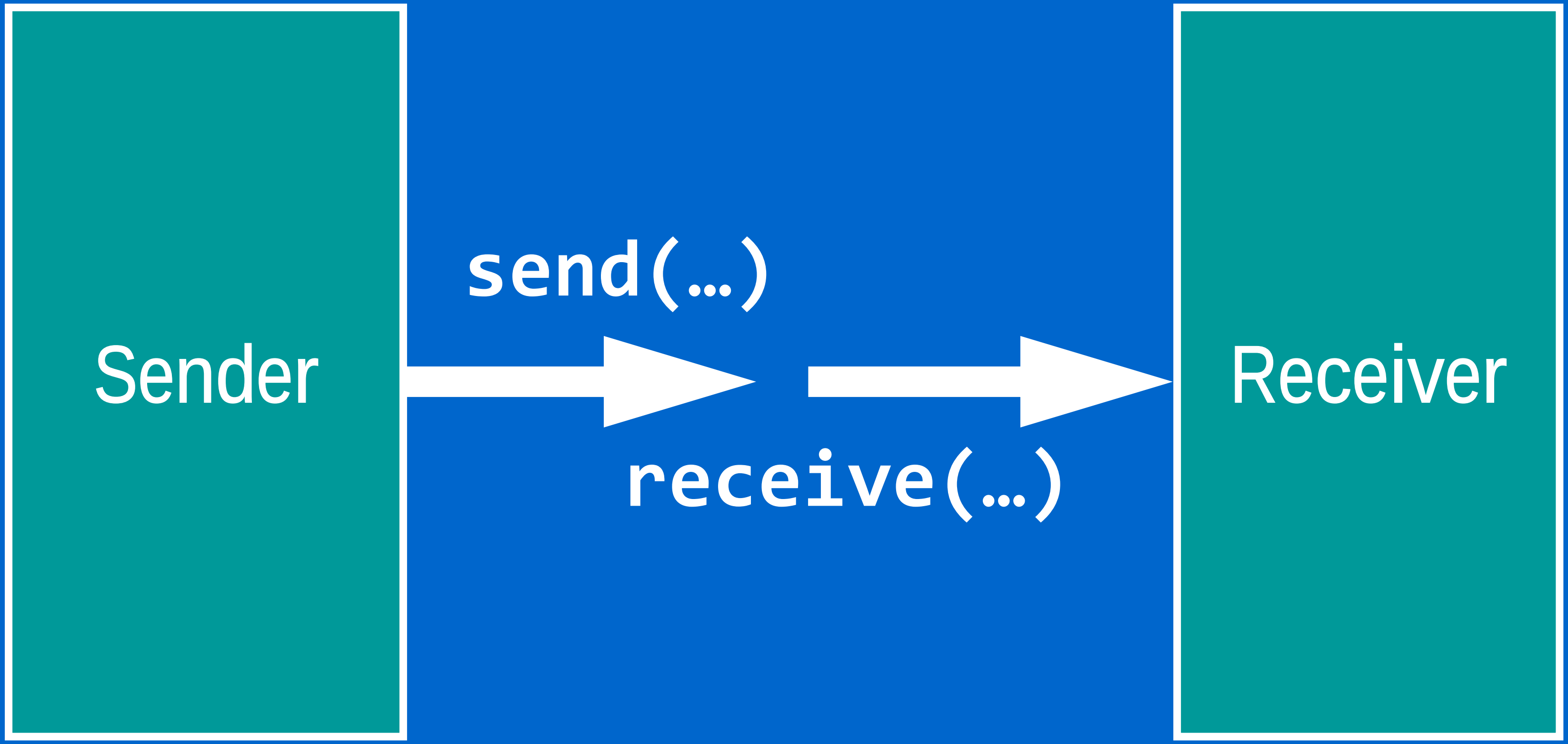
Blocking primitives (I)

- A *blocking send* does not return until the receiving process has received the message
  - No *buffering* is needed
  - *Analogous to what is happening when you call somebody who does not have voice mail*

Blocking primitives (II)

- A *blocking receive* does not return until a message has been received
- *Like waiting by the phone for an important message or staying all day by your mailbox waiting for the mail carrier*

Blocking primitives (III)



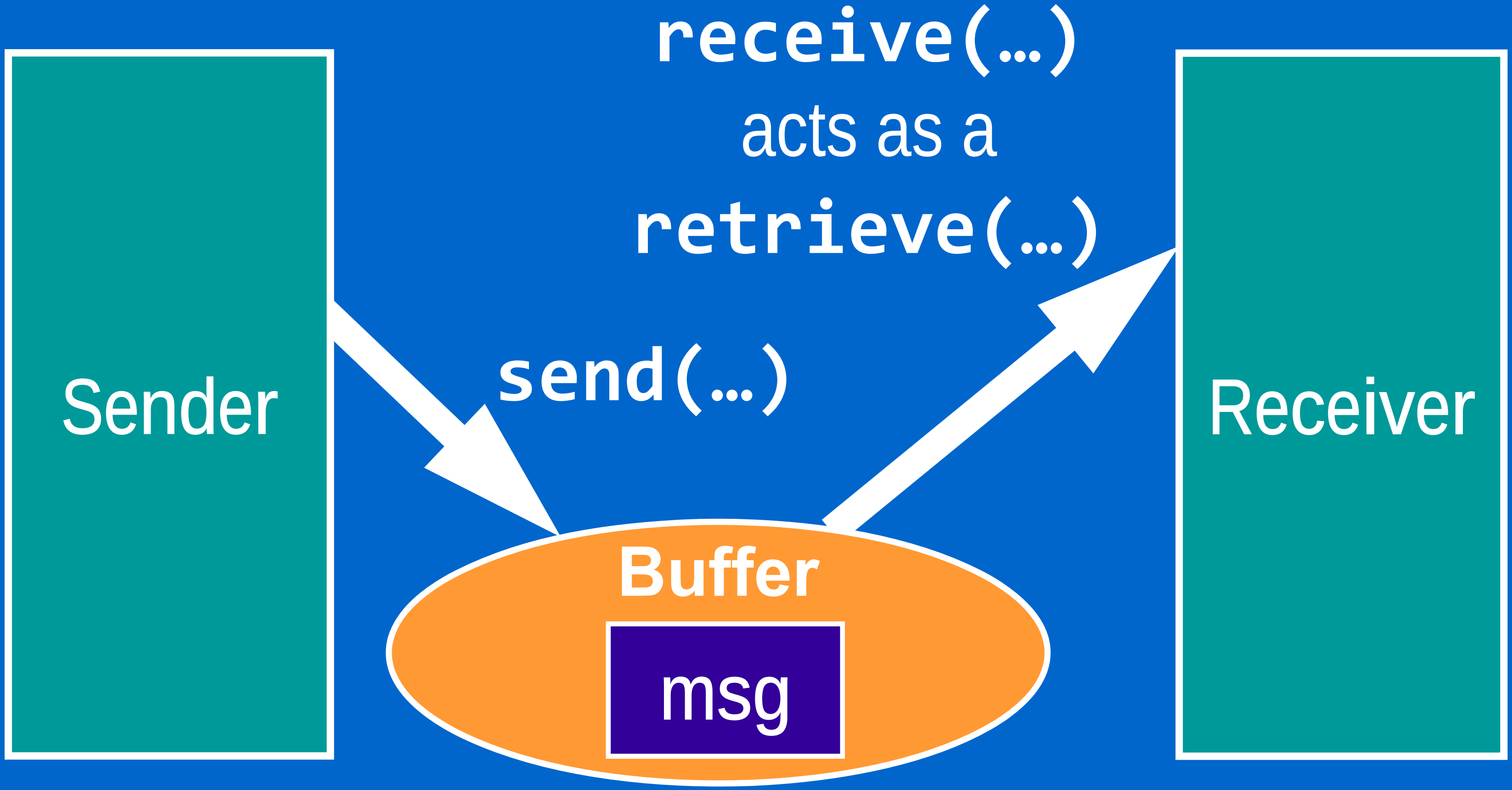
Non-blocking primitives (I)

- A *non-blocking send* returns as soon as the message has been accepted for delivery by the OS
  - Assumes that the OS can store the message in a *buffer*.
  - *Like mailing a letter: once the letter is dropped in the mailbox, we are done.* The mailbox will hold your letter until a postal employee picks it up

Non-blocking primitives (II)

- A *non-blocking receive* returns as soon as it has either retrieved a message or learned that the mailbox is empty
  - *Like checking whether your mail has arrived or not*

Non-blocking primitives (III)



receive(…) acts as a **retrieve(…)**

Simulating blocking receives

- Can simulate a blocking receive with a non-blocking receive within a loop:

```
do {
 code = receive(mbox,msg,size);
 sleep(1); // delay
} while (code == EMPTY_MBOX);
```

  – Known as a *busy wait*

Simulating blocking sends

- Can simulate a blocking send with two non-blocking sends and a blocking receive-:
  - Sender sends message and requests an acknowledgement (ACK)
  - Sender waits for ACK from receiver usign a blocking receive
  - Receiver sends ACK

The standard choice

- In general we prefer
  - *Indirect naming*
  - *Non-blocking sends*
    - Sender does not care about what happens once the message is sent
    - *Similar to UNIX delayed writes*
  - *Blocking receives*
    - Receiver needs the data to continue

Buffering

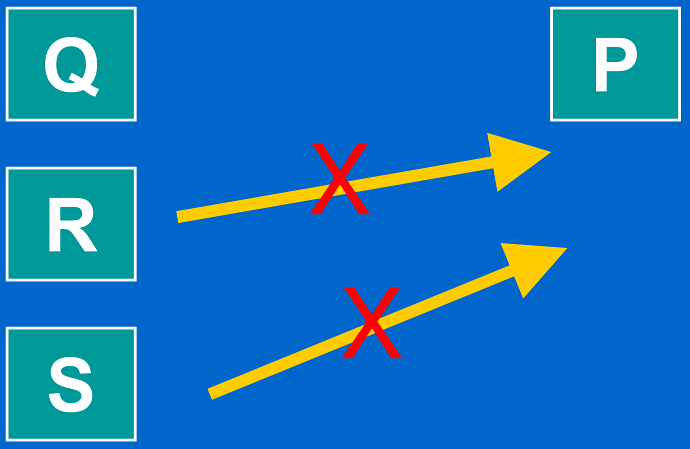
- *Non-blocking primitives* require *buffering* to let OS store somewhere messages that have been sent but not yet received
- These buffers can have
  - *Bounded capacity*
    - Refuse to receive messages when the buffer is full
  - Theoretically *unlimited capacity.*

An explosive combination (I)

- *Blocking receive* does not go well with *direct communication*
  - Processes cannot wait for messages from several sources without using special parallel programming constructs:
    - *Dijkstra's alternative command*

An explosive combination (II)

- Using blocking receives with direct naming does not allow the receiving process to receive any messages from any process but the one it has specified



```
receive(Q, msg)
```

Exception condition handling

- Must specify what to do if one of the two processes dies
  - Especially important whenever the two processes are on two different machines
    - Must handle
      - *Host failures*
      - *Network partitions*

Quality of service

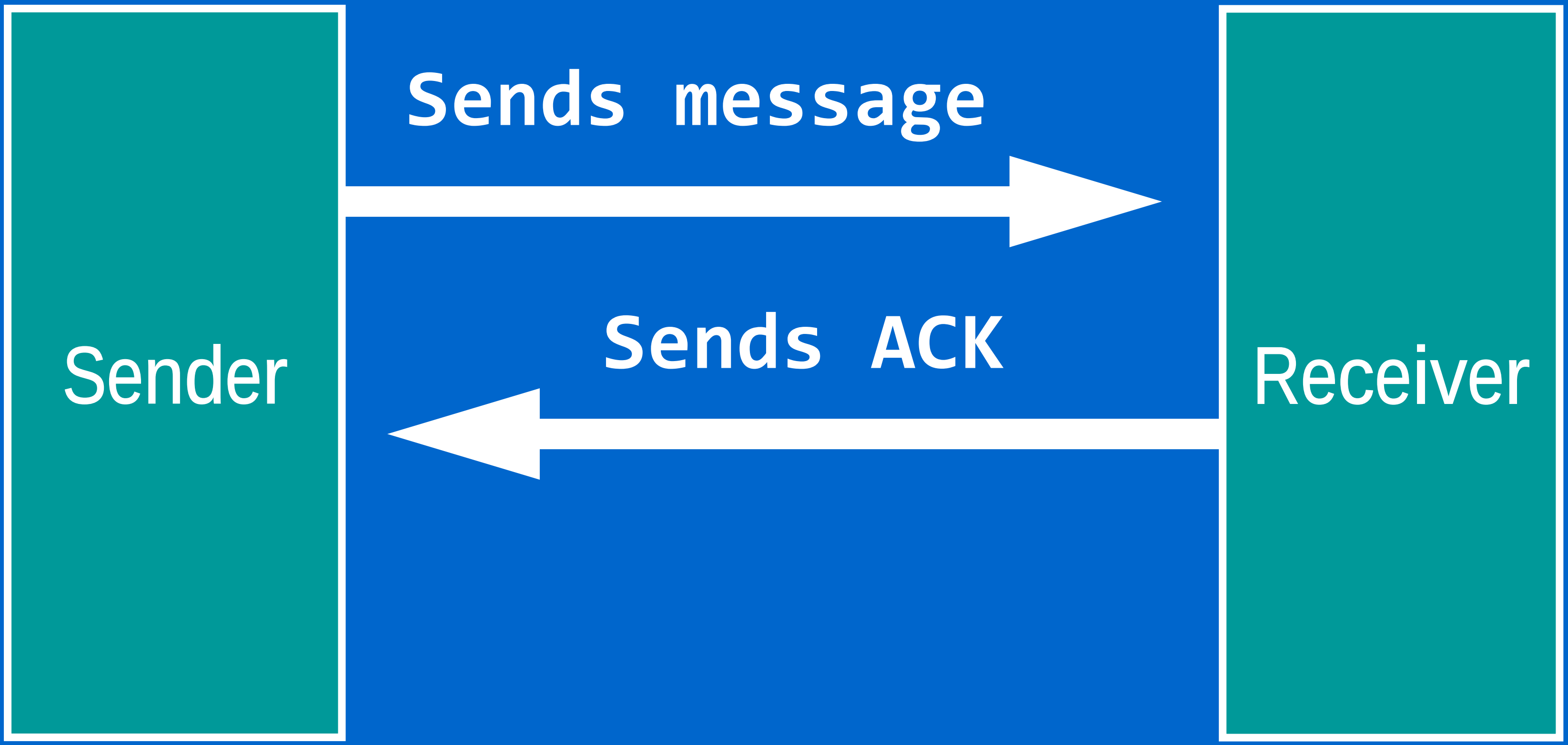
- When sender and receiver are on different machines, messages
  - Can be *lost*, *corrupted* or *duplicated*
  - Arrive *out of sequence*

- Can still decide to provide *reliable message delivery*

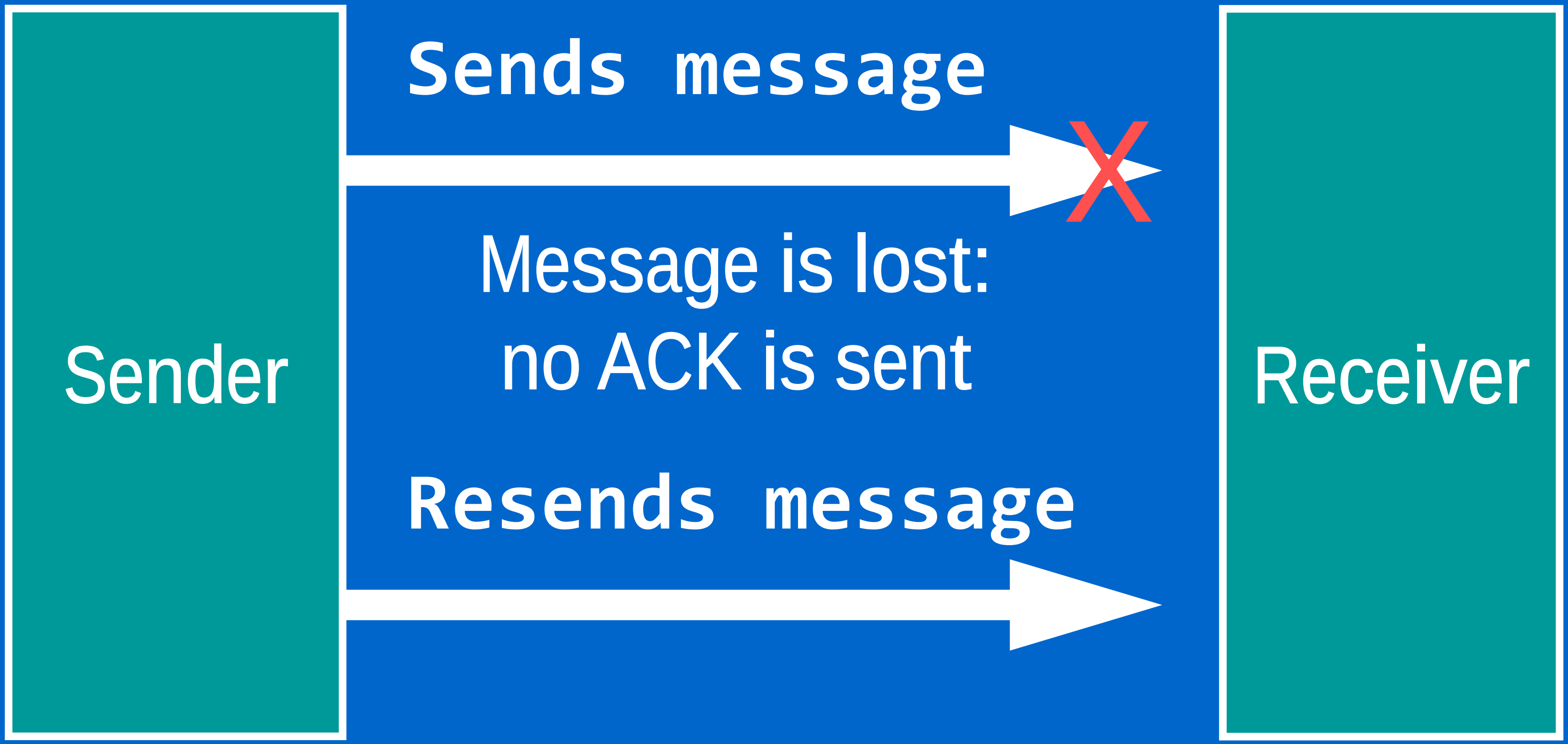
Positive Acknowledgments

- Basic technique for providing reliable delivery of messages
- Destination process sends an *acknowledgment message* (ACK) for every message that was correctly delivered
  - Damaged messages are ignored
- Sender resends any message that has not been acknowledged within a fixed time frame

First Scenario



Second Scenario



Sender

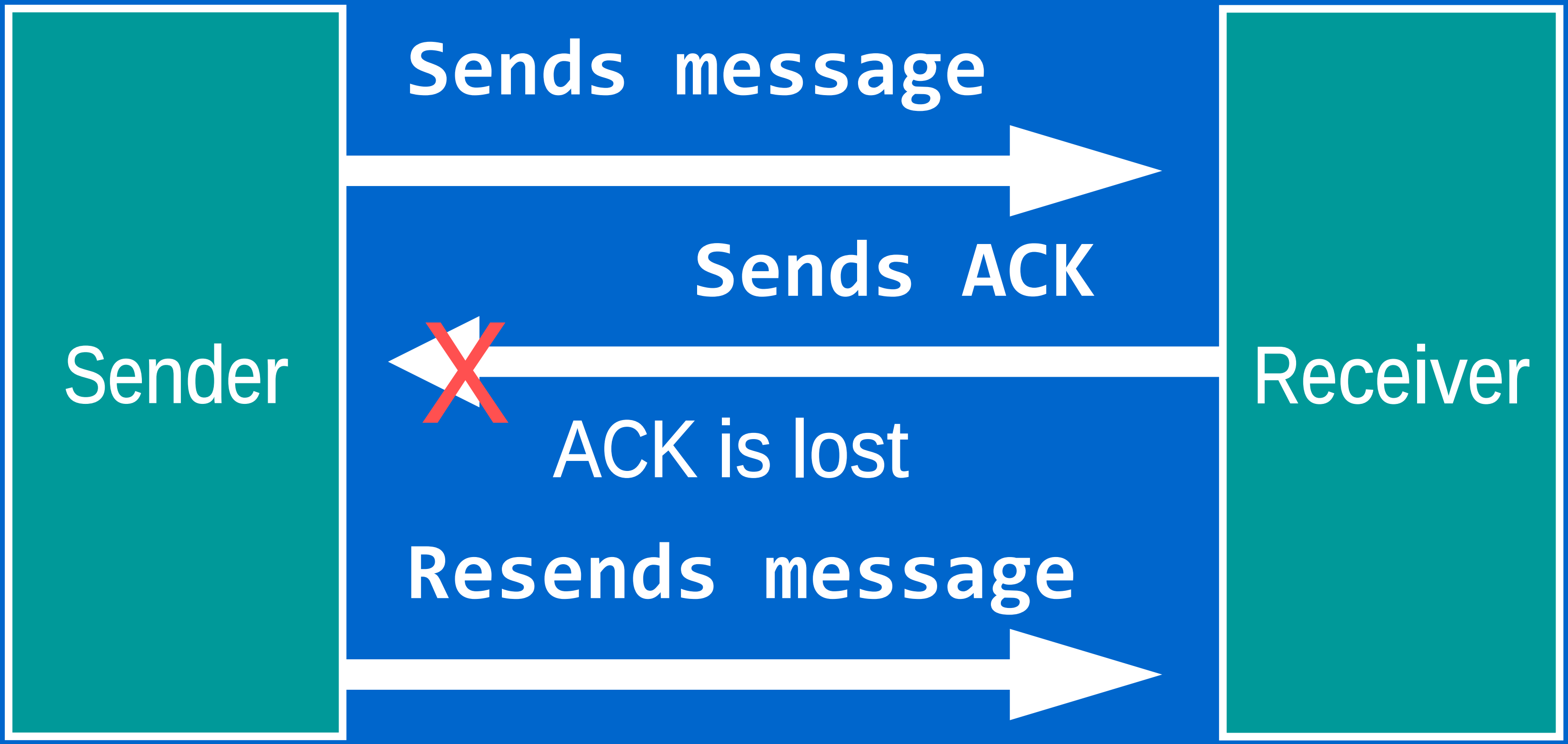
Sends message

Message is lost:
no ACK is sent

Resends message

Receiver

Third Scenario (I)



Sender

Sends message

Sends ACK

ACK is lost

Resends message

Receiver

Third Scenario (II)

- Receiver *must* acknowledge a second time the message
  - Otherwise it would be resent one more time

- Rule is
  - *Acknowledge any message that does not need to be resent!*

Classes of service

- *Datagrams:*
  - Messages are send one at time
- *Virtual circuits:*
  - Ordered sequence of messages
  - *Connection-oriented* service
- *Streams*:
  - Ordered sequence of bytes
  - Message boundaries are ignored

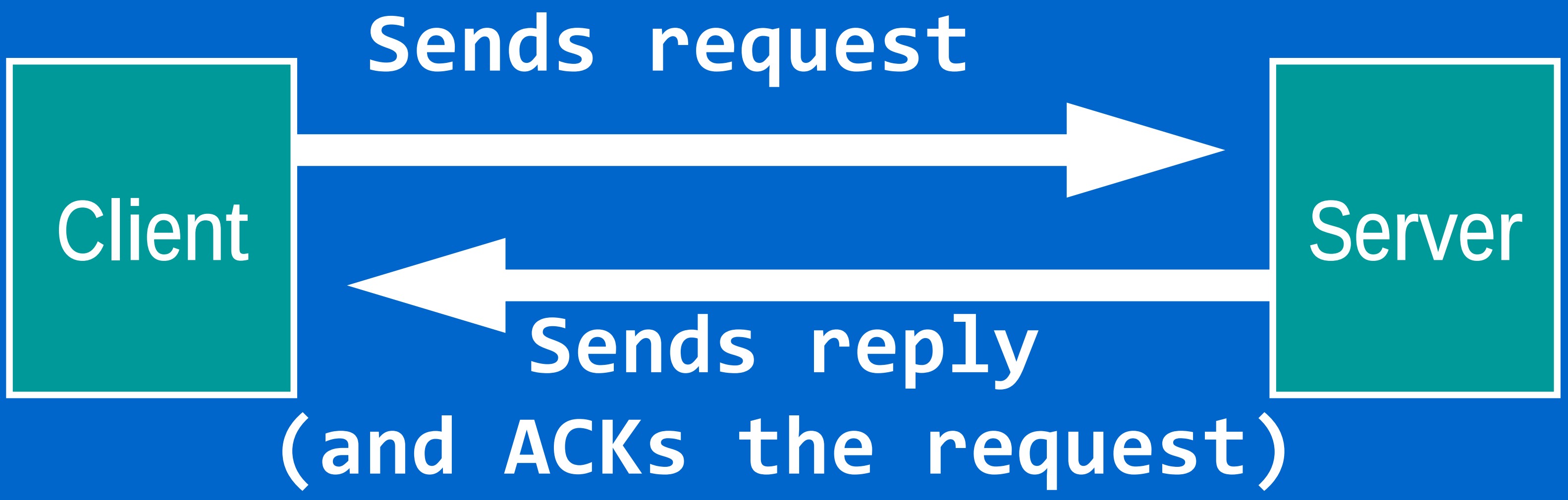
Datagrams

- Each message is sent *individually*
  - Some messages can be *lost*, other *duplicated* or arrive *out of sequence*
  - *Equivalent of a conventional letter*
- *Reliable datagrams:*

  resent until they are acknowledged
- *Unreliable datagrams*

Unreliable datagrams (I)

- Messages are not acknowledged
- Works well when message requests a reply
  - – Reply is *implicit ACK* of message



Unreliable datagrams (II)

- Exactly what we do in real life:
  - *We rarely ACK emails and other messages*
  - *We reply to them!*

- Sole reason to ACK a request is when it might take a long time to reply to it

UDP

- *User Datagram Protocol*
- Best known datagram protocol
- Provides an unreliable datagram service
  - Messages can be *lost*, *duplicated* or arrive *out of sequence*
- Best for short interactions
  - One request and one reply

Virtual circuits (I)

- Establish a *logical connection* between the sender and the receiver
- Messages are *guarante*ed to arrive in sequence without lost messages or duplicated messages
  - *Analogous to the words of a phone conversation*

Virtual circuits (II)

- Require setting up a virtual connection *before* sending any data
  - Costlier than datagrams
- Best for transmitting large amounts of data that require sending several messages
  - *File transfer protocol* (FTP)
  - *Hypertext transfer protocol* (HTTP)

Streams

- Like virtual circuits
- Do *not* preserve message boundaries:
  - Receiver sees a *seamless stream of bytes*
- Offspring of UNIX philosophy
  - Record boundaries do not count
  - Message boundaries should not count

TCP

- Transmission Control Protocol
- Best known stream protocol
- Provides a reliable stream service
- Said to be *heavyweight*
  - Requires three messages (*packets*) to establish a virtual connection

Datagrams and Streams

- *Datagrams:*
  - Unreliable
  - Not ordered
  - Lightweight
  - Deliver messages
- *Example:*
  - UDP

- *Streams:*
  - Reliable
  - Ordered
  - Heavyweight
  - Stream-oriented
- *Example:*
  - TCP

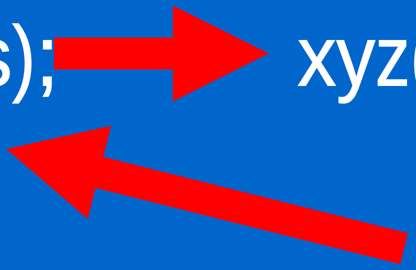
REMOTE PROCEDURE CALLS

- Apply to **client-server** model of computation
- A typical client-server interaction:

```
send_req(args);          rcv_req(&args);
                         process(args, &results);
                         send_reply(results);
rcv_reply(&results);
```

RPC (cont’d)

- Very similar to a procedure call to a procedure:
- xyz(args, &results);

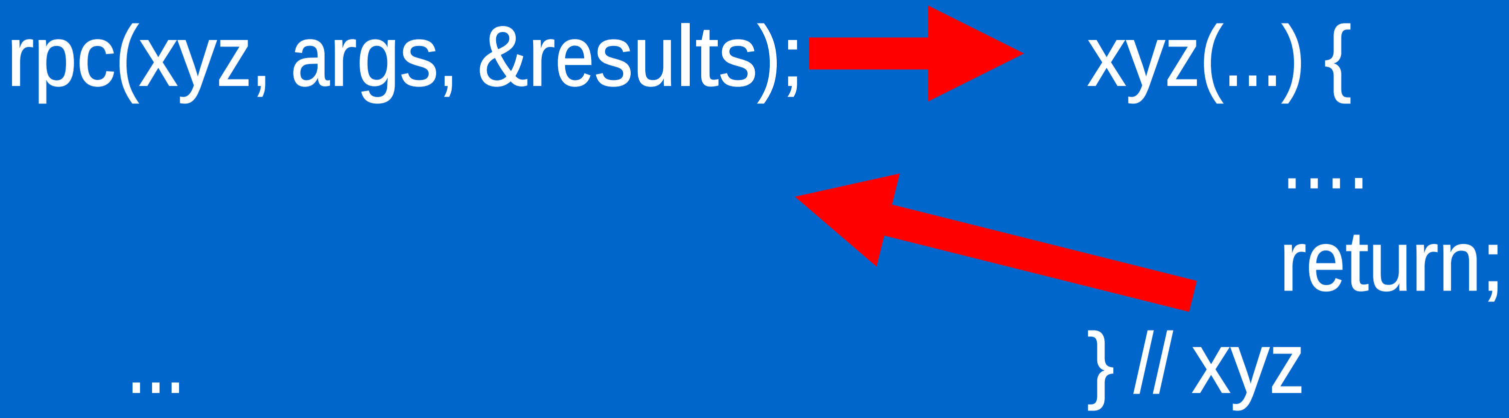


```
xyz(args, &results);          xyz(...) {
                                  ....
                                  return;
    ...                       } // xyz
```

- Try to use the same formalism

RPC (cont’d)

- We could write



```
rpc(xyz, args, &results);        xyz(...) {
                                         ....
                                         return;
    ...                          } // xyz
```

and let system take care of all message passing details

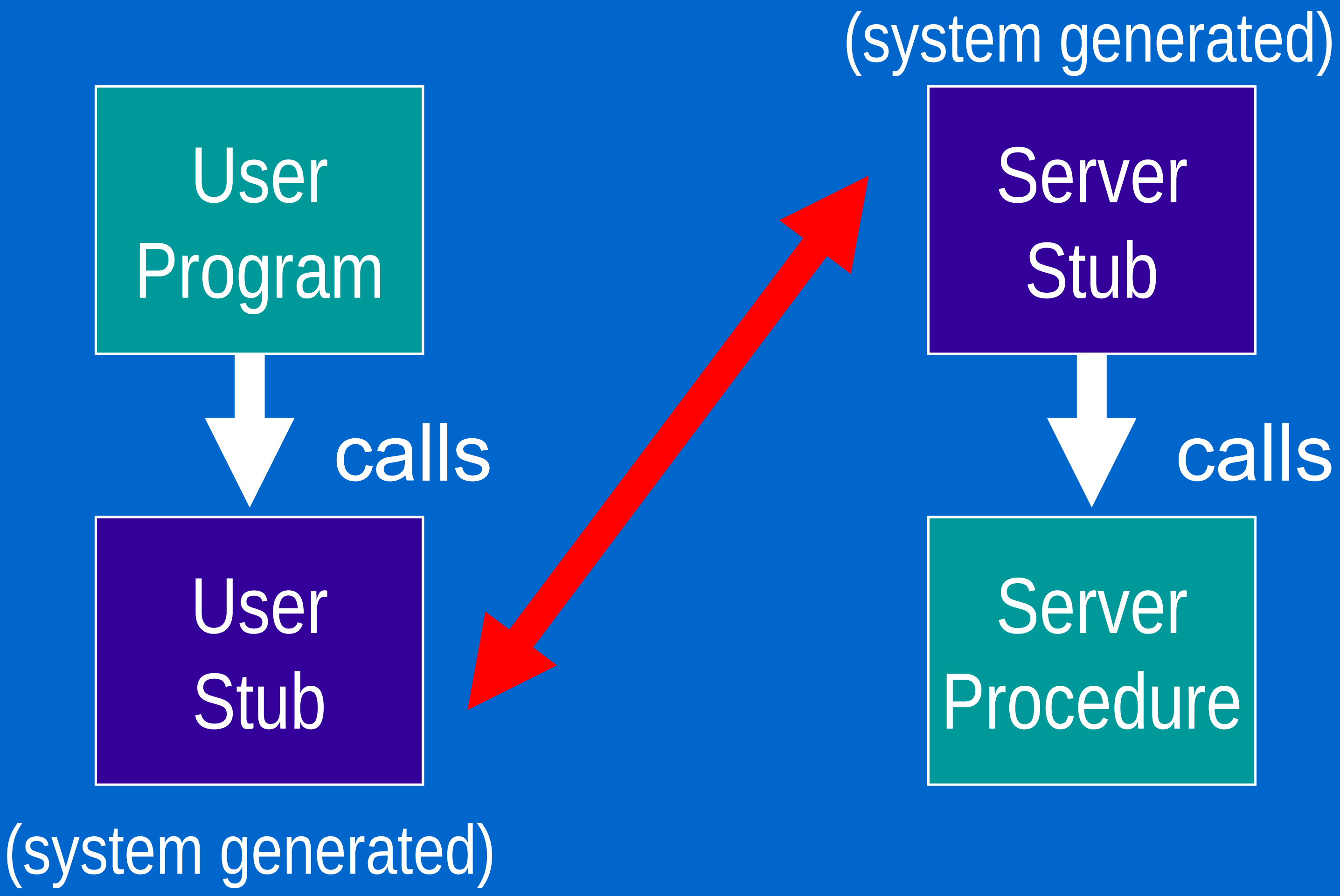
Advantages

- Hides all details of message passing
  - Programmer can focus on the logic of her application
- Provides a higher level of abstraction
- Extends a well-known model of programming
  - Anybody that can use procedures and function can quickly learn to use remote procedure calls

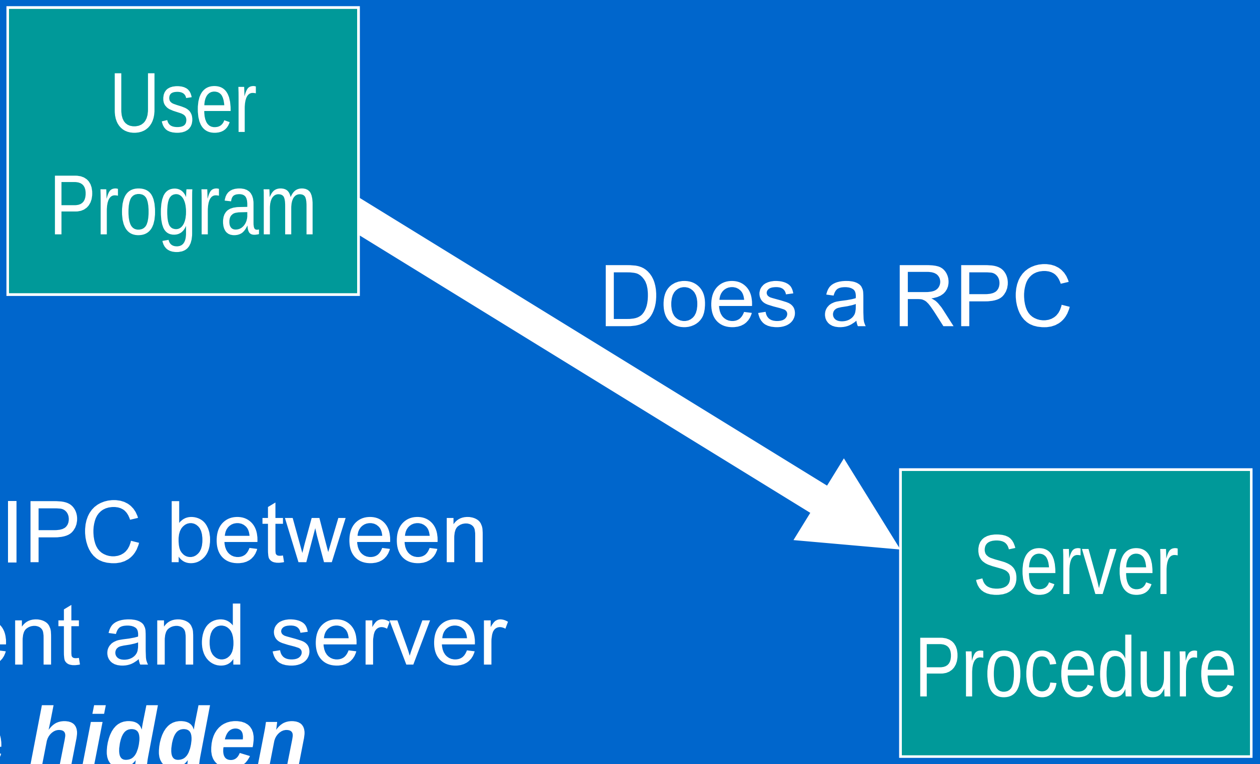
Disadvantage

- The illusion is not perfect
  - RPCs do not always behave exactly like regular procedure calls
    - Client and server do not share the same address space
- Programmer must remain aware of these subtle and not so subtle differences

General Organization



What the programmer sees



User Program

Does a RPC

Server Procedure

All IPC between client and server are ***hidden***

The user program

- Contains the user code
- Calls the user stub

```
rpc(xyz, args, &results);
```

- *Appears* to call the server procedure

The user stub

- Procedure generated by RPC package:
  - Packs arguments into request message and performs required data conversions (*argument marshaling*)
  - Sends request message
  - Waits for server's reply message
  - Unpacks results and performs required data conversions (*argument unmarshaling*)

The server stub

- Generic server generated by RPC package:
  - Waits for client requests
  - Unpacks request arguments and performs required data conversions
  - Calls appropriate server procedure
  - Packs results into reply message and performs required data conversions
  - Sends reply message

The server procedure

- Procedure called by the server stub
- Written by the user
- Does the actual processing of user requests

Differences with regular PC

- Client and server processes *do not share* the *same address space*
- Client and server can be on *different machines*
- Must handle *partial failures*

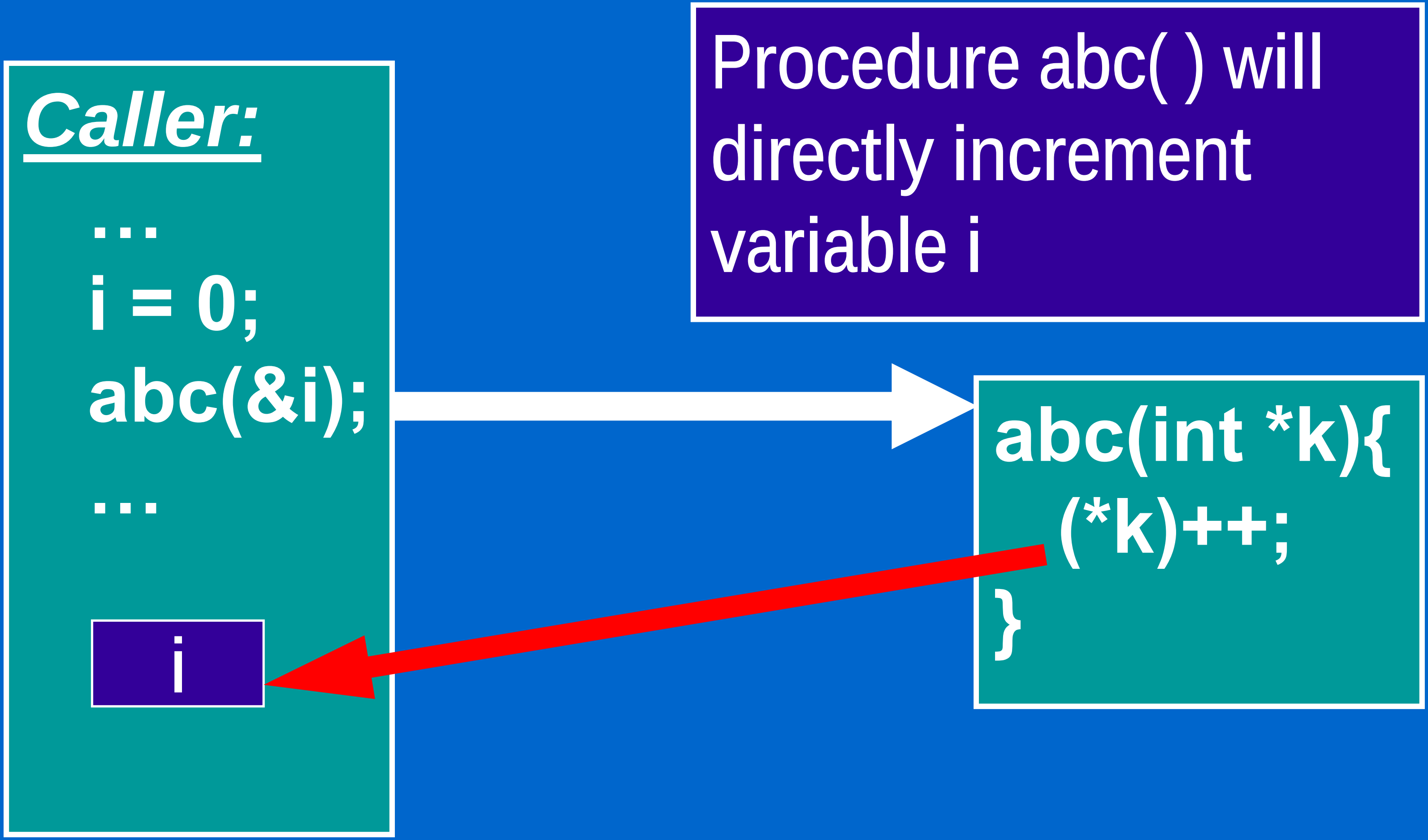
No shared address space

- This means
  - *No global variables*
  - *Cannot pass addresses*
    - Cannot pass arguments by reference
    - Cannot pass dynamic data structures through pointers

The solution

- RPC *can pass arguments by value and result*
  - Pass the *current value* of the argument to the remote procedure
  - *Copy* the *returned value* in the user program
- Not the same as passing arguments by reference

Passing by reference



Procedure abc( ) will directly increment variable i

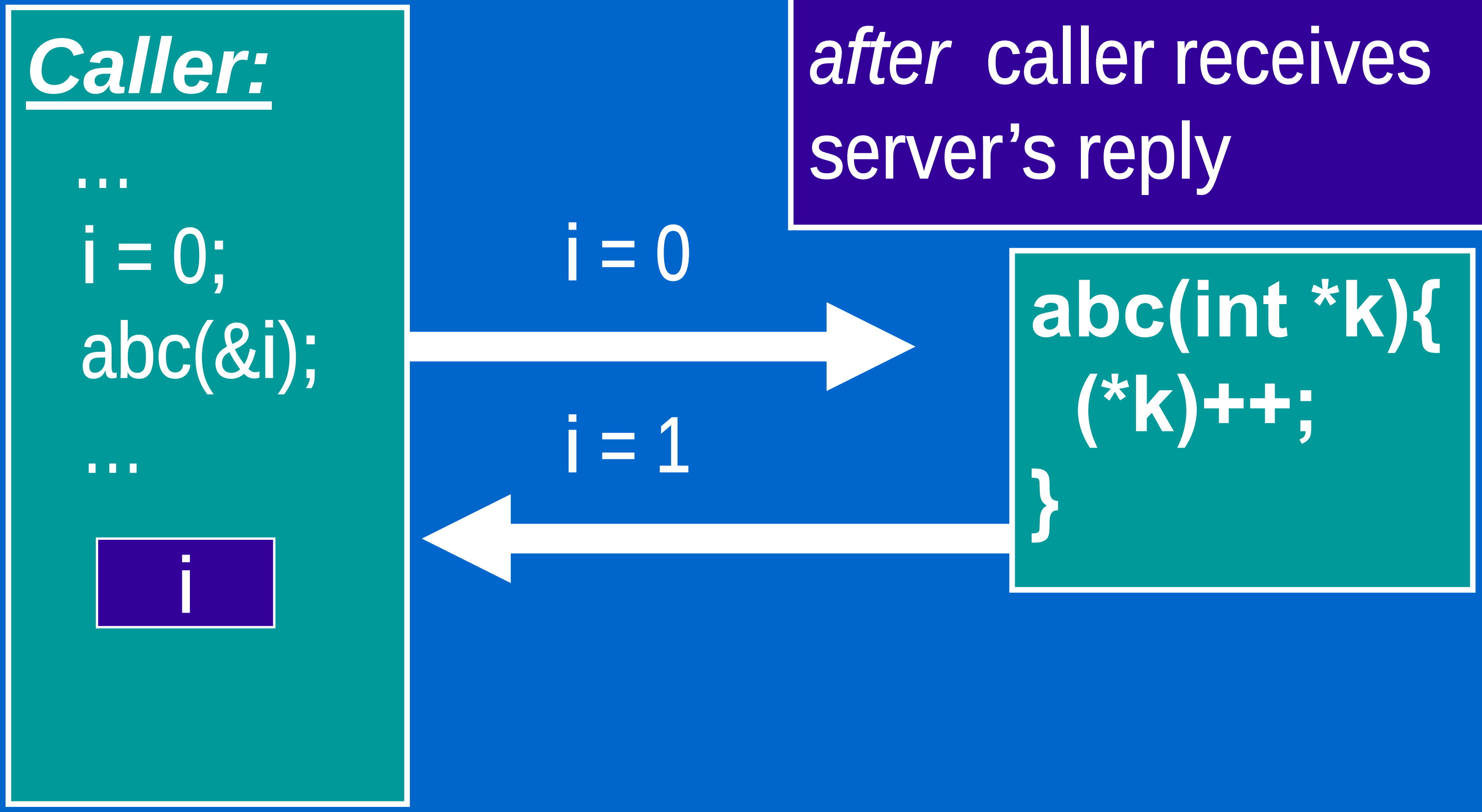
Caller:

```
…
i = 0;
abc(&i);
…
```

```
abc(int *k){
   (*k)++;
}
```

Passing by value and result

Variable i is increased *after* caller receives server’s reply



Caller:

```
...
i = 0;
abc(&i);
...
```

```
abc(int *k){
  (*k)++;
}
```

An example (I)

- Procedure doubleincrement

```
doubleincrement(int *p,int *q) {
   (*p)++ ; (*q)++ ;
} // doubleincrement
```

- Calling

```
      doubleincrement(&m, &m);
```

should increment *m twice*

An example (II)

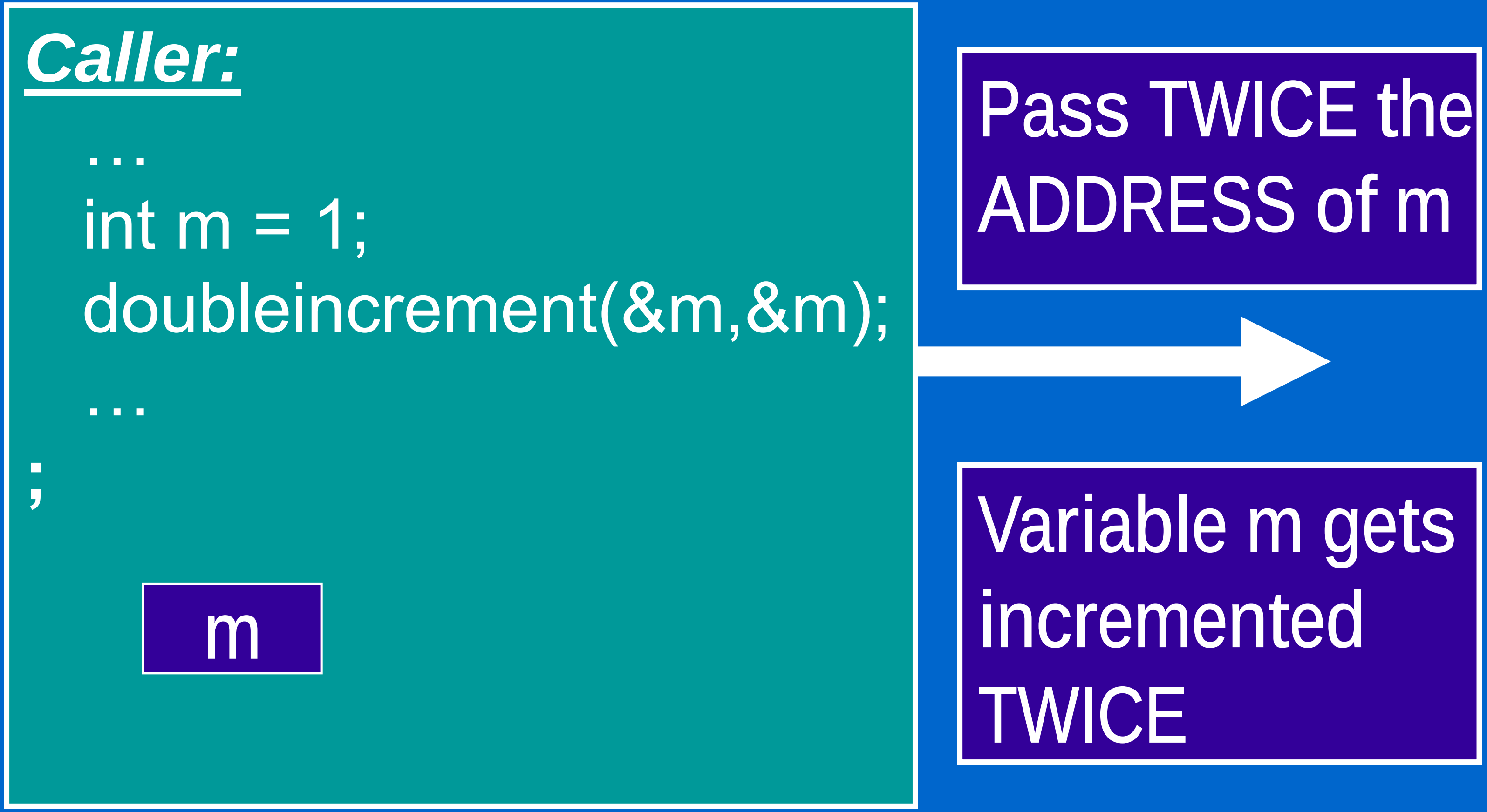
- Calling

  ```
  doubleincrement(&m, &m);
  ```

  passing arguments by *value and return* only increments m *once*
- Let us consider the code fragment

  ```
  int m = 1;
  doubleincrement(&m, &m);
  ```

Passing by reference



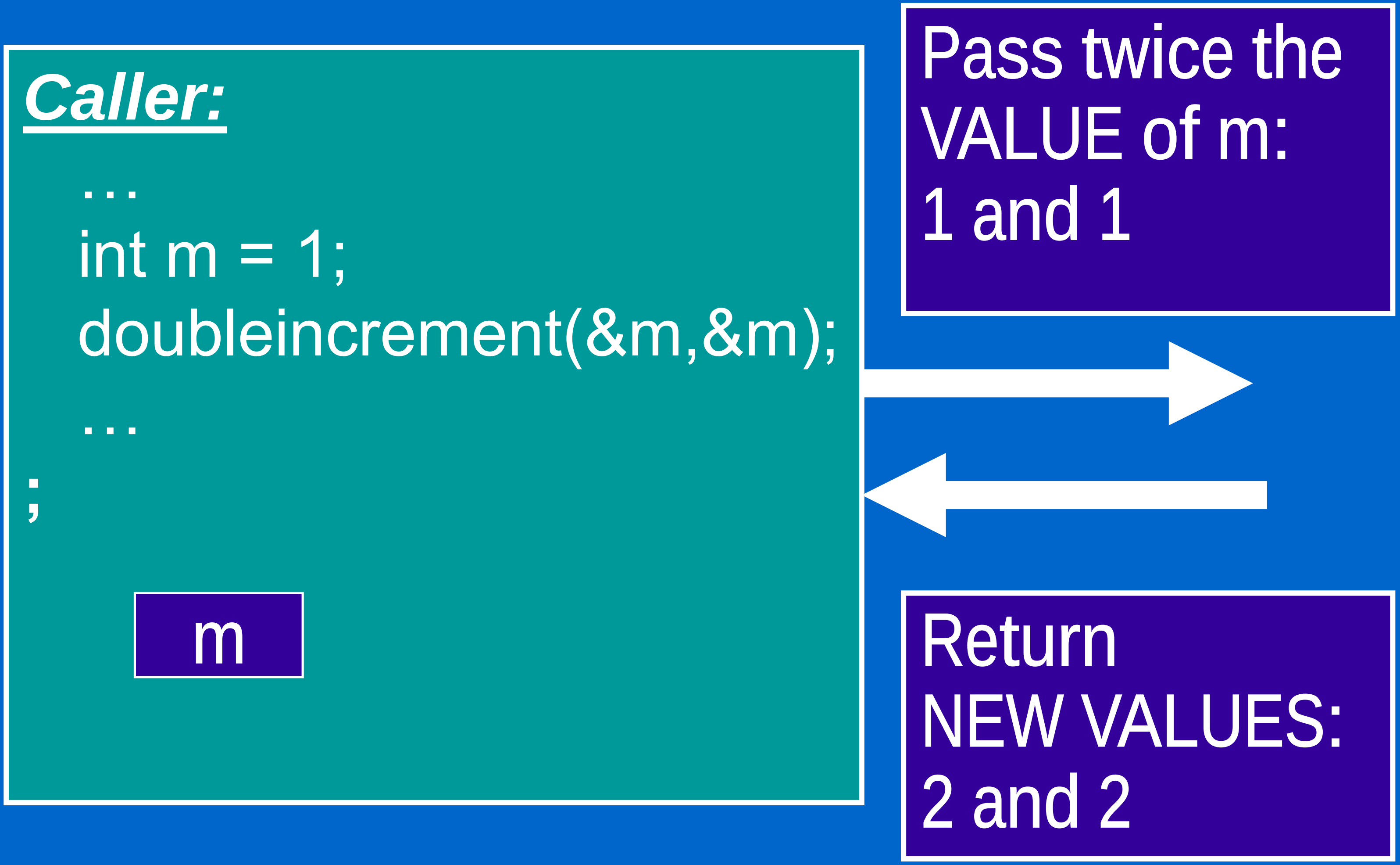
Caller:

```
   …
   int m = 1;
   doubleincrement(&m,&m);
   …
;
```

Pass TWICE the ADDRESS of m

Variable m gets incremented TWICE

Passing by value and result



__Caller:__

```
   …
   int m = 1;
   doubleincrement(&m,&m);
   …
;
```

Pass twice the VALUE of m:
1 and 1

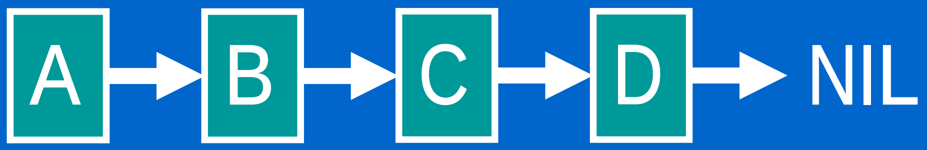
Return
NEW VALUES:
2 and 2

Passing dynamic types (I)

- Cannot pass dynamic data structures through pointers
- Must send a copy of data structure
- For a linked list
  - Send array with elements of linked list plus unpacking instructions

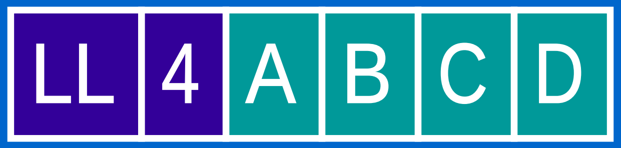
Passing dynamic types (II)

- We want to pass



A B C D NIL

- We send to the remote procedure



LL	4	A	B	C	D

- Header identifies linked list with four elements

The NYC Cloisters

Rebuilt in NYC from actual cloister stones

Architecture considerations

- The machine representations of floating point numbers and byte ordering conventions can be different:
  - *Little endians* start at the *least* significant byte:
    - *Intel's 80x86 including Pentium*
  - *Big-endians* start at the *most* significant byte:
    - *Sun’s SPARC and most RISC processors*

The solution

- Define a network order and convert all numerical variables to that order
  - Use **`hton`** family of functions
  - *Same as requiring all air traffic control communications to be in English*

Detecting partial failures

- The client must detect *server failures*
  - Can send *are you alive?* messages to the server at fixed time intervals
  - *That is not hard!*

Handling partial executions

- Client must deal with the possibility that the server could have crashed *after* having partially executed the request
  - ATM machine calling the bank computer
    - Was the account debited or not?

First solution (I)

- *Ignore* the problem and *always resubmit* requests that have not been answered
  - Some requests may be executed more than once
- Will work if all requests are *idempotent*
  - Executing them several times has the same effect as executing them exactly once

First solution (II)

- Examples of idempotent requests include:
  - Reading *n* bytes from a fixed location
    - *NOT reading next n bytes*
  - Writing *n* bytes starting at a fixed location
    - *NOT writing n bytes starting at current location*
- Technique is used by all RPCs in the Sun Microsystems' *Network File System* (NFS)

Second solution

- Attach to each request a *serial number*
  - Server can detect replays of requests it has previously received and refuse to execute them
  - *At most once* semantics
- Cheap but not perfect
  - Some requests could end being partially executed

Third solution

- Use a *transaction mechanism*
  - Guarantees that each request will *either* be *fully executed* or have *no effect*
  - *All or nothing* semantics
- Best and costliest solution
- Use it in all *financial transactions*

An example

- Buying a house using *mortgage money*
  - Cannot get the mortgage without having a title to the house
  - Cannot get title without paying first previous owners
  - Must have the mortgage money to pay them
- Sale is a complex atomic transaction

Realizations (I)

- *Sun RPC:*
  - Developed by Sun Microsystems
  - Used to implement their Network File System
- *MSRPC (Microsoft RPC):*
  - Proprietary version of the DCE/RPC protocol
  - Was used in the Distributed Component Object Model (DCOM).

Realizations (II)

- *SOAP:*
  - Exchanges XML-based messages
  - Runs on the top of HTTP
    - Very portable
    - Very verbose
- *JSON-RPC:*
    - Uses *JavaScript Object Notation* (JSON)