Chapter IV
INTER-PROCESS COMMUNICATION

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Chapter overview

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

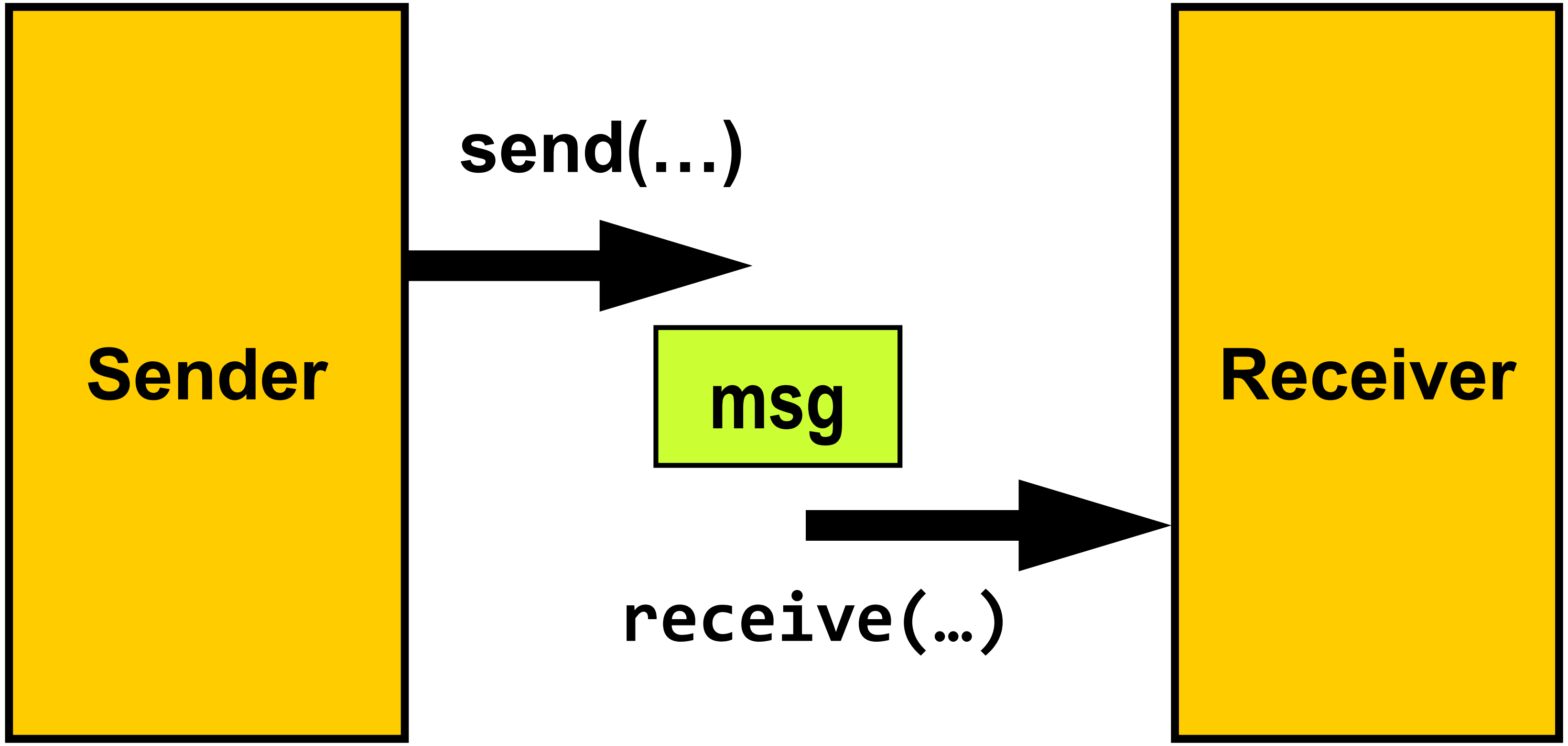
Message passing (I)

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

    ```
    send(addr, msg, length);
    ```
  - ***A receive***

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

Message passing (II)



Advantages

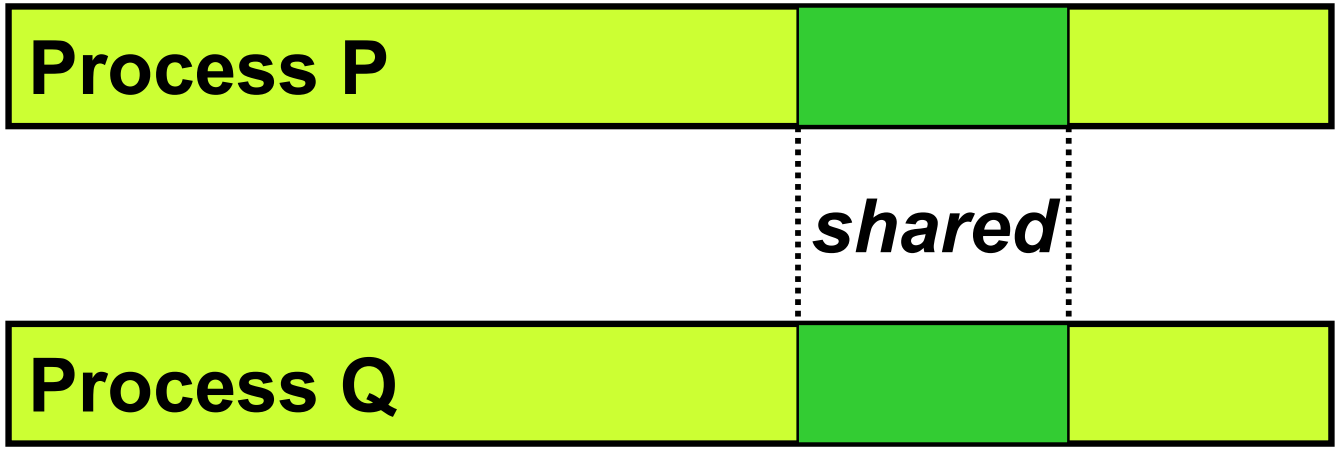
- ***Very general***
  - Sender and receivers can be on different machines
- ***Relatively secure***
  - Receiver can inspect the messages it has received before processing them

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

Limitations

- ***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

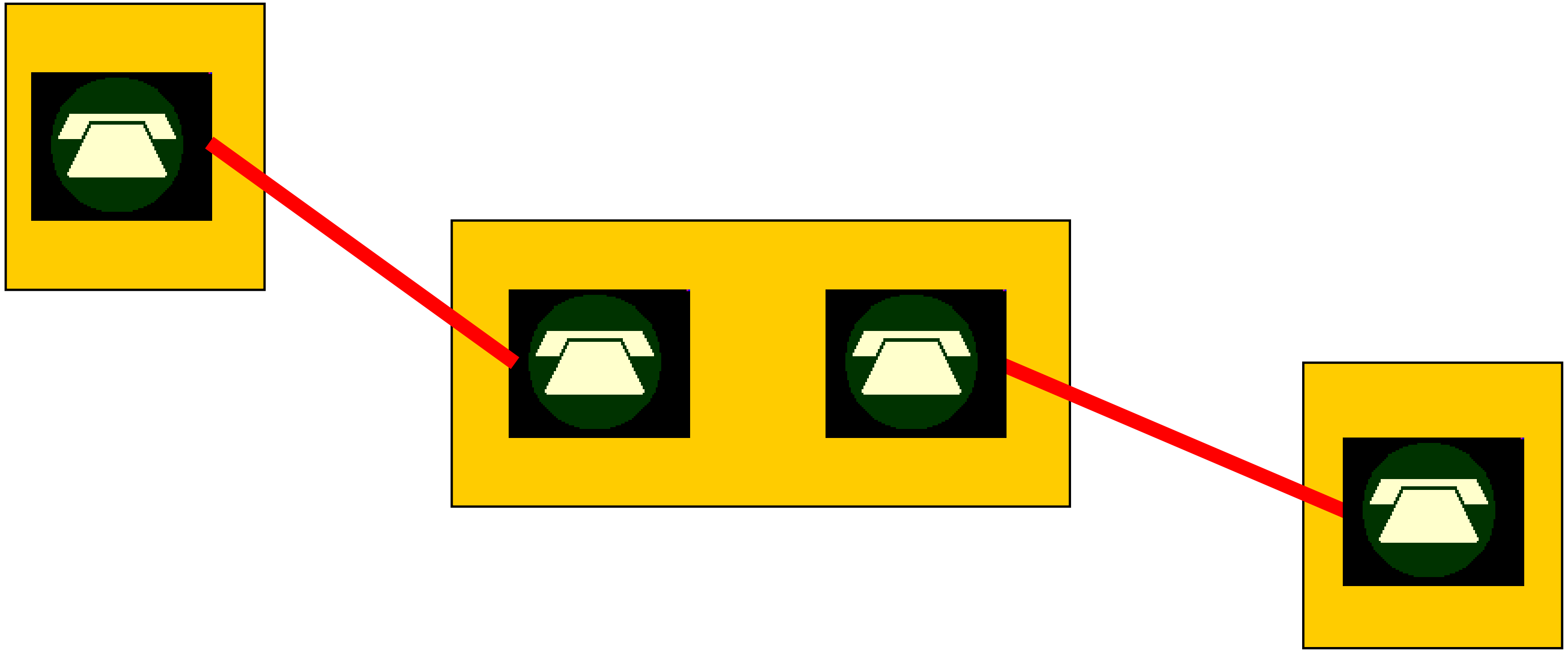
- Direct/Indirect communication
- Blocking/Non-blocking primitives
- Exception handling
- Quality of service
  - Unreliable/reliable datagrams
  - Virtual circuits, streams

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)

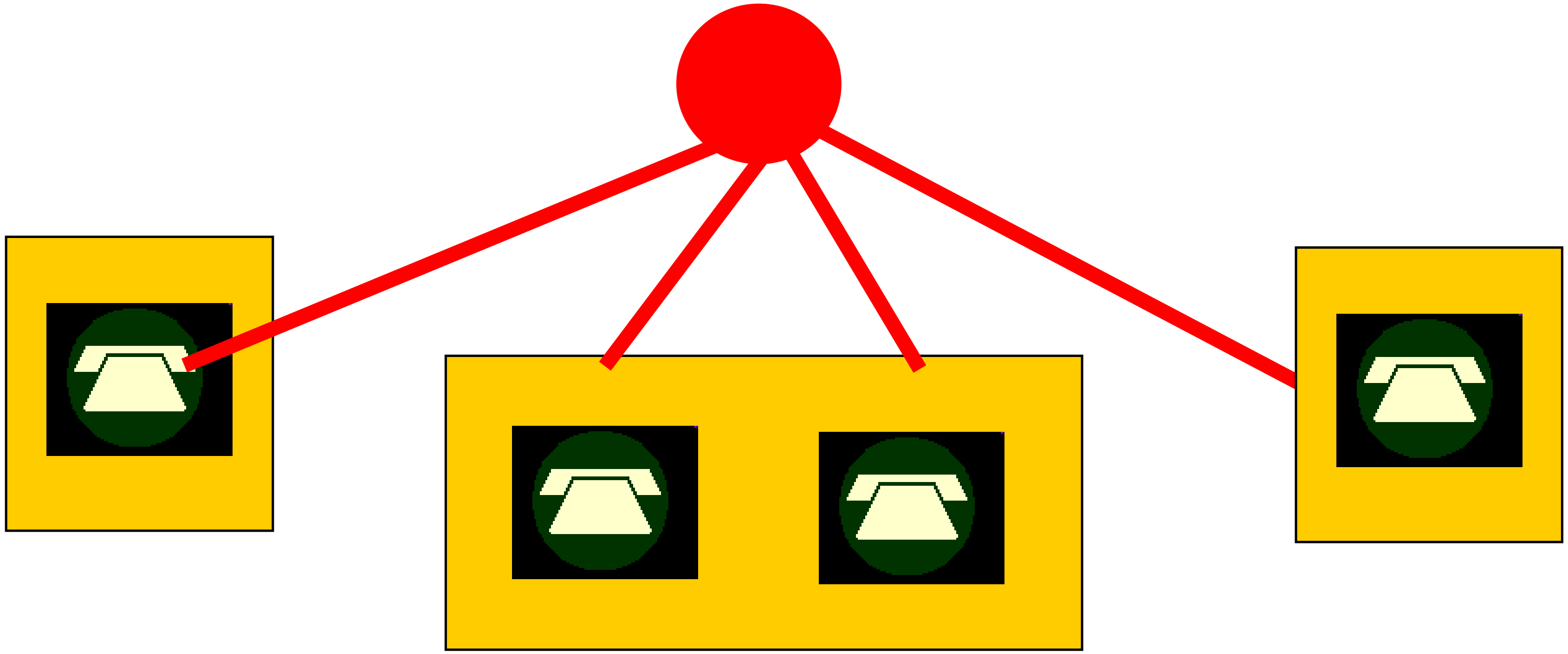
- Send and receive primitives now specify an ***intermediary entity*** as destination or source: the ***mailbox***

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

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

Back to the phone analogy (I)

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



Back to the phone 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***
- ***<u>Example:</u>*** System V UNIX ***message queues***

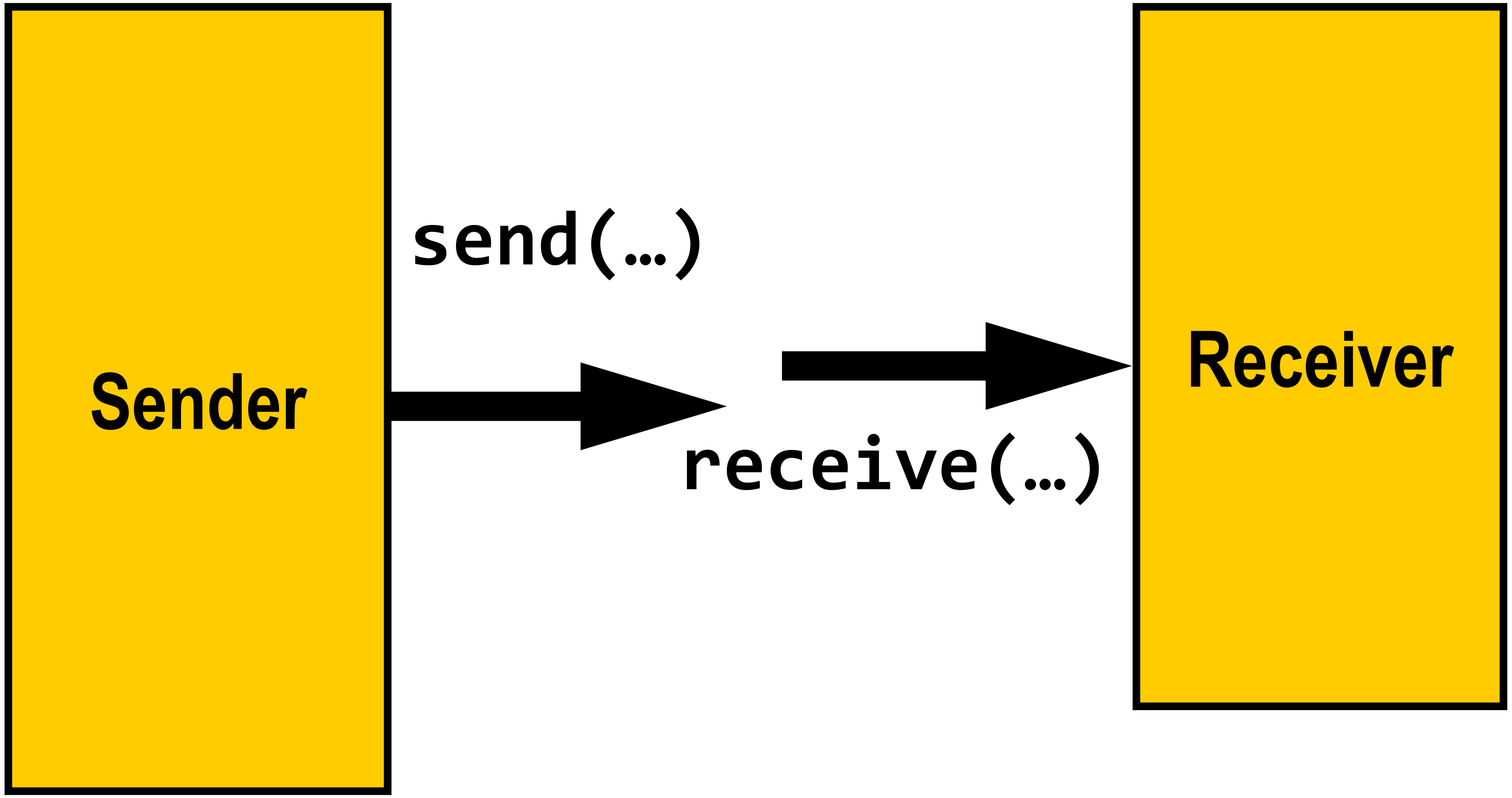
Blocking primitives (I)

- 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)



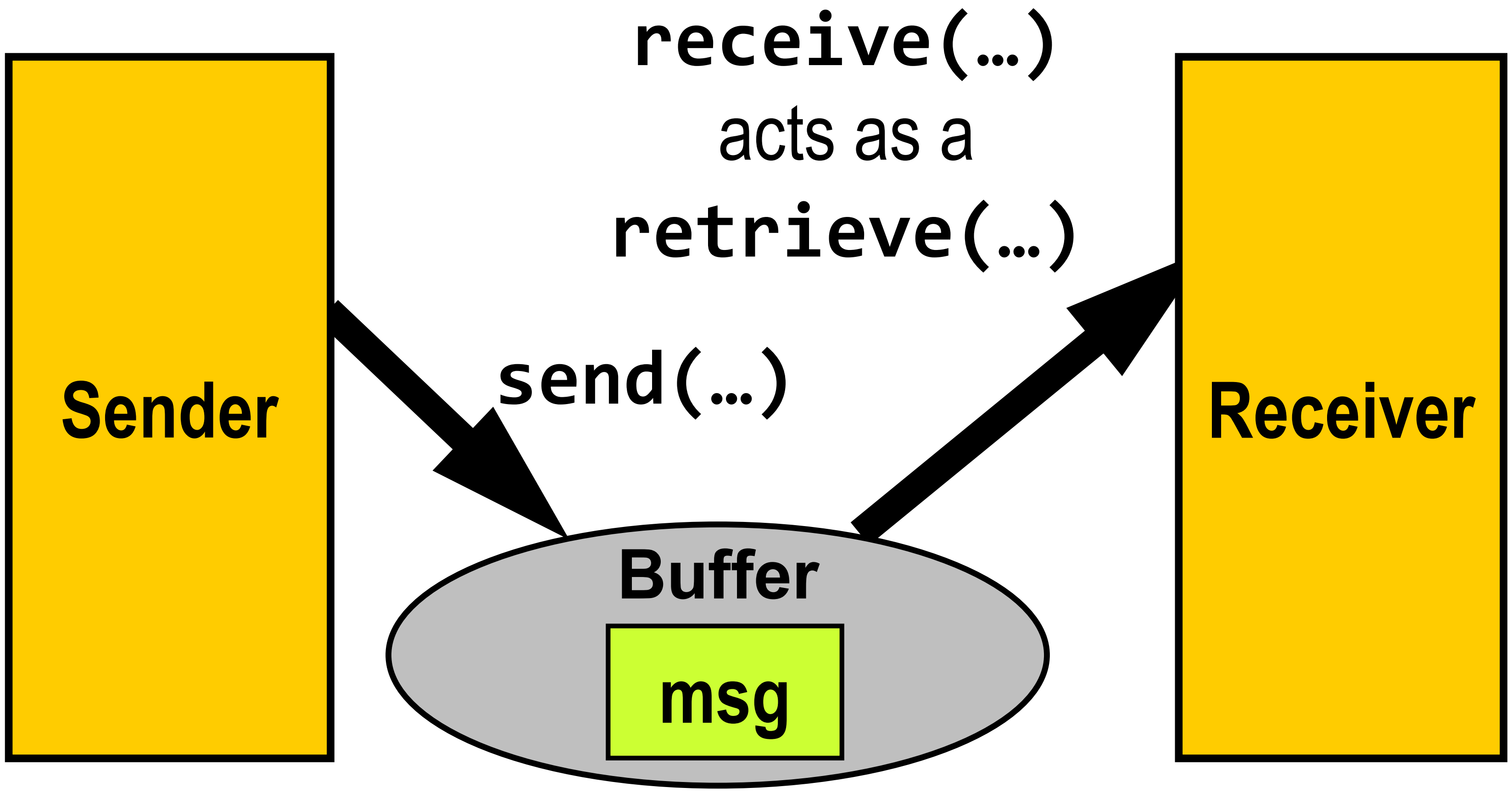
Non-blocking primitives (I)

- 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)



Simulating blocking receives

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

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

- Known as a ***busy wait***
  - *Costlier than a **blocking 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 using a blocking receive
  - Receiver sends ACK
- *Think certified mail with return receipt requested*

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

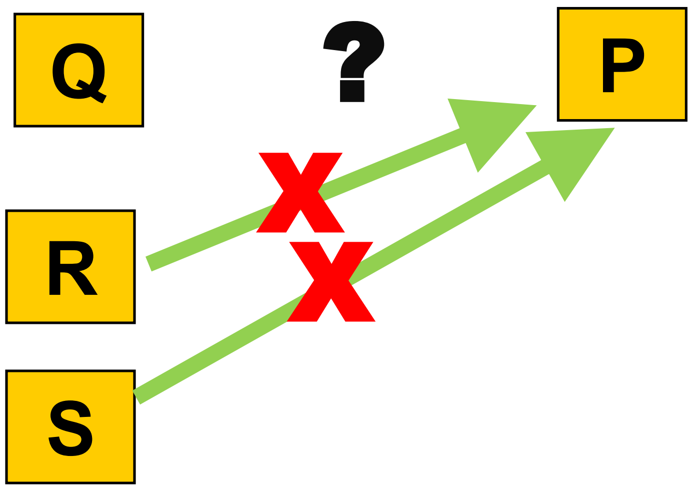
- ***Non-blocking primitives*** require ***buffering*** to let OS store somewhere messages that have been sent but not yet received
- These buffers can have
  - ***Bounded capacity***
    - Refuse to receive messages when the buffer is full
  - Theoretically ***unlimited capacity.***

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 other process***




```
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***

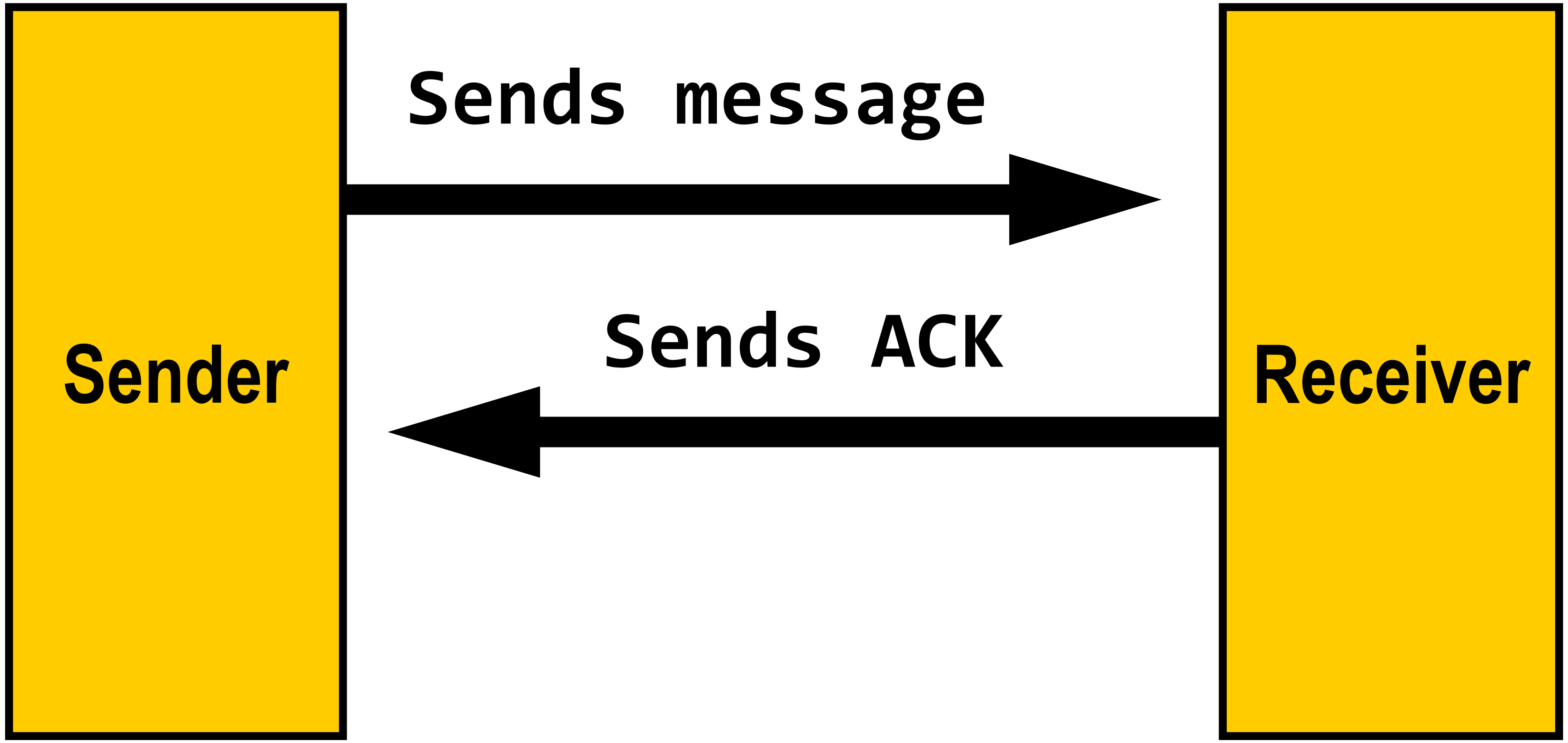
Quality of service

- 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***
  - *Using positive acknowledgments*

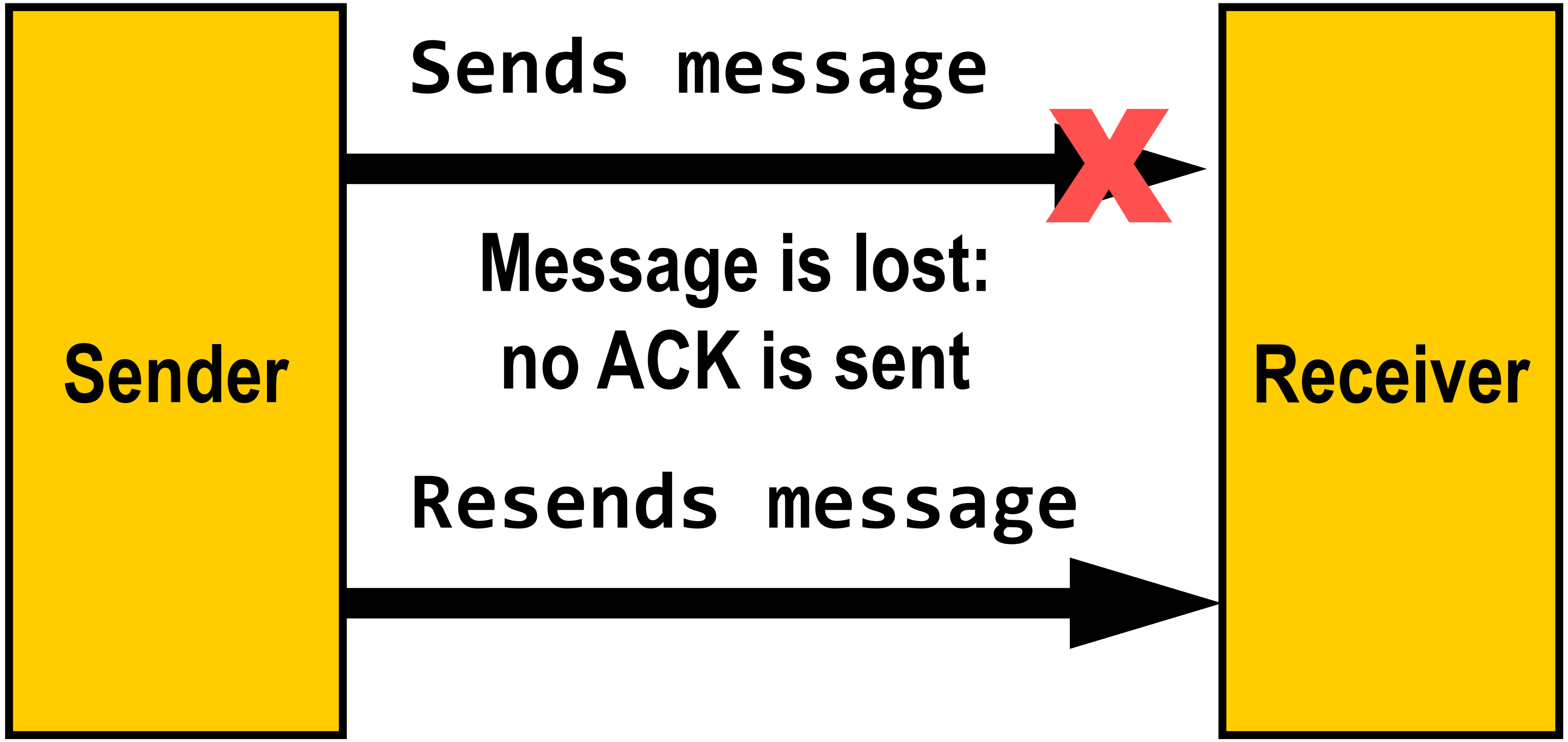
Positive acknowledgments

- 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

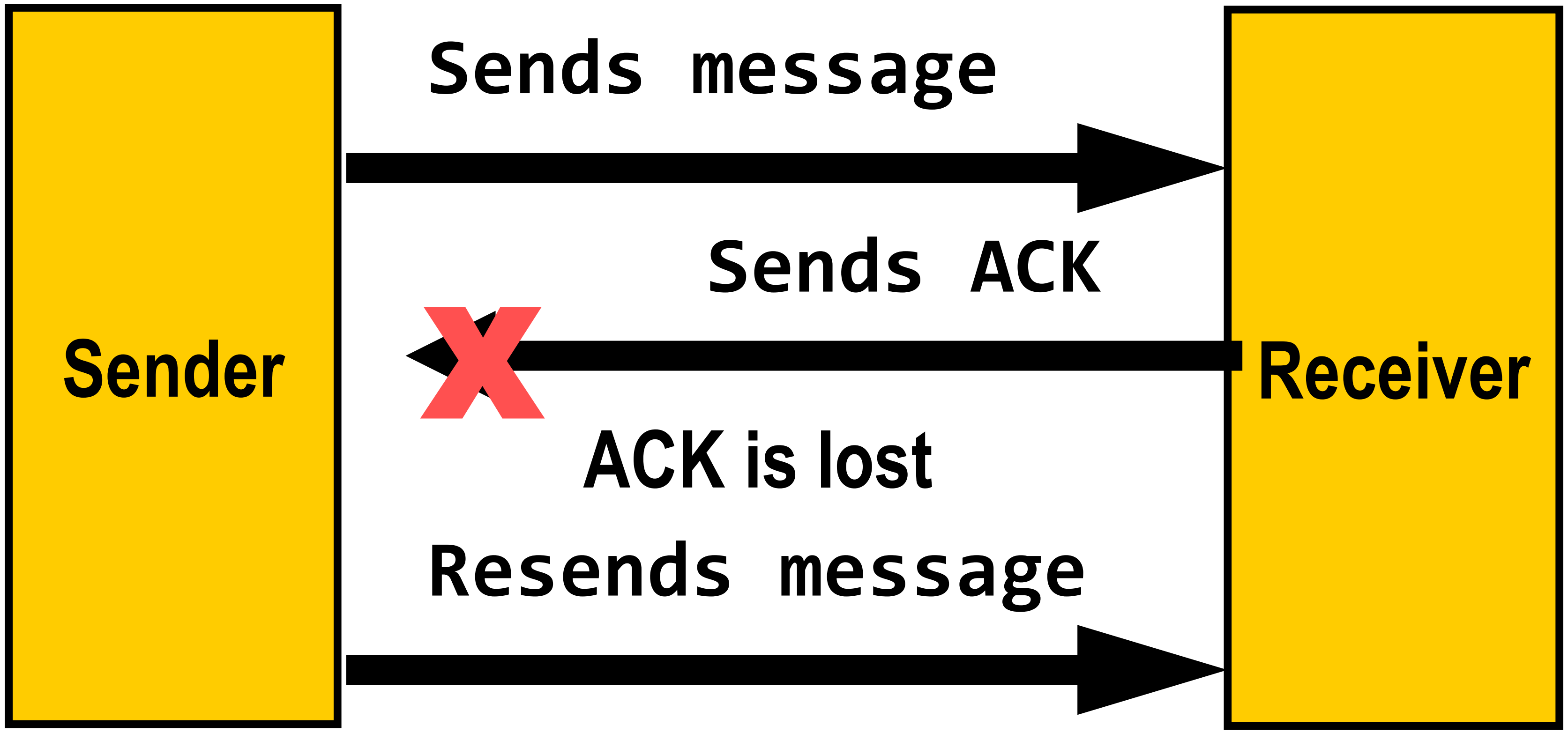
First scenario



Second scenario



Third scenario (I)



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

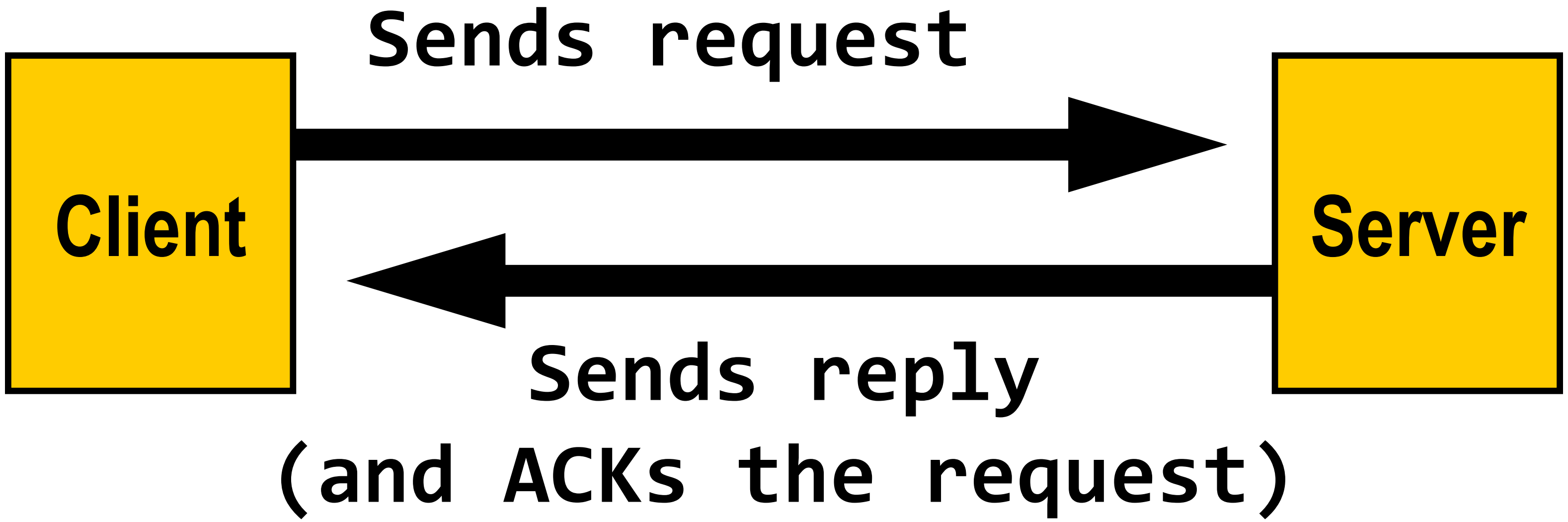
- ***Datagrams:***
  - Messages are send one at time
- ***Virtual circuits:***
  - Ordered sequence of messages
  - ***Connection-oriented*** service
- ***Streams***:
  - Ordered sequence of bytes
  - Message boundaries are ignored

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
  - Request and reply fit in single messages.

Virtual circuits (I)

- Establish a ***logical connection*** between the sender and the receiver
- Messages are ***guaranteed*** to arrive in sequence without lost messages or duplicated messages
  - *Same as 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
    - Ignore them
  - Message boundaries should not count
    - Ignore them

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
  - Deliver byte streams
- ***Example:***
  - TCP

A case study

- Voice over IP (VoIP)
  - Uses the internet for phone calls
  - Much cheaper than conventional copper-wire technology
    - Rapidly replacing it
  - Relies on best-effort networks
    - No quality of service (QoS) guarantees

TCP or UDP?

- TCP would provide
  - Safe, reliable data transmission
  - Unacceptable delays whenever the network is congested
- We use UDP
  - Lower latency
    - Handles better congested networks
  - Users tolerate the occasional loss of voice data

UDP Joke

“Hello, I would like to tell you a UDP joke but I am afraid you will not get it”

TCP Joke

"Hi, I'd like to hear a TCP joke."
"Hello, would you like to hear a TCP joke?"
"Yes, I'd like to hear a TCP joke."
"OK, I'll tell you a TCP joke."
"Ok, I will hear a TCP joke."
"Are you ready to hear a TCP joke?"
"Yes, I am ready to hear a TCP joke."
"Ok, I am about to send the TCP joke. It will last 10 seconds, it has two characters, it does not have a setting, it ends with a punchline."
"Ok, I am ready to get your TCP joke that will last 10 seconds, has two characters, does not have an explicit setting, and ends with a punchline."
"I'm sorry, your connection has timed out.
...Hello, would you like to hear a TCP joke?"

Remote Procedure Calls

Motivation (I)

- 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);
```

Motivation (II)

- Very similar to a conventional procedure call:
- `xyz(args, &results);` → `xyz(...) {`

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

- Try to use the same formalism

The big idea

- We could write

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

and let the system take care of all message passing details

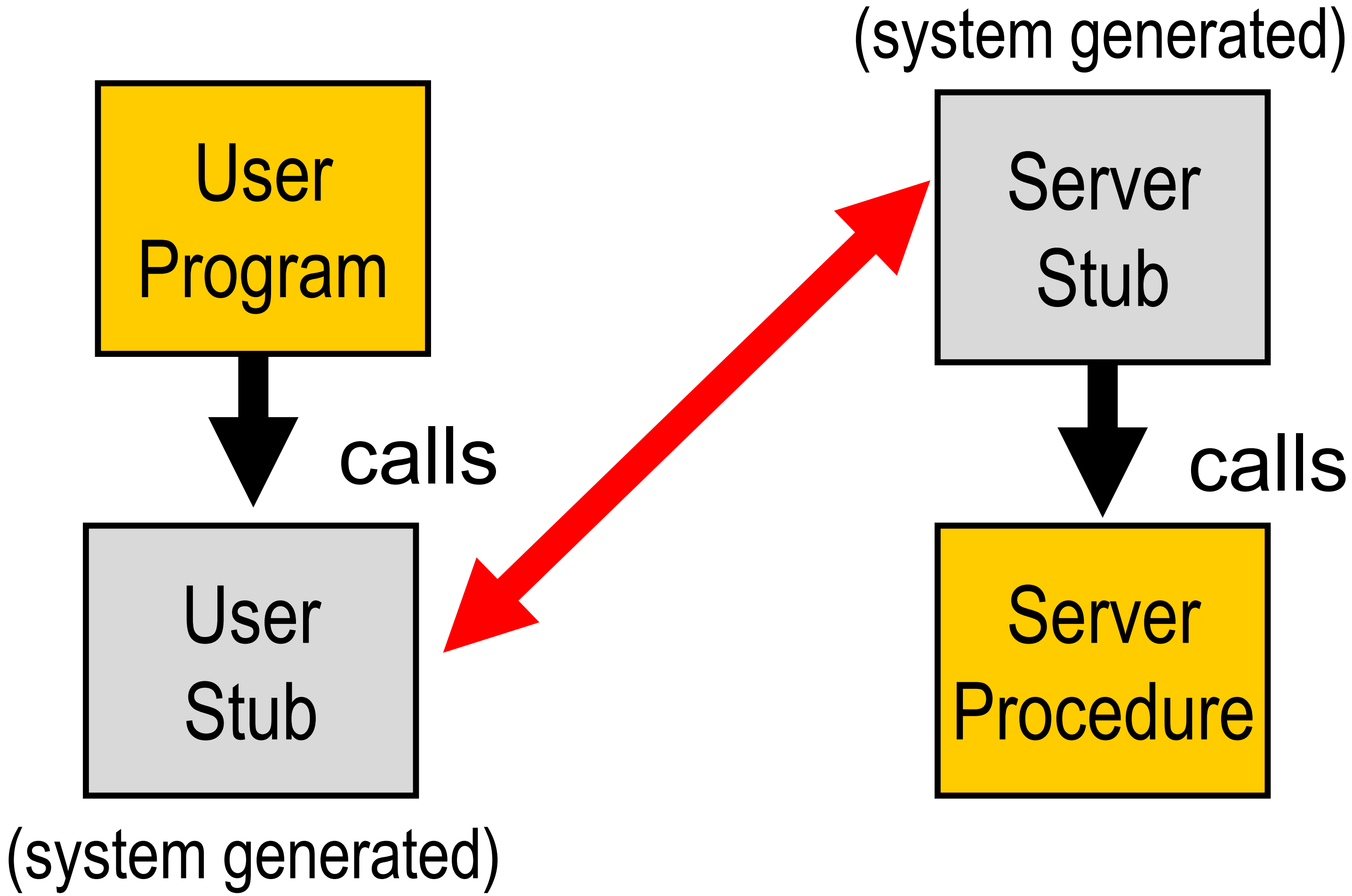
Advantages

- Hides all details of message passing
  - Programmers can focus on the logic of their applications
- 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

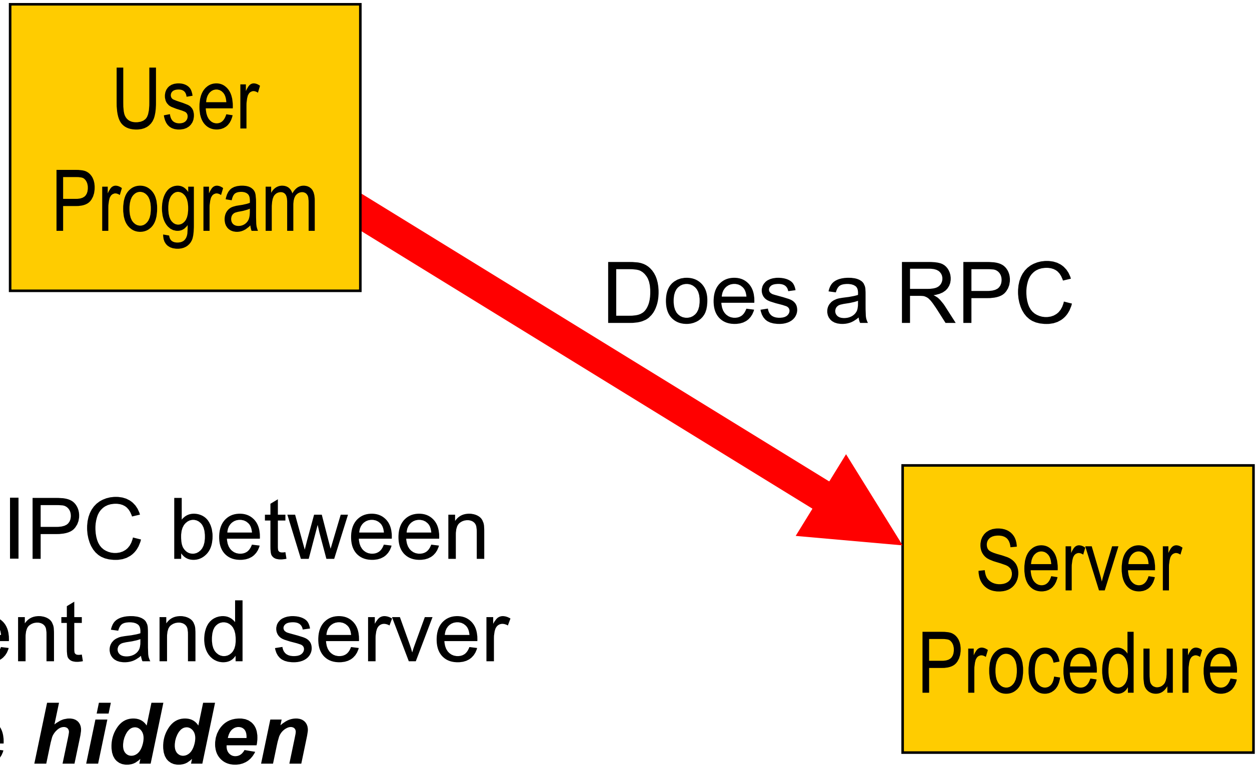
Disadvantage

- The illusion is ***not perfect***
  - RPCs do not always behave 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



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 ***do not share*** a ***common address space***
  - Two different processes with different address spaces
- Client and server can be on ***different machines***
- Must handle ***partial failures***

No common address space

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

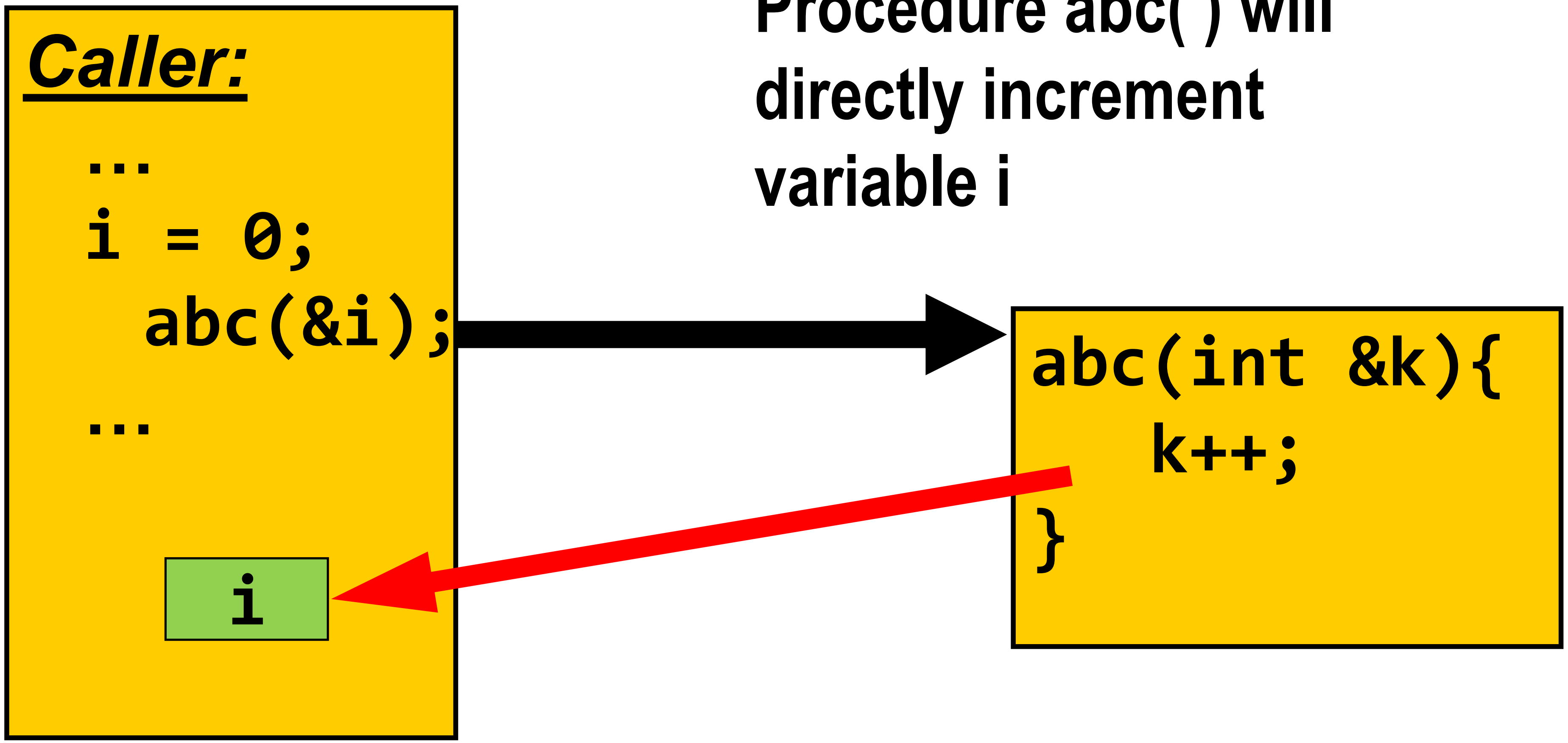
The solution

- 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

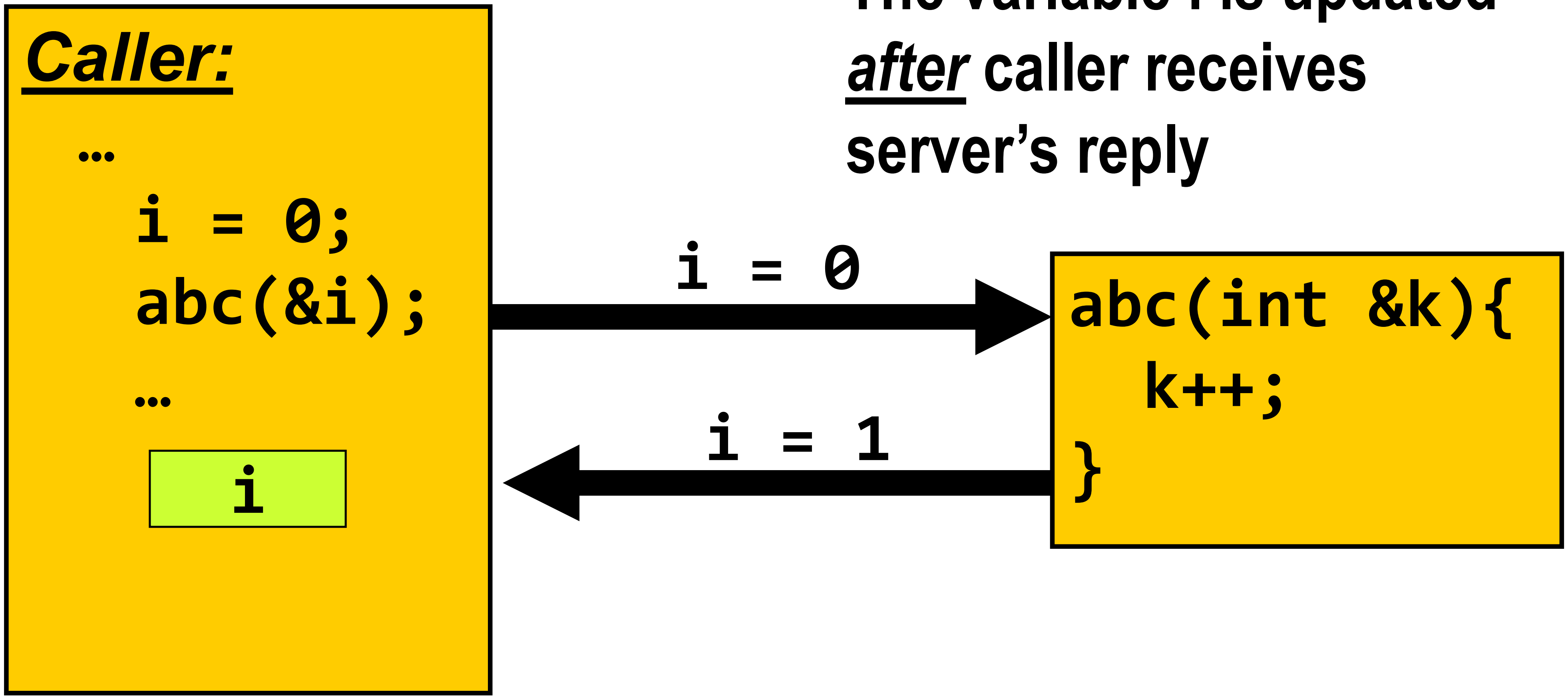
Passing by reference

Procedure abc( ) will directly increment variable i



Passing by value and result

The variable i is updated *after* caller receives server’s reply



An example (I)

- Function ***doubleincrement***

```
void doubleincrement(int &a, int &b) {
    a++; b++;
} // 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);
…
```

m

Pass TWICE the ADDRESS of m

Variable m gets incremented TWICE

Passing by value and result

Caller:

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

m
```

Pass twice the VALUE of m: 1 and 1

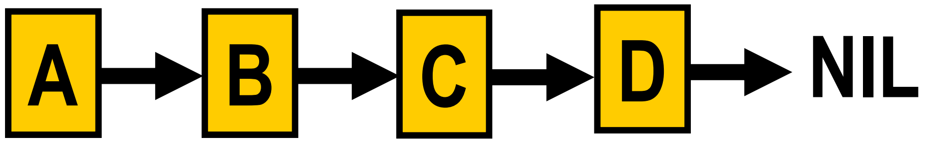
Return two NEW VALUES: 2 and 2

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



- We send to the remote procedure

- Header identifies linked list (LL) with four elements (4)

The NYC Cloisters

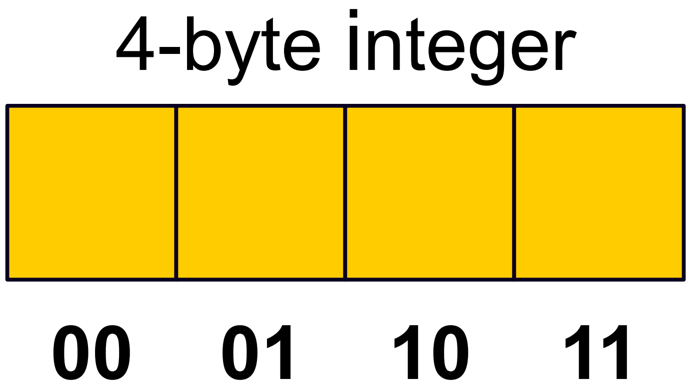
Rebuilt in NYC from actual cloister stones

Architecture considerations

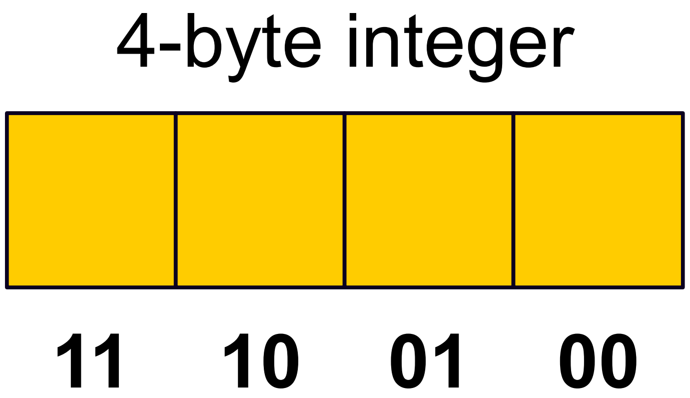
- The machine representations of floating point numbers and byte ordering conventions can be different:
  - ***Little-endians*** start with ***least*** significant byte:
    - *Intel's 80x86* , AMD64 / x86-64
  - ***Big-endians*** start with ***most*** significant byte:
    - *IBM z and OpenRISC*

If you really want to know

- ***Big-endians***



- ***Little-endians***



The standard solution

- Define a ***network order*** and convert all numerical variables to that network order
  - Use **`hton`** family of functions
  - *Same as requiring all air traffic control communications to be in English*
  - *If you want to know, the network order is big-endian*

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

Another example

Realizations (I)

For your information

- ***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)

For your information

- ***SOAP:***
  - Exchanges XML-based messages
  - Runs on the top of HTTP
    - Very portable
    - Very verbose

- ***JSON-RPC:***
  - Uses ***JavaScript Object Notation*** (**JSON**)