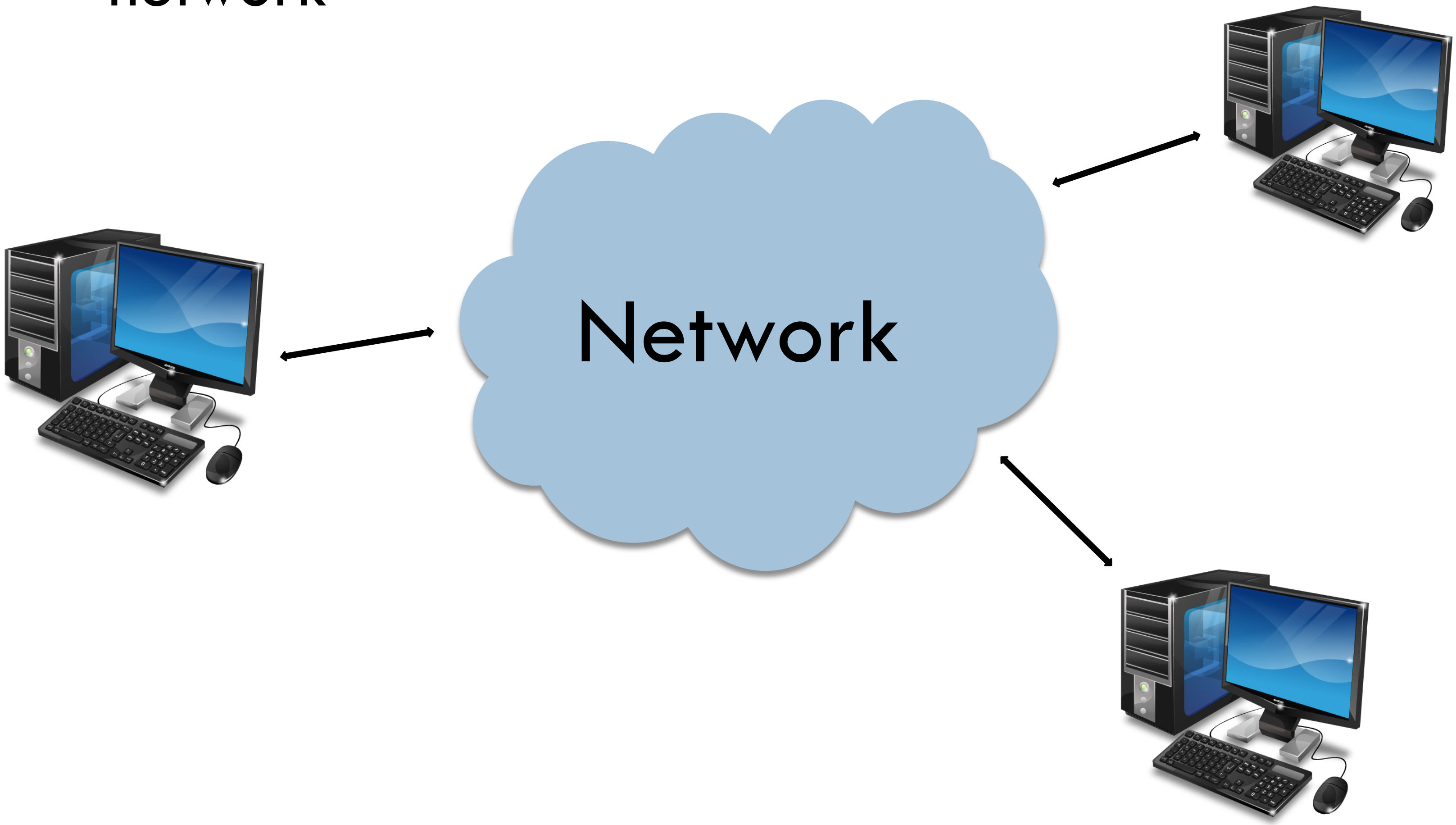
SOCKET

Valerio Di Valerio

The Problem

- Communication between computers connected to a network



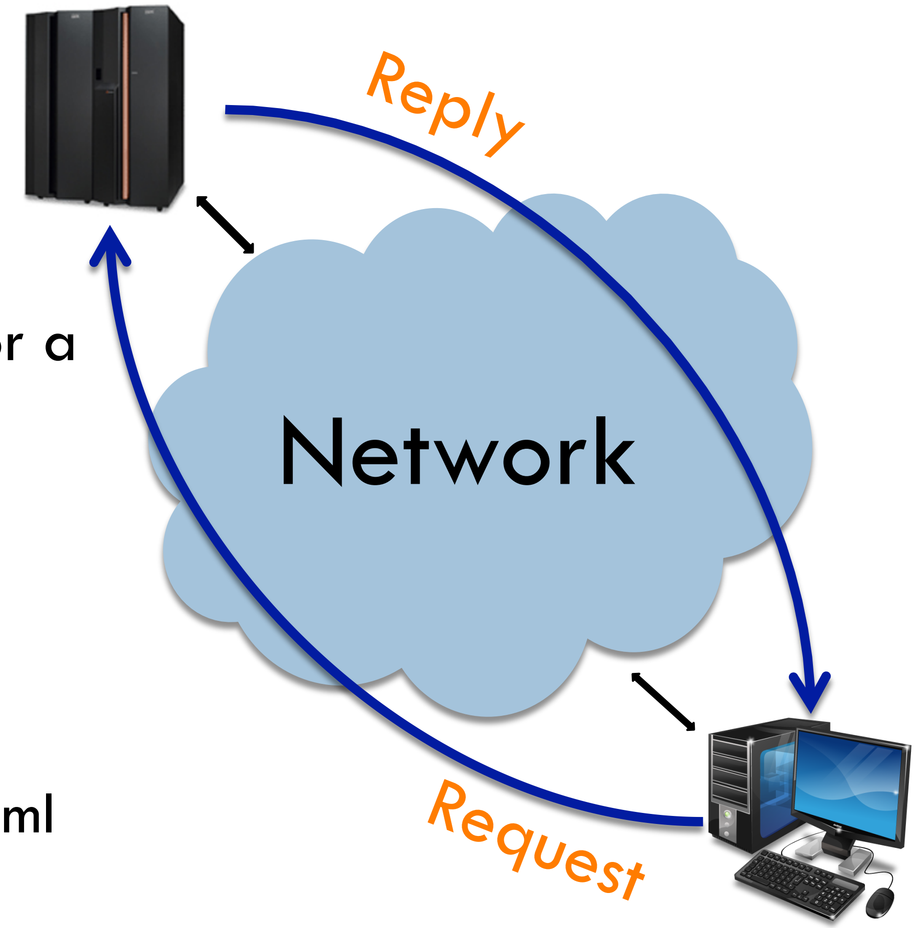
Network applications

- A set of processes distributed over a network that communicate via messages
  - Ex: Browser Web, BitTorrent, ecc…
- Processes communicate via *services* offered by the operating system
  - What kind of services?! TCP, UDP and IP protocols…
- Most famous network application architecture: client/server

Client/server model

Network application has two components: *client* and *server*

- **Client:**
  - Initiates communication
  - Requests a service
    - Es: Chrome sends a request for a Web site:
- **Server:**
  - Waits a request
  - Provides the service
    - Es: Web server providing an html page

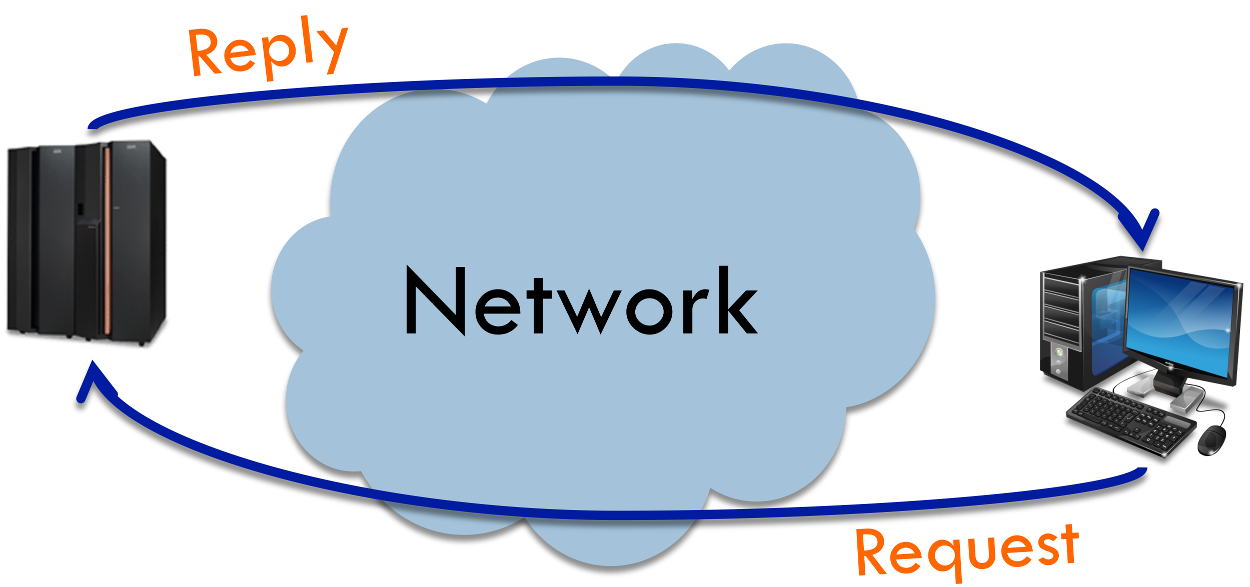


Peer-to-Peer model

See previous lesson!

Two main problems

- **Network addressing:** how to unambiguously identify the process running on a remote host
- **Data transport:** how to transfer bits to the destination



Addressing and data transport in TCP/IP

- **Addressing** based on two components
  - IP address: identifies the remote host (actually the network interface)
  - Port number: identifies the running process
- **Data transport** based on two protocols
  - TCP: connection oriented, stream oriented, reliable data transfer
  - UDP: message oriented, no connection, no reliable data transfer

How to interact with TCP/UDP

- Protocols run "inside" the operating system
  - OSs usually implement the protocol stack TCP/IP
- Our applications run "outside" the operating system
- Result: our applications need to interact with the OS to send data to TCP/IP
- Interaction is possible using a set of interfaces called Application Programming Interface (API)

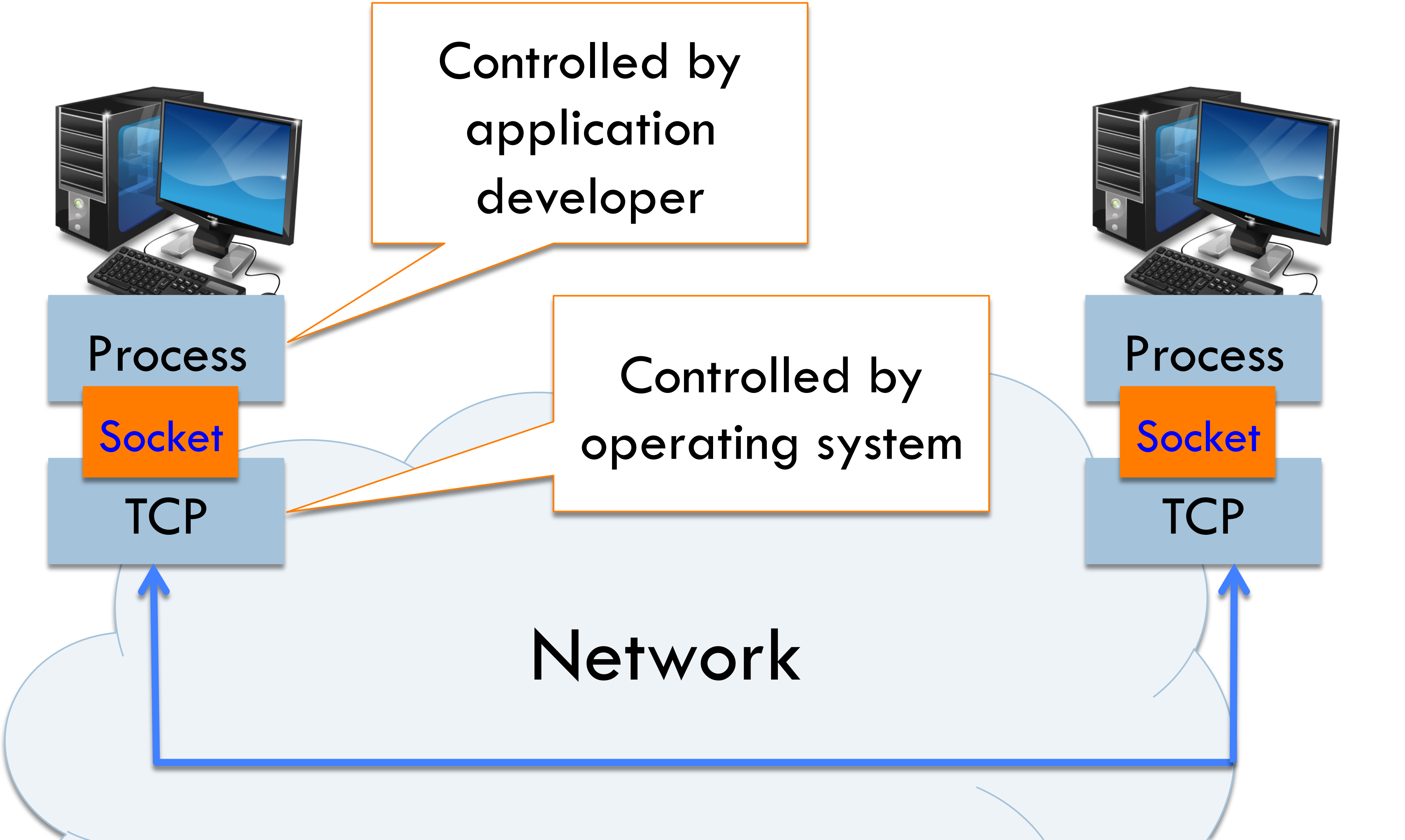
Application Programming Interfaces (API)

- They standardize interaction with the OS specifying:
  - Function prototypes
  - Input/output parameters
- Socket: Internet API
  - Originated with the BSD Unix operating system in 1983 and developed in C
  - Now available on many OSs
  - The Python interface is a straightforward transliteration of the Unix interface for sockets implemented in C

Socket

- It is a “door” between application and transport protocols (TCP o UDP)
  - Allows to send/receive data from the network
- It represents the communication endpoint
  - A socket is owned by the application
- It provides to developers a high level interface to transport protocols

Socket


Controlled by application developer
Controlled by operating system
Process
Socket
TCP
Process
Socket
TCP
Network

Socket in Python

- Socket creation:

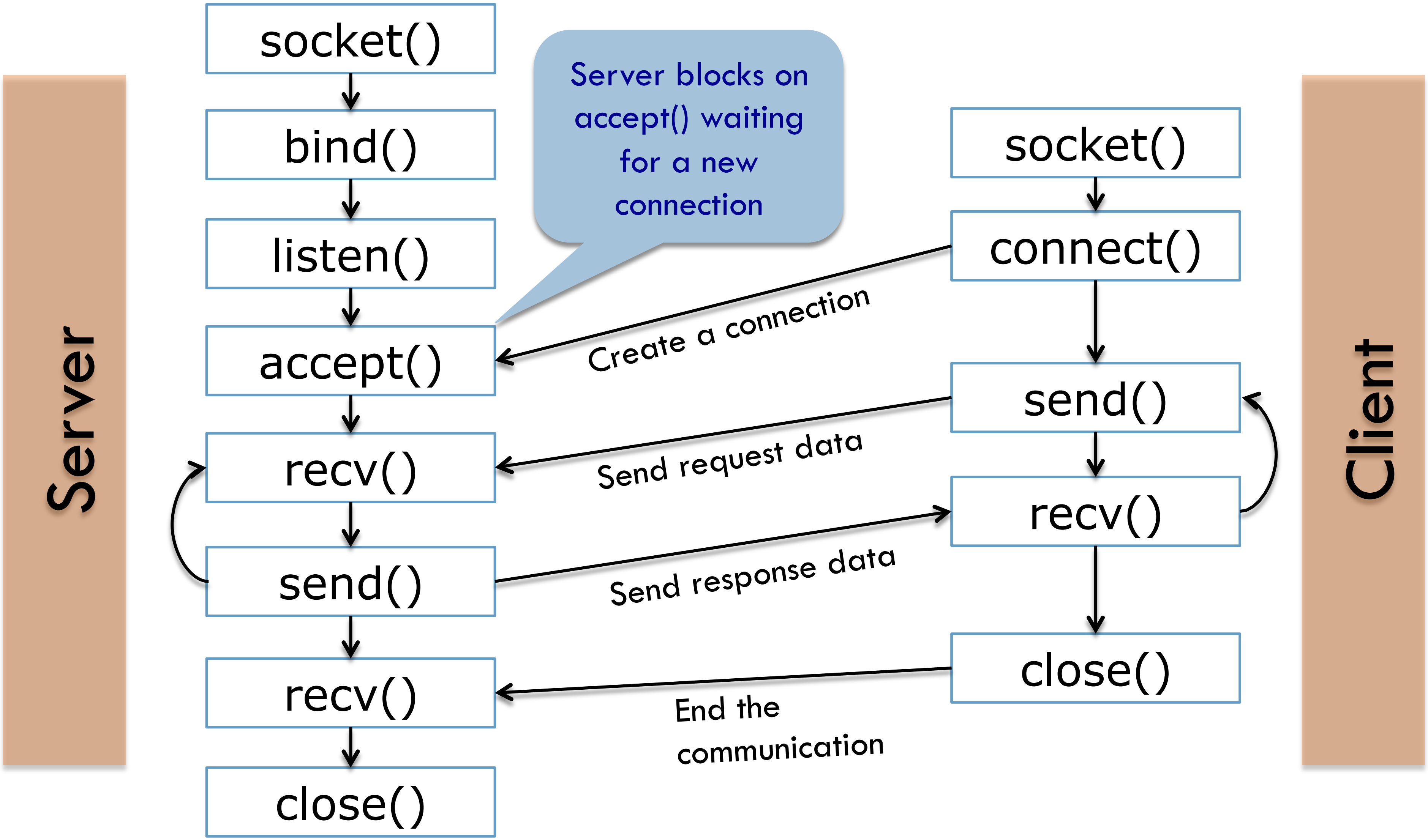
```
import socket
s = socket.socket(addr_family, type, protocol)
```

- It is the first function executed both by the client and the server
  - The OS initializes all the resources needed to manage data transfer
- It returns the socket…
  - or raises an exception if something goes wrong

Socket in Python

- *addr_family* : the protocol family
  - socket.AF_INET: IPv4 protocol
  - socket.AF_INET6: IPv6 protocol
  - socket.AF_UNIX: to manage communication between processes on the same host
- *type* : the communication type
  - socket.SOCK_STREAM: stream (connection) oriented
  - socket.SOCK_DGRAM: message oriented
  - socket.SOCK_RAW: provide access to the network layer
- *protocol* : a specific protocol
  - If set to 0 (or omitted) the default protocol defined by the couple *addr_family* + *type* will be used
  - Es: socket.AF_INET + socket.SOCK_STREAM = TCP

Connection oriented communication



Bind a socket to an address

socket.bind(*address*)

- Thanks to the bind() function the OS will forward the received packets to the correct process!
- *address* is a tuple (host, port) for the AF_INET address family
  - *host* is a string representing either a hostname in Internet domain notation like "www.repubblica.it" or an IPv4 address like "213.92.16.191"
  - *port* is an integer

Socket addresses in Python

- host = “” (i.e., an empty string) specifies all local network interfaces
- host = “localhost” specifies the *loopback* interface
  - A virtual network interface used to manage communication between processes running on the same machine
  - Bypasses local network interface hardware and lower layers of the protocol stack
  - Useful for testing and development
  - “localhost” corresponds to the reserved IP address 127.0.0.1
- Example:

```
import socket
sock = socket.socket(AF_INET, SOCK_STREAM)
sock.bind(("",9000))
sock.bind(("localhost",9000))
sock.bind(("192.168.2.1",9000))
```

A note on port numbers

- Managed by *Internet Assigned Numbers Authority* (IANA)
  - maintains the official assignments of port numbers for specific uses
- Well-known ports (range 0-1023)
  - Used by system processes that provide widely used network services
    - 21 -> FTP, 23 -> Telnet, 25 -> SMTP (Mail), 80 -> HTTP (Web)
  - On Unix OS a process needs root privileges to be able to bind on these ports
- Registered ports (range 1024-49151)
  - The IANA registers uses of these ports as a convenience to the Internet community
    - 1863 -> MSNP, 3074 -> Xbox LIVE,
  - Registered ports can be used by ordinary users
- Dynamic ports (range 49152–65535)
  - They cannot be registered with IANA
  - Used for custom or temporary purposes

listen() function

`socket.listen(backlog)`

- Tells the OS to start listening for connections on the socket
- *backlog* argument specifies the maximum number of queued connections
  - the maximum value is system-dependent
- On Linux it refers to the established connections (3-way handshake completed)
  - Security reason: SYN flood attack
- If backlog is full, new connection requests can be ignored or refused by the OS
- 3-way handshake completely managed <u>by the OS</u>

Example: a simple server (to be cont'd)

```
import socket

HOST = ""
PORT = 1060

sock = socket.socket(AF_INET, SOCK_STREAM)
sock.bind((HOST,PORT))
sock.listen(5)
```

Create socket

Bind to the specified address

Start listening for connections on the socket

connect() function

socket.connect(*address*)

- Connects to a remote socket at *address*.
- If a TCP socket is used, connect() tells the OS to start the 3-way handshake
- *address* is a tuple (host, port) (for the AF_INET address family)
- Example:

```
import socket
sock = socket(AF_INET, SOCK_STREAM)
sock.connect(("www.python.org", 80))
```

accept() function

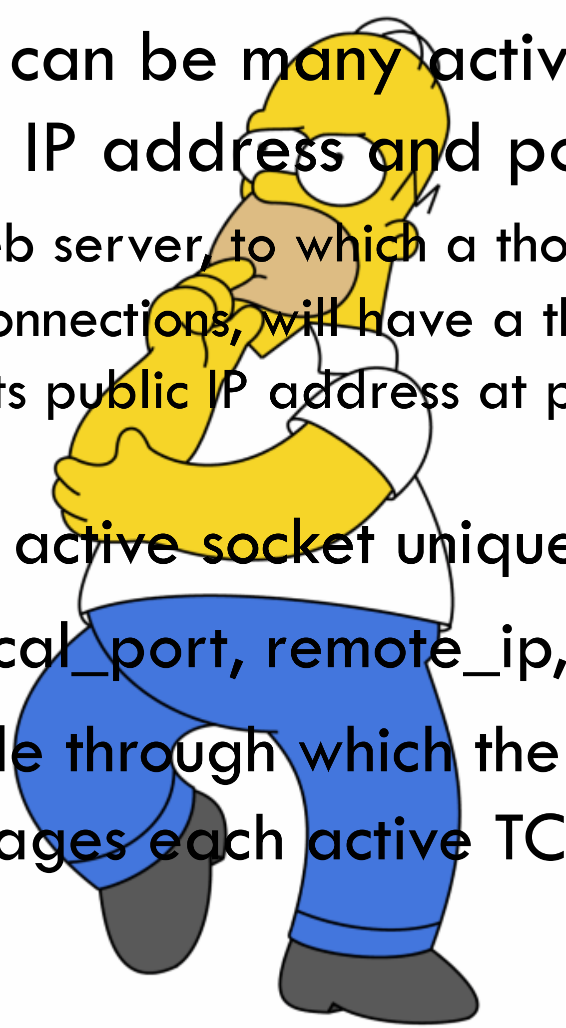
sock, *address* = socket.accept()

- It allows the server to take the first established connection from the backlog
- If backlog is empty, accept() <u>blocks</u> until a connection is received
- Return values:
  - *address* is the address of the client that connected
  - *sock* is a **new** socket, the one actually used to transfer data with the connected client

Passive and active sockets

- Server uses two different sockets for each client connection
- The passive socket, created by socket()
  - Holds the “socket name” (i.e., the address and port number) at which the server is ready to receive connections
  - No data can ever be received or sent by this kind of port
  - It does not represent any actual network conversation
  - Used to listen to incoming connections (using listen() function)
- The active socket, returned by accept()
  - It has the same “socket name” of the passive socket
  - It is bound to one particular remote conversation partner
  - It can be used only for talking back and forth with that partner

Passive and active sockets



- Problem: there can be many active sockets that all share the same IP address and port number
  - Ex: a busy web server, to which a thousand clients have made HTTP connections, will have a thousand active sockets all bound to its public IP address at port 80

- What makes an active socket unique is a <u>four-tuple</u>:

  (local_ip, local_port, remote_ip, remote_port)

- It is this four-tuple through which the operating system names and manages each active TCP connection

Example: a simple server (cont'd)

```
import socket

HOST = ""
PORT = 1060

sock = socket.socket(AF_INET, SOCK_STREAM)
sock.bind((HOST,PORT))
sock.listen(5)
while 1:
        sock_cli, addr = sock.accept()
        …
        # SERVE THE REQUEST
```

Start an infinite loop to serve all clients requests

Accept a new client connection

Send data

numBytesSent = socket.send(*string[, flags]*)

- *string* represents the data to be sent
- *numBytesSent* represents the number of bytes sent
- NB: applications are responsible for checking that **all** data have been sent
  - if only some of the data were transmitted, the application needs to attempt delivery of the remaining data.
- TCP considers your outgoing and incoming data as streams, with no beginning or end
  - It feels free to split them up into packets however it wants!

Send data

- After a TCP send(), networking stack will face one of three situations
  - The data can be immediately accepted by the system
    - send() returns immediately, and it will return the length of your data string
  - The network card is busy and outgoing internal data buffer for this socket is full
    - send() blocks, pausing your program until the data can be accepted
  - The outgoing buffer is almost full
    - send() completes immediately and returns the number of bytes accepted from the beginning of your data string, but leaves the rest of the data unprocessed

Send data

- send() is usually called inside a loop like this…

```
bytes_sent = 0
while bytes_sent < len(message):
    message_remaining = message[bytes_sent:]
    bytes_sent += sock.send(message_remaining)
```

- …or it is replaced by:

socket.sendall(*string[, flags]*)

- It continues to send data from *string* until either all data have been sent or an error occurs
- It is more efficient than the above example, because it is implemented in C
- Example: sock.sendall(message)

Receive data

data = socket.recv(*bufsize*[, *flags*])

- *bufsize* is an integer that specifies the maximum amount of data to be received at once
- *data* is a string representing the data received
- NB: similarly to send(), applications are responsible for checking that **all** data have been received!
- Unfortunately, we do not have a function similar to sendall()

Receive data

- The operating system's implementation of recv() is similar to that of send():
  - If no data are available, then recv() blocks and your program pauses until the data arrive
  - If plenty of data are available in the incoming buffer, then recv() returns *#bufsize bytes*
  - If the buffer contains a bit of data, but less than *#bufsize*, then you are immediately returned the available data, even if they are not as much as the requested data
- recv() returns empty string if there are no more data
  - This means that the other end of the connection has been closed (see next slides)

Receive data

- Problem: how can we understand if we have received **all** the data?

Receive data: examples

```
def recv_all(sock, length):
        data = ''
        while 1:
                read_data = sock.recv(length)
                if read_data == '':
                        break
                data += read_data
        return data
```

We read data until the other end of the connection has been closed

Receive data: examples

```
def recv_all(sock, length):
        data = ''
        while len(data) < length:
                read_data = sock.recv(length - len(data))
                if read_data == '':
                        raise EOFError('socket closed')
                data += read_data
        return data
```

We keep reading until we receive #length bytes

If the connection is closed unexpectedly we raise an error

Example: a simple server

```
import socket

HOST = “”
PORT = 1060

sock = socket.socket(AF_INET, SOCK_STREAM)
sock.bind((HOST,PORT))
sock.listen(5)
while 1:
        sock_cli, addr = sock.accept()
        message = recv_all(sock_cli, 16)
        print 'The incoming sixteen-octet message says', repr(message)
  sock_cli.sendall(’Hello World!')
  sock_cli.close()
        print 'Reply sent, socket closed'
```

Close a connection

```
socket.close()
```

- Close the socket
- All future operations on the socket object will fail
- Releases the resource associated with a connection but does not necessarily close the connection immediately
  - Operating system first sends data that are still in the buffer

Close a connection

socket.shutdown(*how*)

- Shut down one or both halves of the connection
  - Shut down communication in one direction but <u>without</u> destroying the socket itself
- *how* can be set to:
  - SHUT_RD, further receives are disallowed
  - SHUT_WR, further sends are disallowed
  - SHUT_RDWR： further sends and receives are disallowed
    - NB: It is <u>different</u> from close()

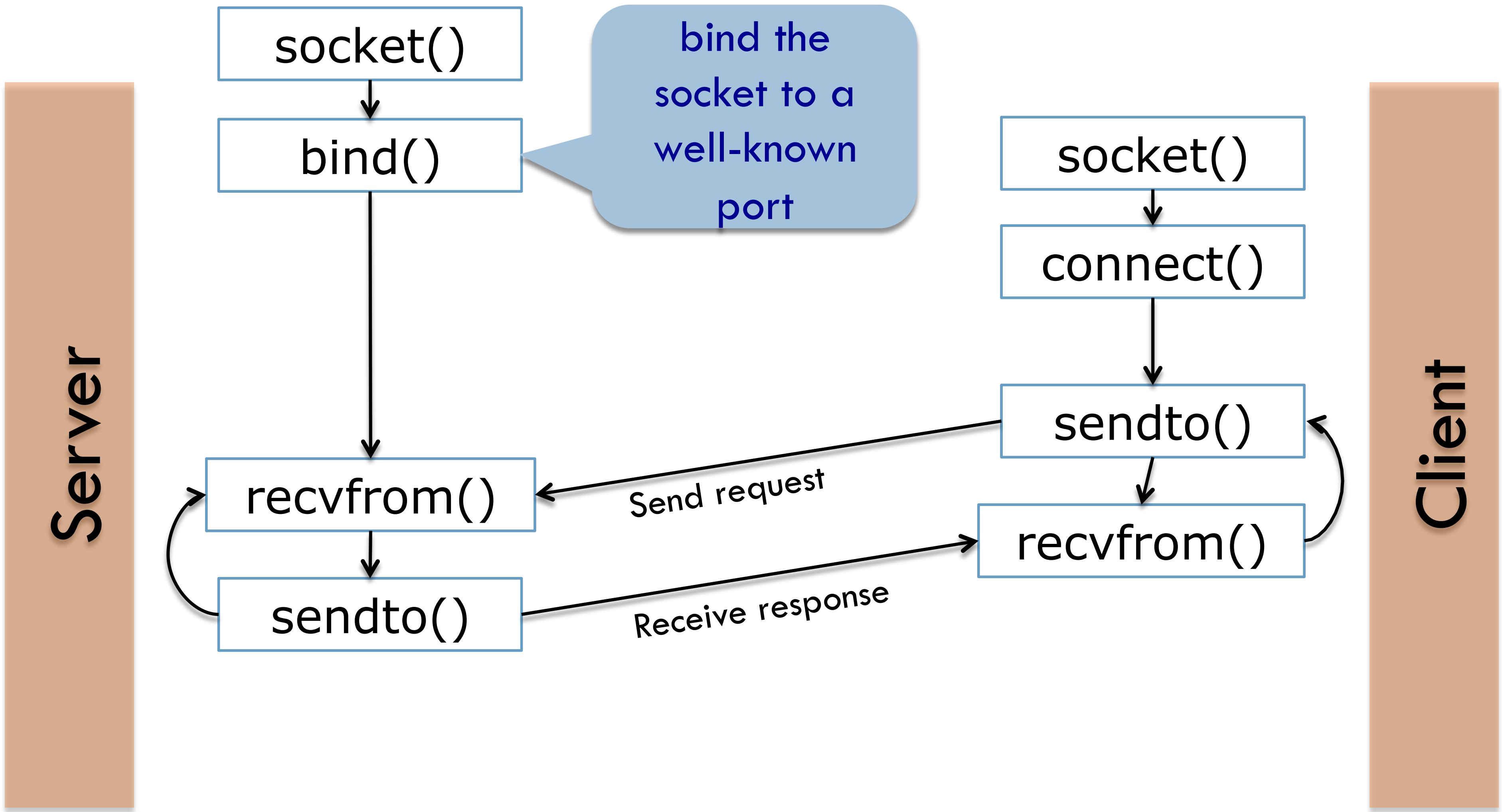
Socket options

socket.setsockopt(*level*, *optname*, *value*)

- There are many options that can be set to sockets
  - *level* specify the protocol level
    - *SOL_SOCKET: generic socket options*
    - *SOL_TCP: TCP socket options*
  - *optname* is the name of the option
    - SO_KEEPALIVE: enables the periodic transmission of messages on a connected socket
    - SO_REUSEADDR: enables local address reuse
    - SO_SNDTIMEO: set timeout value for output
    - SO_RCVTIMEO: set timeout value for input
  - *value* is the option value (it is option dependant)

Example: TCP ECHO server!

Connectionless communication



Send data

numBytesSent = socket.sendto(*string[, flags]*, *address*)

- *string* represents the data to be sent
- *address* represents the address of remote host
  - *Communication is connectionless!!*
- *numBytesSent* represents the number of bytes sent
- NB: communication **is not** reliable!
- There are no guarantees that the packet is successfully delivered to remote host

Receive data

string, address = socket.recvfrom(*bufsize[, flags]*)

- *bufsize* is the maximum amount of data to be received
- *string* represents the received data
- *address* represents the address of remote host
  - *Communication is connectionless!!*
- NB: receives packets from **any** remote host

Example: a simple server

```
import socket

sock = socket.socket(socket.AF_INET, socket.SOCK_DGRAM)

MAX = 65535
PORT = 1060

sock.bind(('127.0.0.1', PORT))

while True:
        msg, address = sock.recvfrom(MAX)
        print 'The client at', address, 'says', repr(msg)
        response = ’The msg was %d bytes long' % len(msg)
        sock.sendto(response, address)
```

Connecting UDP sockets

- We can use the connect() function with UDP sockets!
- We can avoid to specify every time the server address when we call sendto()
- Client is *not* susceptible to receiving packets from other senders
- NB: using connect() on an UDP socket does **not** send any data over the network!!

Unblock functions

socket.settimeout(*value*)

- Problem: What if the response sent by the server is lost?
- *We do **not** want to block the client forever…*
- *…but it is not easy to understand why the packet has not arrived:*
  - The reply is only taking a long time to come back
  - The reply (or the request!) is lost
  - Server is down
- Solution: use a timeout!
- if #value seconds elapse since the process is blocked, the OS raises a socket.timeout exception

Example: settimeout()

```
sock.connect((HOST, PORT))
delay = 0.1
while True:
        sock.send('Send this message!')
        sock.settimeout(delay)
        try:
            data = sock.recv(MAX)
        except socket.timeout:
            delay *= 2  # Exponential backoff
            if delay > 2.0:
                raise RuntimeError('Maybe the server is down')
        else:
            break   # we are done
```

Example: UDP server!

Want to know more?

- Book:
  - Foundations of Python Network Programming, *by Brandon Rhodes and John Goerzen*
- Python official documentation:
  - https://docs.python.org/2/library/socket.html
  - https://docs.python.org/2/howto/sockets.html