COMP 431
Internet Services & Protocols

Client/Server Computing & Socket Programming

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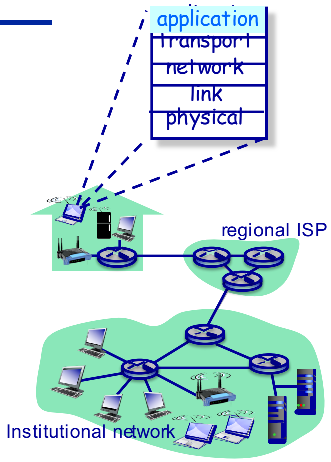
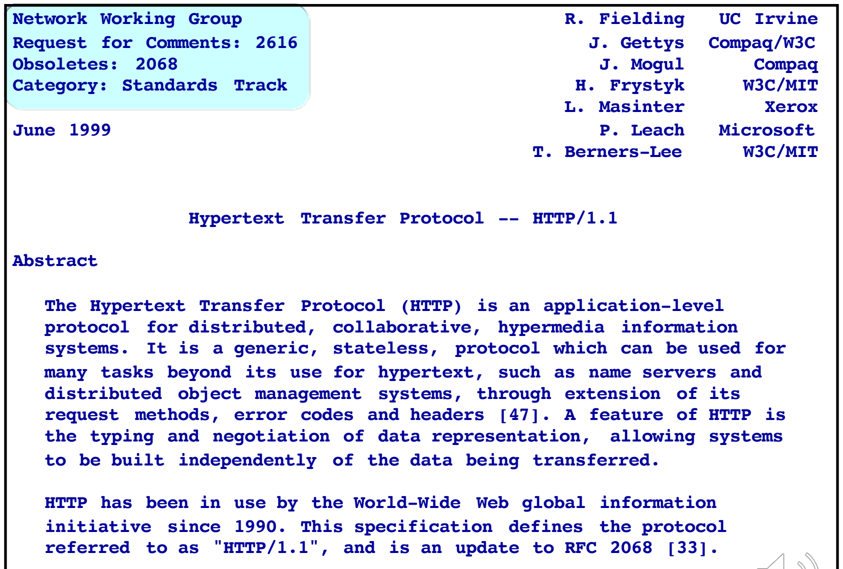
Application-Layer Protocols
Overview

- Application-layer protocols define:
  - » The types of messages exchanged
  - » The syntax and semantics of messages
  - » The rules for when and how messages are sent
- Public protocols (defined in RFCs)
  - » HTTP, FTP, SMTP, POP, IMAP, DNS
- Proprietary protocols
  - » RealAudio, RealVideo
  - » Skype
  - » …





```
Network Working Group                                      R. Fielding   UC Irvine
Request for Comments: 2616                                   J. Gettys  Compaq/W3C
Obsoletes: 2068                                               J. Mogul      Compaq
Category: Standards Track                                   H. Frystyk     W3C/MIT
                                                           L. Masinter       Xerox
June 1999                                                     P. Leach   Microsoft
                                                        T. Berners-Lee     W3C/MIT


                    Hypertext Transfer Protocol -- HTTP/1.1

Abstract

   The Hypertext Transfer Protocol (HTTP) is an application-level
   protocol for distributed, collaborative, hypermedia information
   systems. It is a generic, stateless, protocol which can be used for
   many tasks beyond its use for hypertext, such as name servers and
   distributed object management systems, through extension of its
   request methods, error codes and headers [47]. A feature of HTTP is
   the typing and negotiation of data representation, allowing systems
   to be built independently of the data being transferred.

   HTTP has been in use by the World-Wide Web global information
   initiative since 1990. This specification defines the protocol
   referred to as "HTTP/1.1", and is an update to RFC 2068 [33].
```

Application-Layer Protocols

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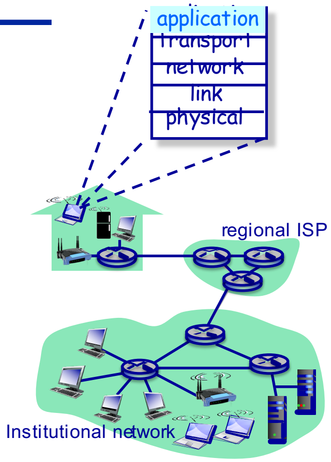
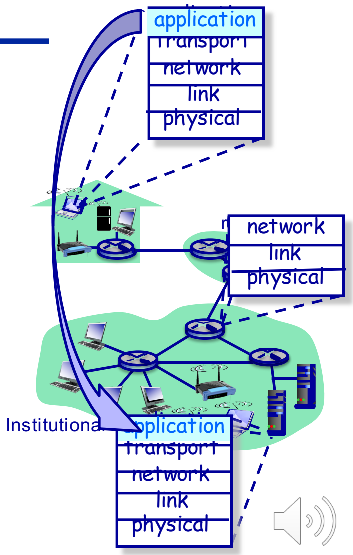


Application-Layer Protocols

Overview

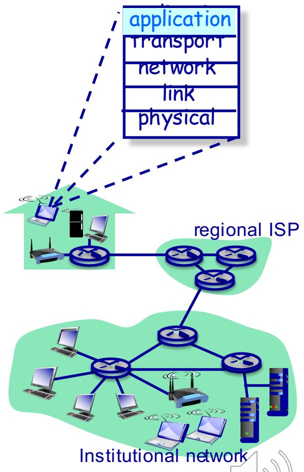
- Application developers write programs that:
  - » Run on (different) end systems
  - » Communicate over network
- Note: application developers don't need to write code for network-core devices
  - » Network devices do not run user applications or application layer protocols



Application-Layer Protocols

Outline

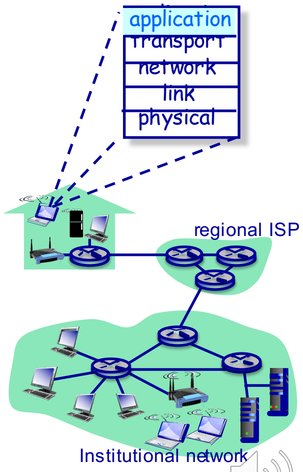
- The architecture of distributed systems
  - » Client/Server computing
  - » Peer-to-Peer computing
  - » Content delivery networks
- The programming model used in constructing distributed systems
  - » Socket programming



Application-Layer Protocols

Outline

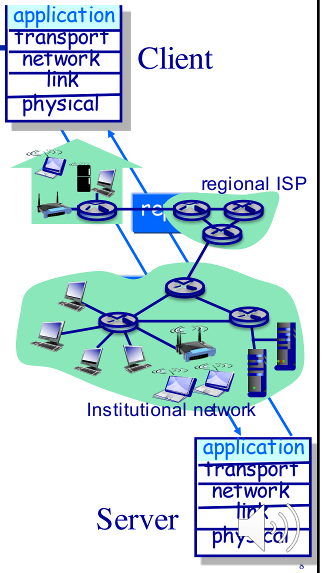
- Example client/server systems and their application-level protocols:
  - » The World-Wide Web (HTTP)
  - » Reliable file transfer (FTP)
  - » E-mail (SMTP & POP)
  - » Internet Domain Name System (DNS)
- Example p2p applications systems:
  - » BitTorrent
- Other protocols and systems:
  - » Streaming media — DASH
  - » Content delivery networks (CDNs)



The Application Layer

The client-server paradigm

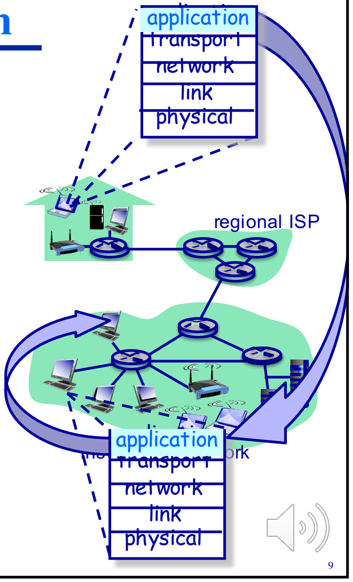
- Typical network application has two pieces: *client* and *server*
- Client:
  - » Initiates contact with server ("speaks first")
  - » Requests service from server
  - » For Web, client is implemented in browser; for e-mail, in mail reader
- Server:
  - » Provides requested service to client
  - » "Always" running
  - » May also include a "client interface"
  - » A server may be a logical machine
    - » Implemented by one of thousands of physical servers in a data center



The Application Layer

The peer-to-peer-paradigm

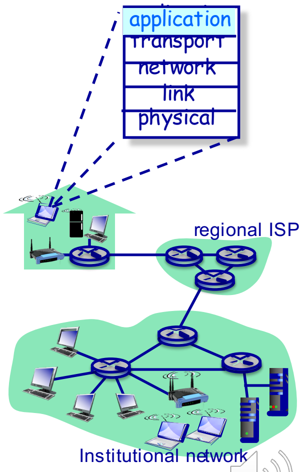
- No “always-on” server
- Arbitrary end systems directly communicate
  - » Peers request service from other peers, provide service in return to other peers
- Self scalability – new peers bring new service capacity, as well as new service demands
- Peers are intermittently connected and change IP addresses
- Complex management

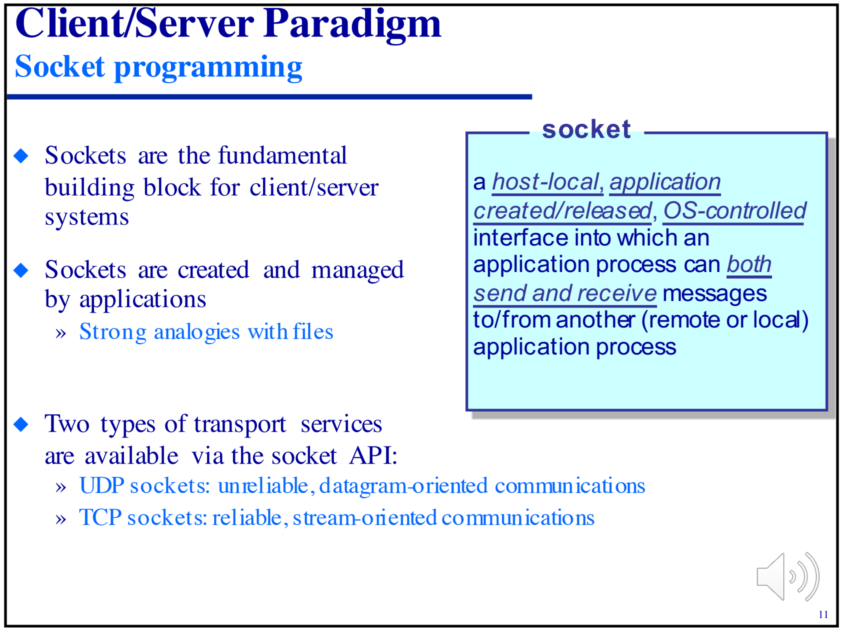


Application-Layer Protocols

Outline

- Example client/server systems and their application-level protocols
  - » The World-Wide Web (HTTP)
  - » Reliable file transfer (FTP)
  - » E-mail (SMTP & POP)
  - » Internet Domain Name System (DNS)
- Protocol design issues:
  - » In-band *vs.* out-of-band control signaling
  - » Push *vs*. pull protocols
  - » Persistent *vs*. non-persistent connections
- Client/server service architectures
  - » Contacted server responds *vs.* forwards request





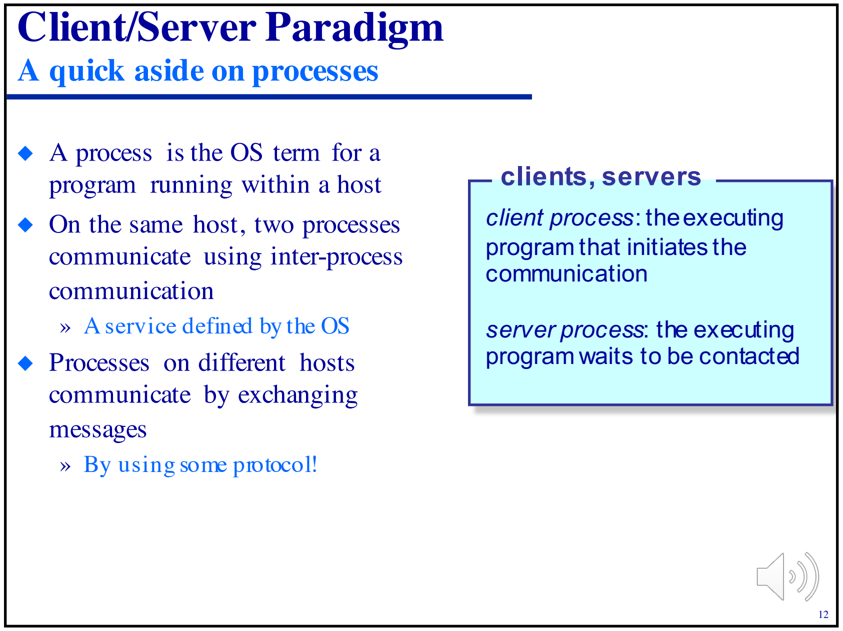
Client/Server Paradigm

Socket programming

- Sockets are the fundamental building block for client/server systems
- Sockets are created and managed by applications
  - » Strong analogies with files
- Two types of transport services are available via the socket API:
  - » UDP sockets: unreliable, datagram-oriented communications
  - » TCP sockets: reliable, stream-oriented communications

socket

a *host-local*, *application created/released*, *OS-controlled* interface into which an application process can *both send and receive* messages to/from another (remote or local) application process



Client/Server Paradigm

A quick aside on processes

- A process is the OS term for a program running within a host
- On the same host, two processes communicate using inter-process communication
  - » A service defined by the OS
- Processes on different hosts communicate by exchanging messages
  - » By using some protocol!

clients, servers

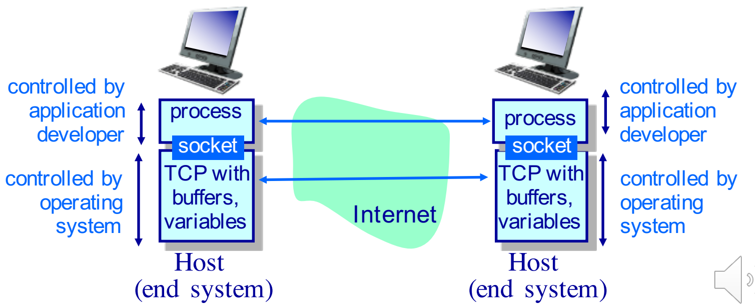
client process: the executing program that initiates the communication

server process: the executing program waits to be contacted

Client/Server Paradigm

Socket-programming using TCP

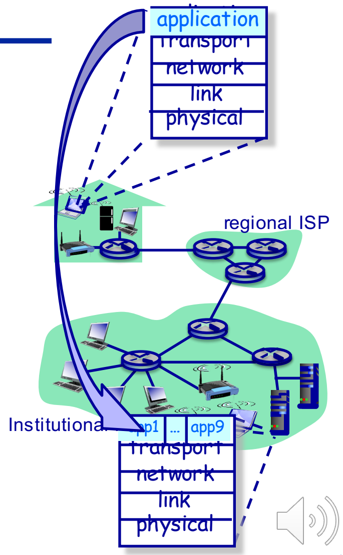
- A socket is an application created, OS-controlled interface into which an application can both send and receive messages to and from another application
  - » A "door" between application processes and end-to-end transport protocols


controlled by application developer
controlled by operating system
process
socket
TCP with buffers, variables
Host
(end system)
Internet
process
socket
TCP with buffers, variables
Host
(end system)
controlled by application developer
controlled by operating system

Client/Server Paradigm

Addressing processes

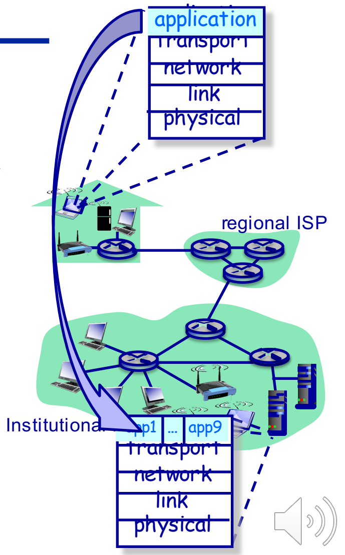
- To receive messages, a process must have an identifier
  - » How does a client identify a server *process*
- We know that a host device has unique 32-bit IP address
- But does the IP address of host suffice for identifying the destination process?
  - » No! Many processes can be (and are!) running on the same host



Client/Server Paradigm

Addressing processes

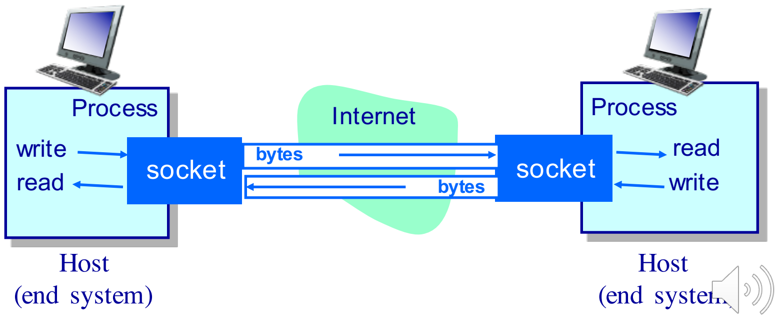
- Processes are identified by a "port number"
  - » Sort of like a socket identifier
- The "server" identifier includes both an IP address and port numbers associated with the server process on the host
- Example port numbers:
  - » HTTP server: 80
  - » mail server: 25
- For a browser to send an HTTP message to *www.cs.unc.edu* the request is addressed to IP address 152.2.131.244 *and* port 80



Socket-programming using TCP

TCP socket programming model

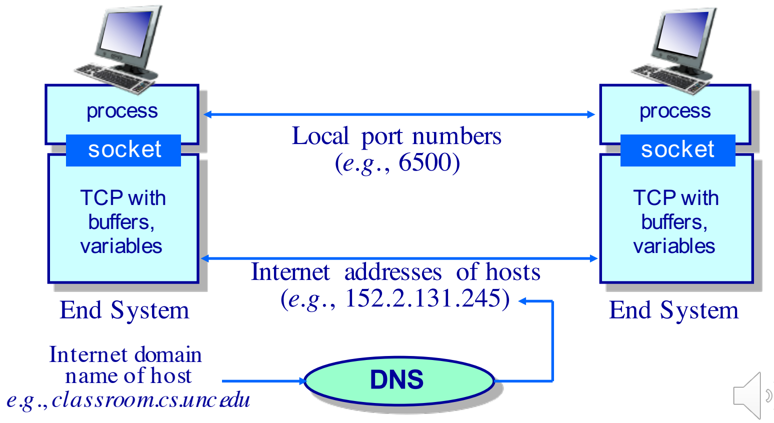
- A TCP socket provides a reliable, bi-directional, byte-stream communications channel from one process to another
  - » A "pair of pipes" abstraction



Socket-programming using TCP

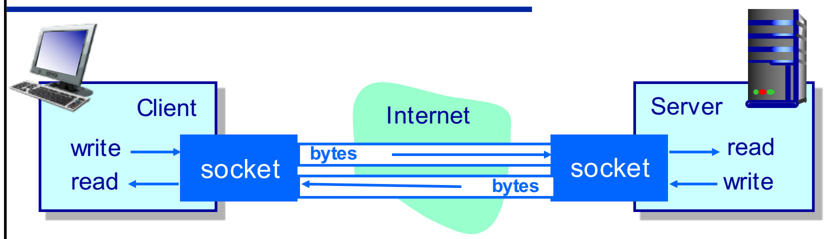
Network addressing for sockets

- Sockets are addressed using an IP address and port number


process
socket
TCP with buffers, variables
process
socket
TCP with buffers, variables
Local port numbers
(*e.g.*, 6500)
Internet addresses of hosts
(*e.g.*, 152.2.131.245)
End System
End System
Internet domain name of host
e.g., *classroom.cs.unc.edu*
DNS

Socket-programming using TCP

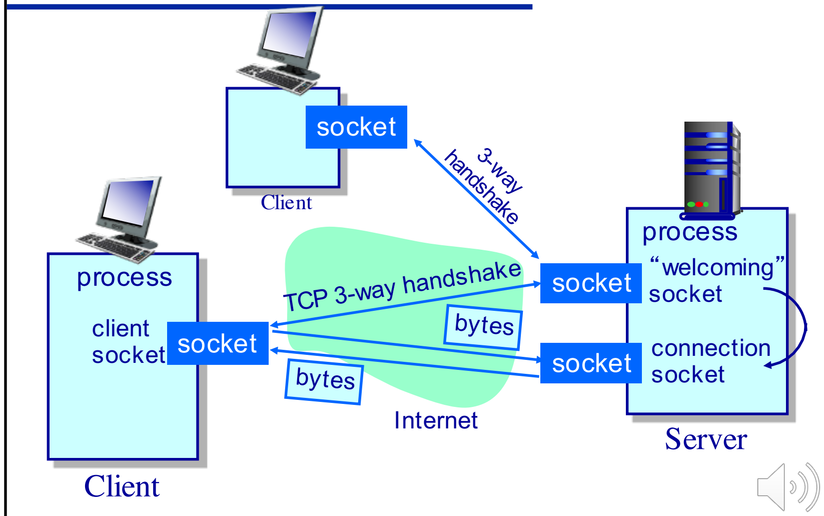
Socket programming in Python



- Client creates a local TCP socket specifying the host and port number of server process
  - » Python resolves host names to IP addresses using DNS
- Client contacts server
  - » Server process must be running
  - » Server must have created socket that "welcomes" client's contact
- When the client creates a socket, the client's TCP establishes connection to server's TCP
- When contacted by a client, server creates a new socket for server process to communicate with client
  - » This allows the server to talk with multiple clients

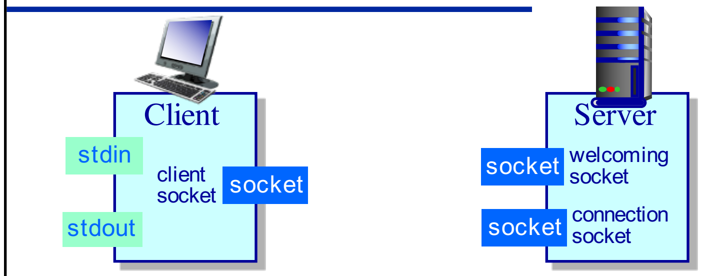
Socket-programming using TCP

Socket creation in the client-server model



Socket-programming using TCP

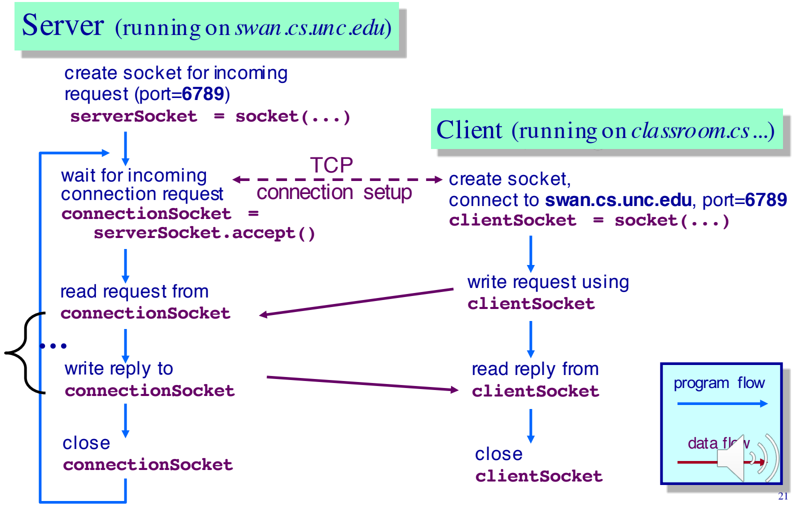
Simple client-server example



- The client reads a line of text from standard input and sends the text to the server via a socket
- The server receives the line of text from the client and converts the line of characters to all uppercase
- The server sends the converted line back to the client
- The client receives the converted text and writes it to standard output

Socket programming with TCP Example

Client/server TCP socket interaction in Python



Server (running on *swan.cs.unc.edu*)

create socket for incoming request (port=**6789**)
`serverSocket = socket(...)`

wait for incoming connection request
`connectionSocket = serverSocket.accept()`

read request from `connectionSocket`

write reply to `connectionSocket`

close `connectionSocket`

Client (running on *classroom.cs...*)

create socket, connect to **swan.cs.unc.edu**, port=**6789**
`clientSocket = socket(...)`

write request using `clientSocket`

read reply from `clientSocket`

close `clientSocket`

Socket Programming with TCP Example

Python client

include Python's socket library

create TCP socket to server on port 12000

get user keyboard input

change text into a sequence of bytes before sending

receive data from server in a buffer

```
from socket import *
serverName = 'snapper.cs.unc.edu'
serverPort = 12000

clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName, serverPort))

sentence = raw_input('Input lowercase sentence:')
clientSocket.send(sentence.encode())

modifiedSentence = clientSocket.recv(1024)
print ('From Server:', modifiedSentence.decode())

clientSocket.close()
```

Socket Programming with TCP Example

Python server

create TCP welcoming socket

server begins listening for incoming TCP requests

server waits on accept() for incoming requests, a new socket is created on return socket to server on port 12000

read bytes from socket

close connection to this client (but not the welcoming socket)

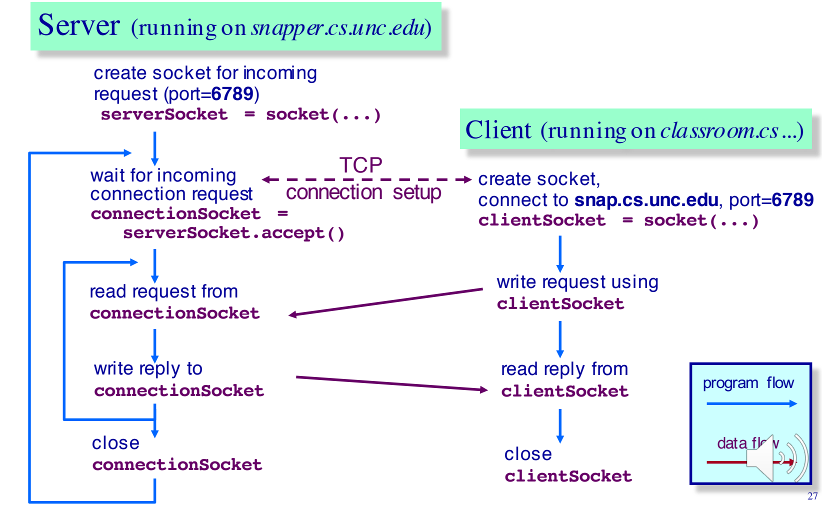
```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind((“,serverPort))
serverSocket.listen(1)
print ‘The server is ready to receive’
while True:
     connectionSocket, addr = serverSocket.accept()

     sentence = connectionSocket.recv(1024).
                                          decode()
     capitalizedSentence = sentence.upper()

     connectionSocket.send(
                    capitalizedSentence.encode())
     connectionSocket.close()
```

Socket Programming with TCP Example

Client/server TCP socket interaction in Python



Server (running on *snapper.cs.unc.edu*)

create socket for incoming request (port=**6789**)
`serverSocket = socket(...)`

wait for incoming connection request
`connectionSocket = serverSocket.accept()`

read request from `connectionSocket`

write reply to `connectionSocket`

close `connectionSocket`

TCP connection setup

Client (running on *classroom.cs* ...)

create socket, connect to **snap.cs.unc.edu**, port=**6789**
`clientSocket = socket(...)`

write request using `clientSocket`

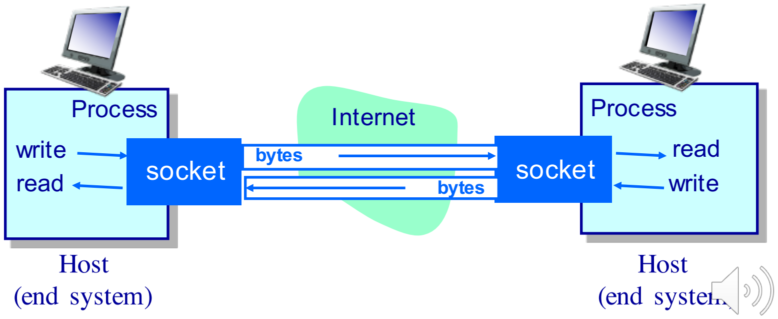
read reply from `clientSocket`

close `clientSocket`

Socket-programming using UDP

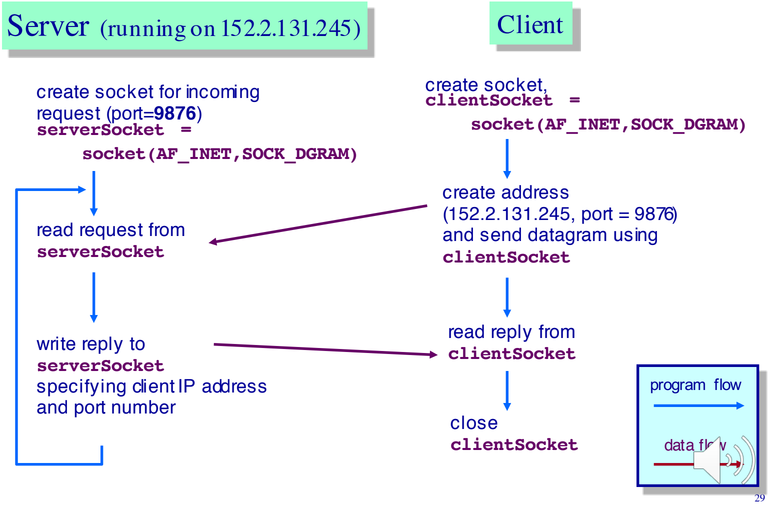
UDP socket programming model

- A UDP socket provides an *unreliable* bi-directional communication channel from one process to another
  - » A "datagram" abstraction



Socket programming with UDP Example

Client/server UDP socket interaction in Python



Server (running on 152.2.131.245)

Client

create socket for incoming request (port=**9876**)
serverSocket =
socket(AF_INET,SOCK_DGRAM)

read request from
serverSocket

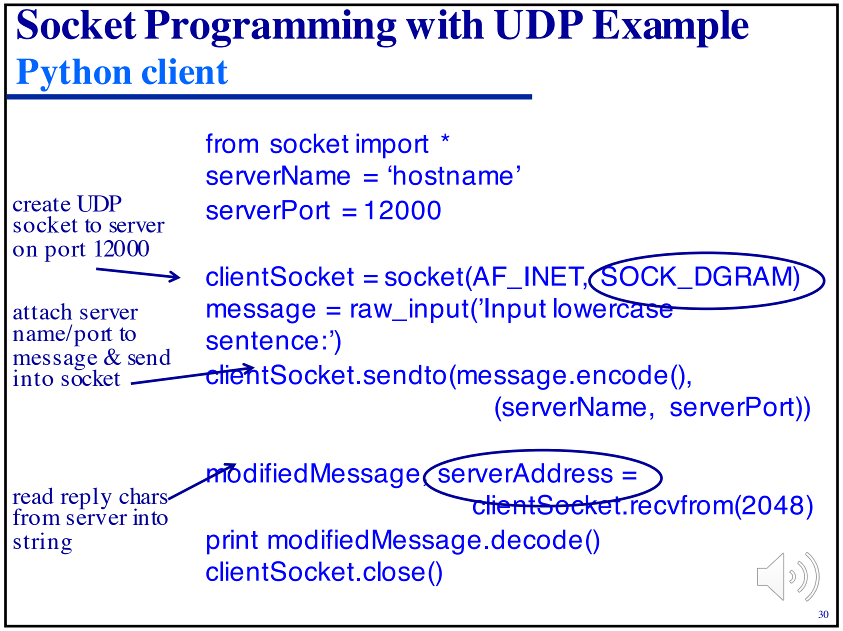
write reply to
serverSocket
specifying client IP address and port number

create socket,
clientSocket =
socket(AF_INET,SOCK_DGRAM)

create address
(152.2.131.245, port = 9876)
and send datagram using
clientSocket

read reply from
clientSocket

close
clientSocket



Socket Programming with UDP Example

Python client

create UDP socket to server on port 12000

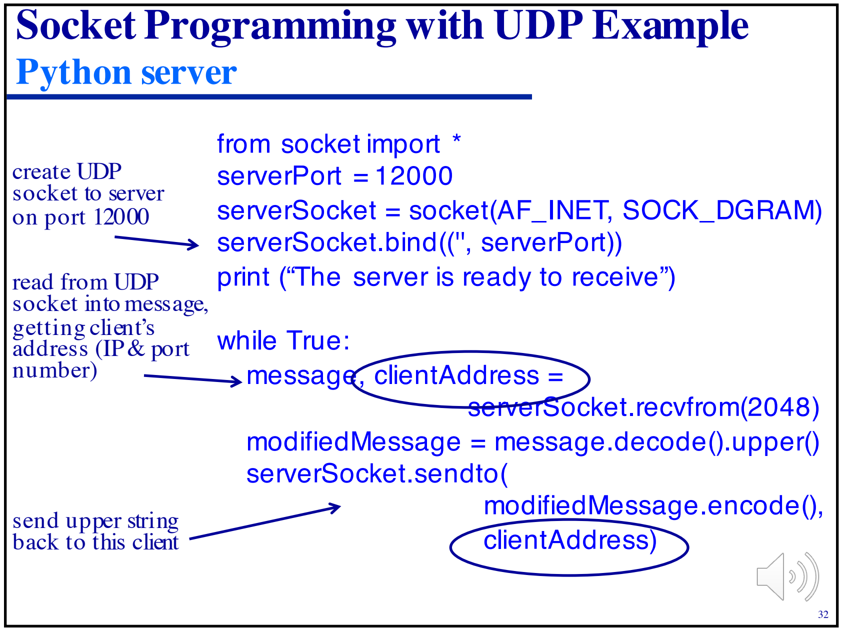
attach server name/port to message & send into socket

read reply chars from server into string

```
from socket import *
serverName = ‘hostname’
serverPort = 12000

clientSocket = socket(AF_INET, SOCK_DGRAM)
message = raw_input(’Input lowercase
sentence:’)
clientSocket.sendto(message.encode(),
                    (serverName, serverPort))

modifiedMessage, serverAddress =
                    clientSocket.recvfrom(2048)
print modifiedMessage.decode()
clientSocket.close()
```



Socket Programming with UDP Example

Python server

create UDP socket to server on port 12000

read from UDP socket into message, getting client’s address (IP & port number)

send upper string back to this client

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET, SOCK_DGRAM)
serverSocket.bind(('', serverPort))
print (“The server is ready to receive”)

while True:
    message, clientAddress =
                 serverSocket.recvfrom(2048)
    modifiedMessage = message.decode().upper()
    serverSocket.sendto(
                 modifiedMessage.encode(),
                 clientAddress)
```

Socket Programming

Services provided by Internet transport protocols

- TCP service:
  - *connection-oriented:* setup required between client, server
  - *reliable transport* between sending and receiving process
  - *flow control:* sender won't overwhelm receiver
  - *congestion control:* throttle sender when network overloaded
  - *does not provide:* timing, minimum bandwidth guarantees
- UDP service:
  - *unreliable* data transfer between sending and receiving process
  - *does not provide:* connection setup, reliability, flow control, congestion control, timing, or minimum bandwidth guarantees

Why bother? Why is there a UDP?