Additional Chapter 2 slides

JFK note: the timeout slides are important IMHO if one is doing a programming assignment (especially an RDT programming assignment in Chapter 3), since students will need to use timers in their code, and the TRY/EXCEPT is really the easiest way to do this. I introduce this here in Chapter 2 with the socket programming assignment since it teaches something (how to handle exceptions/timeouts), and lets students learn/practice that before doing the RDT programming assignment, which is harder

Application layer: overview

- Principles of network applications
- Web and HTTP
- E-mail, SMTP, IMAP
- The Domain Name System DNS
- P2P applications
- video streaming and content distribution networks
- socket programming with UDP and TCP

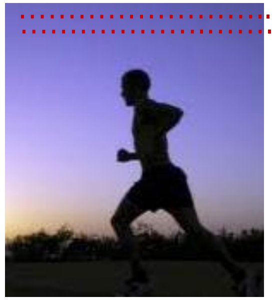
Video Streaming and CDNs: context

- stream video traffic: major consumer of Internet bandwidth
  - Netflix, YouTube, Amazon Prime: 80% of residential ISP traffic (2020)
- *challenge:* scale - how to reach ~1B users?
- *challenge:* heterogeneity
  - different users have different capabilities (e.g., wired versus mobile; bandwidth rich versus bandwidth poor)
- *solution:* distributed, application-level infrastructure

Multimedia: video

- video: sequence of images displayed at constant rate
  - e.g., 24 images/sec
- digital image: array of pixels
  - each pixel represented by bits
- coding: use redundancy *within* and *between* images to decrease # bits used to encode image
  - spatial (within image)
  - temporal (from one image to next)

spatial coding example: instead of sending *N* values of same color (all purple), send only two values: color value (*purple) and number of repeated values* (N)



frame *i*

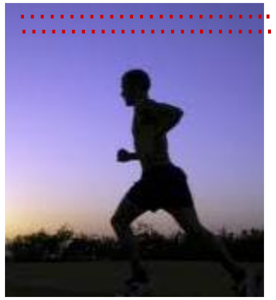
temporal coding example: instead of sending complete frame at i+1, send only differences from frame i

frame *i+1*

Multimedia: video

- CBR: (constant bit rate): video encoding rate fixed
- VBR: (variable bit rate): video encoding rate changes as amount of spatial, temporal coding changes
- examples:
  - MPEG 1 (CD-ROM) 1.5 Mbps
  - MPEG2 (DVD) 3-6 Mbps
  - MPEG4 (often used in Internet, 64Kbps – 12 Mbps)

spatial coding example: instead of sending *N* values of same color (all purple), send only two values: color value (*purple*) *and number of repeated values* (N)



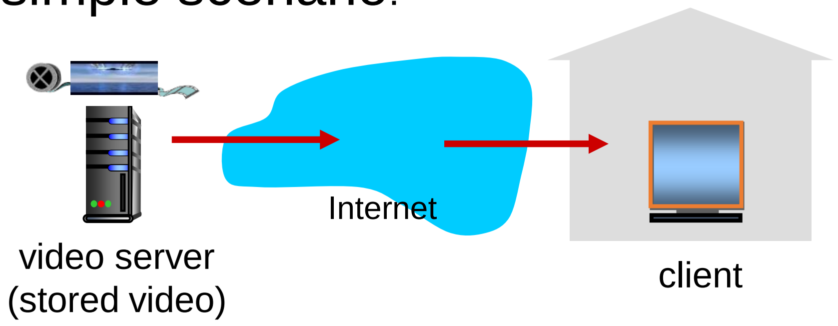
frame *i*

temporal coding example: instead of sending complete frame at i+1, send only differences from frame i

frame *i+1*

Streaming stored video

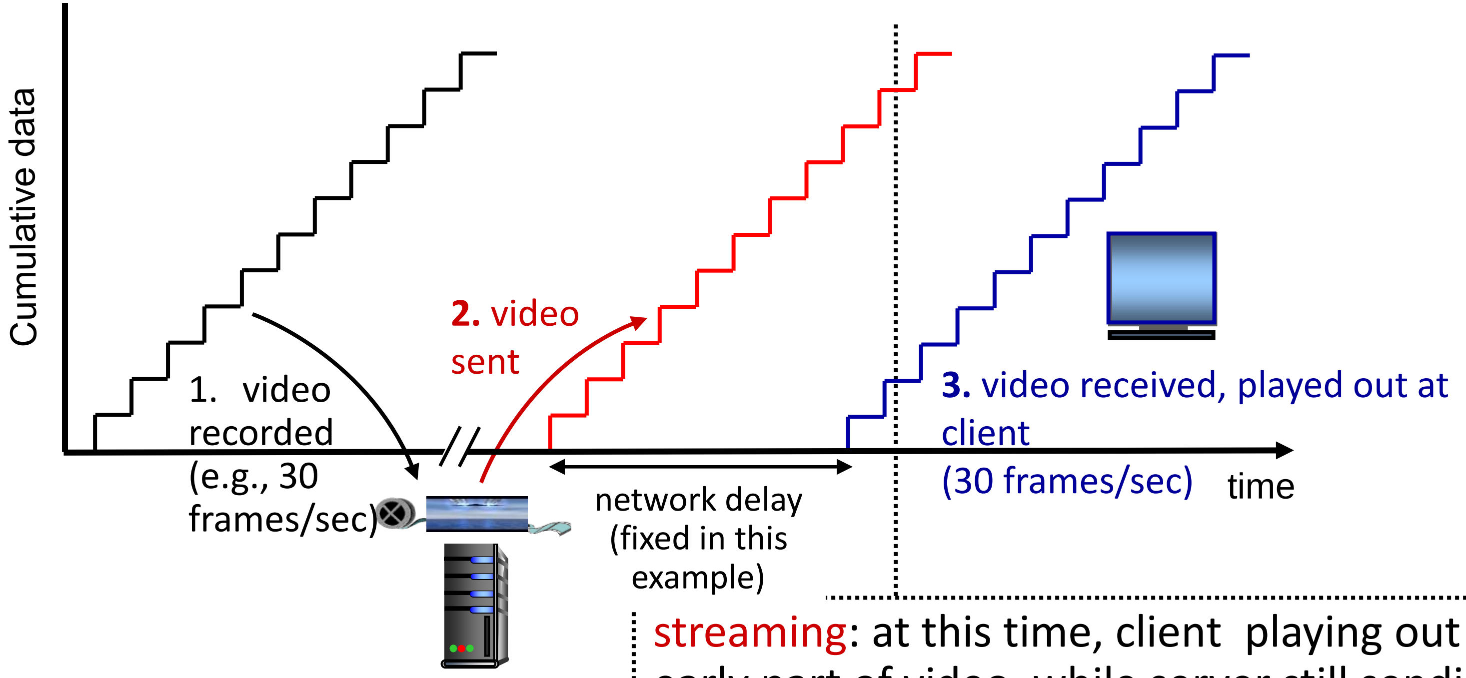
simple scenario:



Main challenges:

- server-to-client bandwidth will *vary* over time, with changing network congestion levels (in house, access network, network core, video server)
- packet loss, delay due to congestion will delay playout, or result in poor video quality

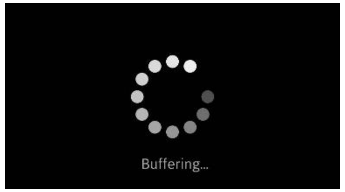
Streaming stored video



streaming: at this time, client playing out early part of video, while server still sending later part of video

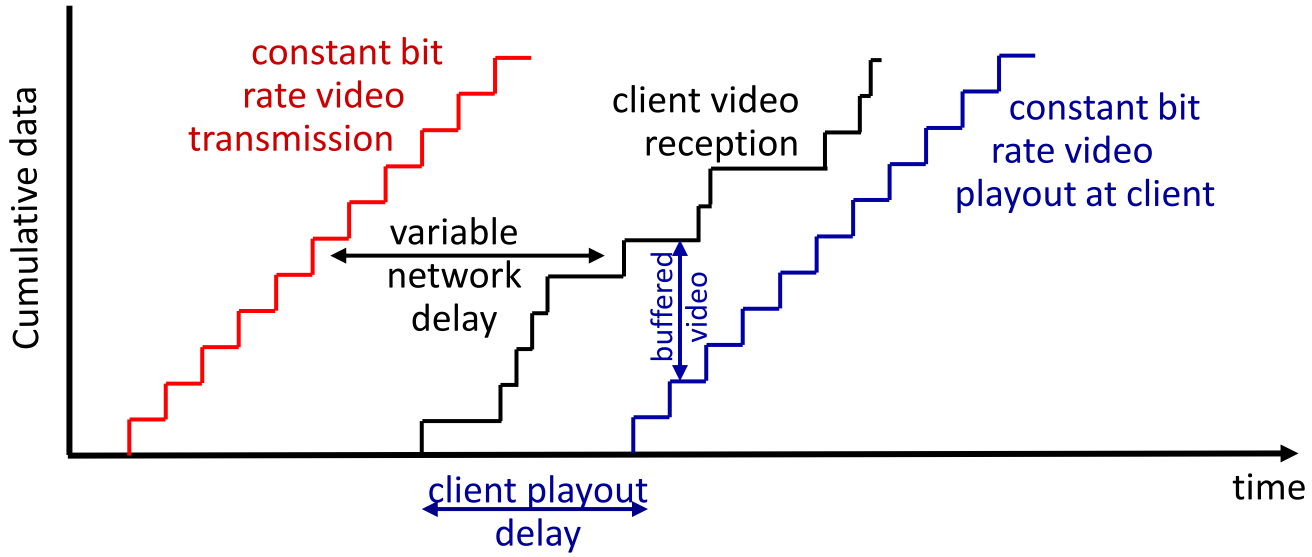
Streaming stored video: challenges

- continuous playout constraint: during client video playout, playout timing must match original timing
  - … but network delays are variable (jitter), so will need client-side buffer to match continuous playout constraint



- other challenges:
  - client interactivity: pause, fast-forward, rewind, jump through video
  - video packets may be lost, retransmitted

Streaming stored video: playout buffering



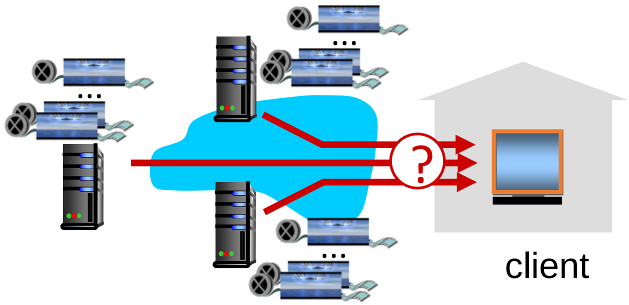
- *client-side buffering and playout delay:* compensate for network-added delay, delay jitter

Streaming multimedia: DASH

*D*ynamic, *A*daptive
*S*treaming over *H*TTP

server:

- divides video file into multiple chunks
- each chunk encoded at multiple different rates
- different rate encodings stored in different files
- files replicated in various CDN nodes
- *manifest file:* provides URLs for different chunks

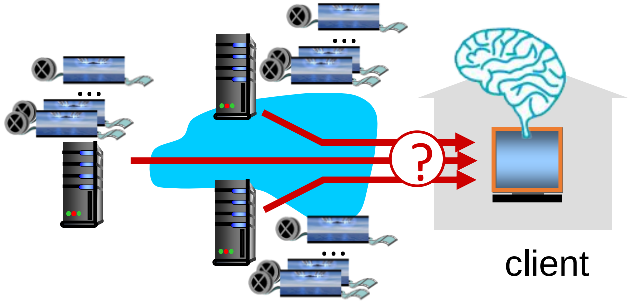


client:

- periodically estimates server-to-client bandwidth
- consulting manifest, requests one chunk at a time
  - chooses maximum coding rate sustainable given current bandwidth
  - can choose different coding rates at different points in time (depending on available bandwidth at time), and from different servers

Streaming multimedia: DASH

- *"intelligence" at client:* client determines
  - *when* to request chunk (so that buffer starvation, or overflow does not occur)
  - *what encoding rate* to request (higher quality when more bandwidth available)
  - *where* to request chunk (can request from URL server that is "close" to client or has high available bandwidth)



Streaming video = encoding + DASH + playout buffering

Content distribution networks (CDNs)

challenge: how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?

- *option 1:* single, large "mega-server"
  - single point of failure
  - point of network congestion
  - long (and possibly congested) path to distant clients

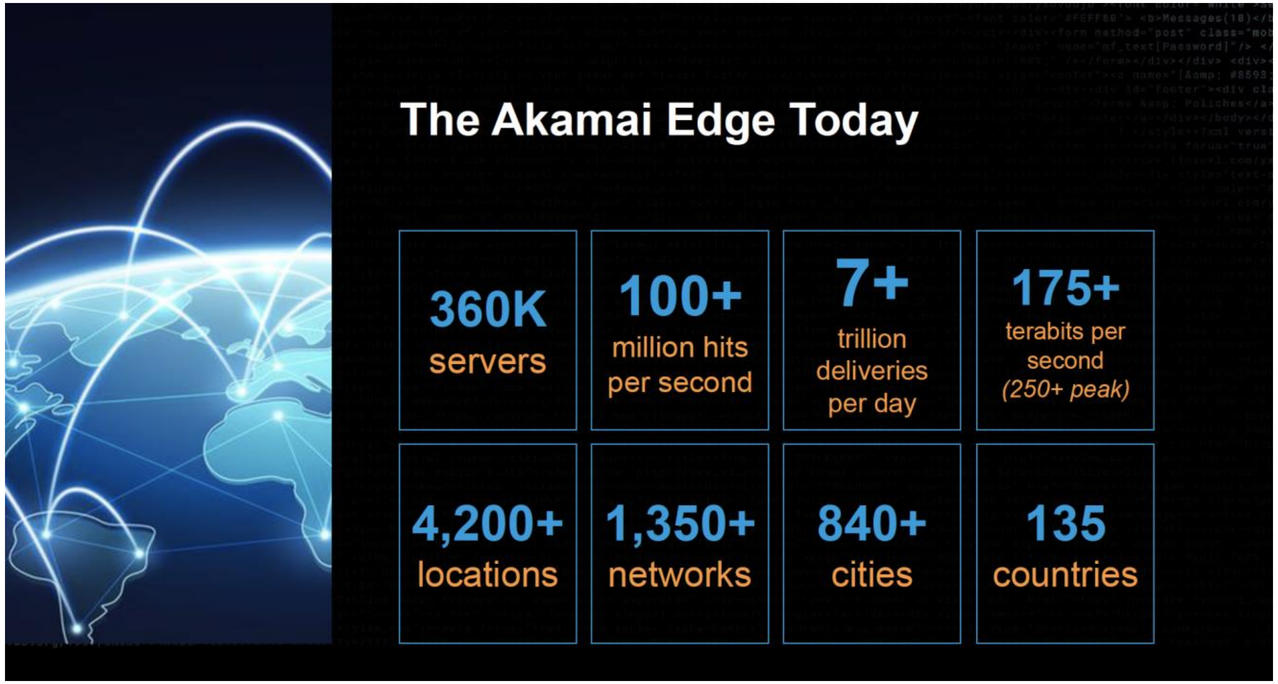
….quite simply: this solution *doesn't scale*

Content distribution networks (CDNs)

challenge: how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?

- *option 2:* store/serve multiple copies of videos at multiple geographically distributed sites *(CDN)*
  - *enter deep:* push CDN servers deep into many access networks
    - close to users
    - Akamai: 240,000 servers deployed in > 120 countries (2015)
  - *bring home:* smaller number (10's) of larger clusters in POPs near access nets
    - used by Limelight

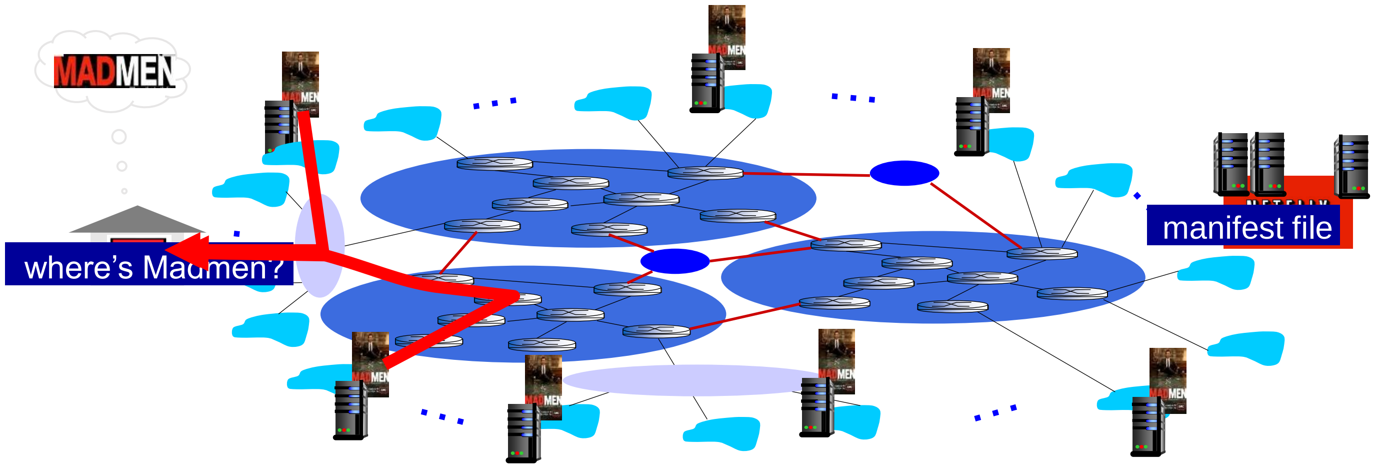
Akamai today:



Source: https://networkingchannel.eu/living-on-the-edge-for-a-quarter-century-an-akamai-retrospective-downloads/

How does Netflix work?

- Netflix: stores copies of content (e.g., MADMEN) at its (worldwide) OpenConnect CDN nodes
- subscriber requests content, service provider returns manifest
  - using manifest, client retrieves content at highest supportable rate
  - may choose different rate or copy if network path congested



Content distribution networks (CDNs)

OTT challenges: coping with a congested Internet from the “edge”

- what content to place in which CDN node?
- from which CDN node to retrieve content? At which rate?

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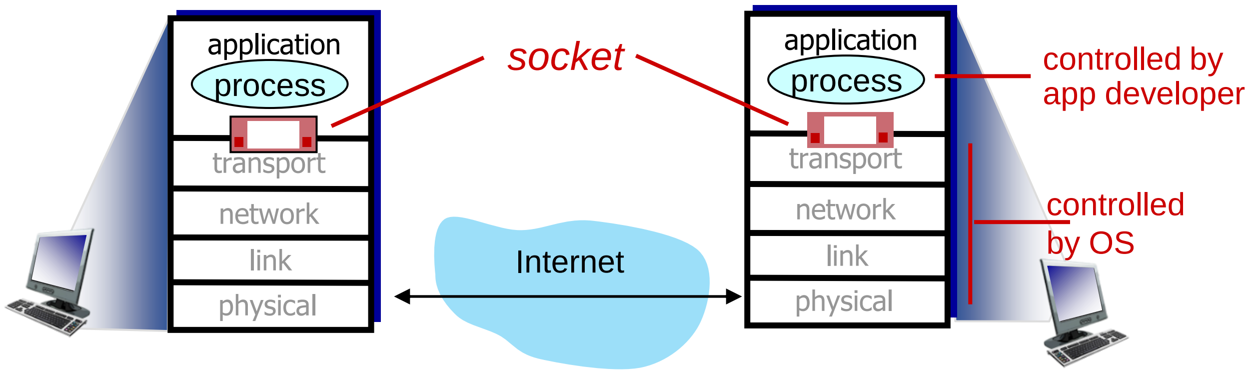
Socket programming

goal: learn how to build client/server applications that communicate using sockets

socket: door between application process and end-end-transport protocol



Socket programming

Two socket types for two transport services:

- *UDP:* unreliable datagram
- *TCP:* reliable, byte stream-oriented

Application Example:

1. client reads a line of characters (data) from its keyboard and sends data to server
2. server receives the data and converts characters to uppercase
3. server sends modified data to client
4. client receives modified data and displays line on its screen

Socket programming with UDP

UDP: no "connection" between client and server:

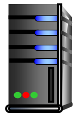
- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- receiver extracts sender IP address and port# from received packet

UDP: transmitted data may be lost or received out-of-order

Application viewpoint:

- UDP provides *unreliable* transfer of groups of bytes ("datagrams") between client and server processes

Client/server socket interaction: UDP



server (running on serverIP)

create socket, port= x:
serverSocket =
socket(AF_INET,SOCK_DGRAM)

read datagram from
serverSocket

write reply to
serverSocket
specifying
client address,
port number

client

create socket:
clientSocket =
socket(AF_INET,SOCK_DGRAM)

Create datagram with serverIP address
And port=x; send datagram via
clientSocket

read datagram from
clientSocket

close
clientSocket

Example app: UDP client

Python UDPClient

include Python's socket library

```
from socket import *
serverName = 'hostname'
serverPort = 12000
```

create UDP socket

```
clientSocket = socket(AF_INET,
                      SOCK_DGRAM)
```

get user keyboard input

```
message = input('Input lowercase sentence:')
```

attach server name, port to message; send into socket

```
clientSocket.sendto(message.encode(),
                    (serverName, serverPort))
```

read reply data (bytes) from socket

```
modifiedMessage, serverAddress =
                    clientSocket.recvfrom(2048)
```

print out received string and close socket

```
print(modifiedMessage.decode())
clientSocket.close()
```

Note: this code update (2023) to Python 3

Example app: UDP server

Python UDPServer

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET, SOCK_DGRAM)          # create UDP socket
serverSocket.bind(('', serverPort))                 # bind socket to local port number 12000
print('The server is ready to receive')
while True:                                         # loop forever
    message, clientAddress = serverSocket.recvfrom(2048)   # Read from UDP socket into message, getting client's address (client IP and port)
    modifiedMessage = message.decode().upper()
    serverSocket.sendto(modifiedMessage.encode(),
                        clientAddress)              # send upper case string back to this client
```

Note: this code update (2023) to Python 3

Socket programming with TCP

Client must contact server

- server process must first be running
- server must have created socket (door) that welcomes client's contact

Client contacts server by:

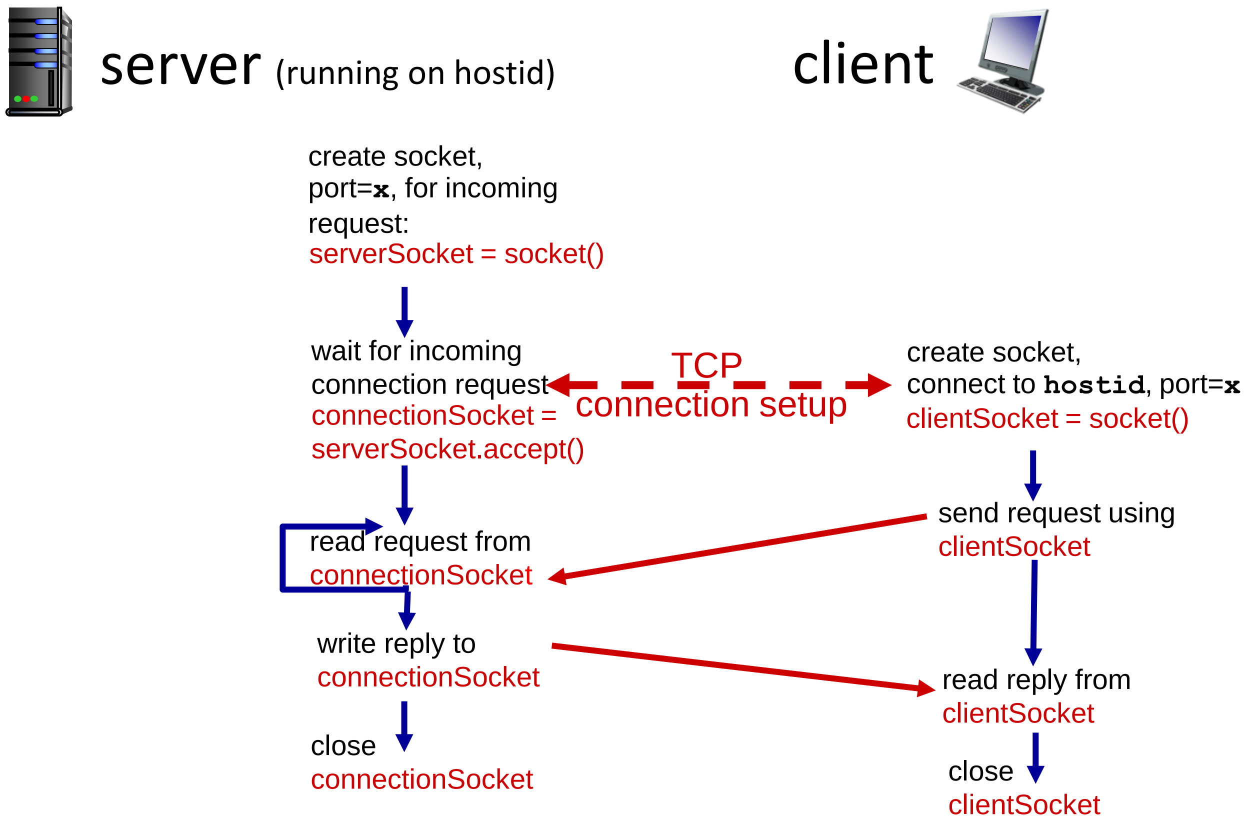
- Creating TCP socket, specifying IP address, port number of server process
- *when client creates socket:* client TCP establishes connection to server TCP

- when contacted by client, *server TCP creates new socket* for server process to communicate with that particular client
  - allows server to talk with multiple clients
  - client source port # and IP address used to distinguish clients (more in Chap 3)

Application viewpoint

TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server processes

Client/server socket interaction: TCP



Example app: TCP client

Python TCPClient

create TCP socket for server, remote port 12000

No need to attach server name, port

```
from socket import *
serverName = 'servername'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName,serverPort))
sentence = input('Input lowercase sentence:')
clientSocket.send(sentence.encode())
modifiedSentence = clientSocket.recv(1024)
print ('From Server:', modifiedSentence.decode())
clientSocket.close()
```

Note: this code update (2023) to Python 3

Example app: TCP server

Python TCPServer

create TCP welcoming socket

server begins listening for incoming TCP requests

loop forever

server waits on accept() for incoming requests, new socket created on return

read bytes from socket (but not address as in UDP)

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

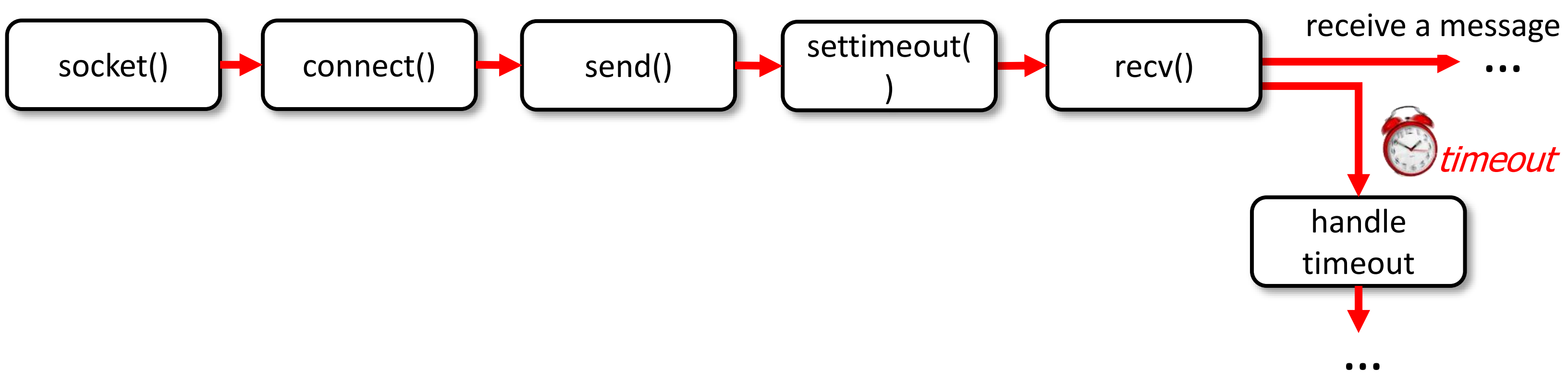
```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind(('',serverPort))
serverSocket.listen(1)
print('The server is ready to receive')
while True:
    connectionSocket, addr = serverSocket.accept()

    sentence = connectionSocket.recv(1024).decode()
    capitalizedSentence = sentence.upper()
    connectionSocket.send(capitalizedSentence.
                                    encode())
    connectionSocket.close()
```

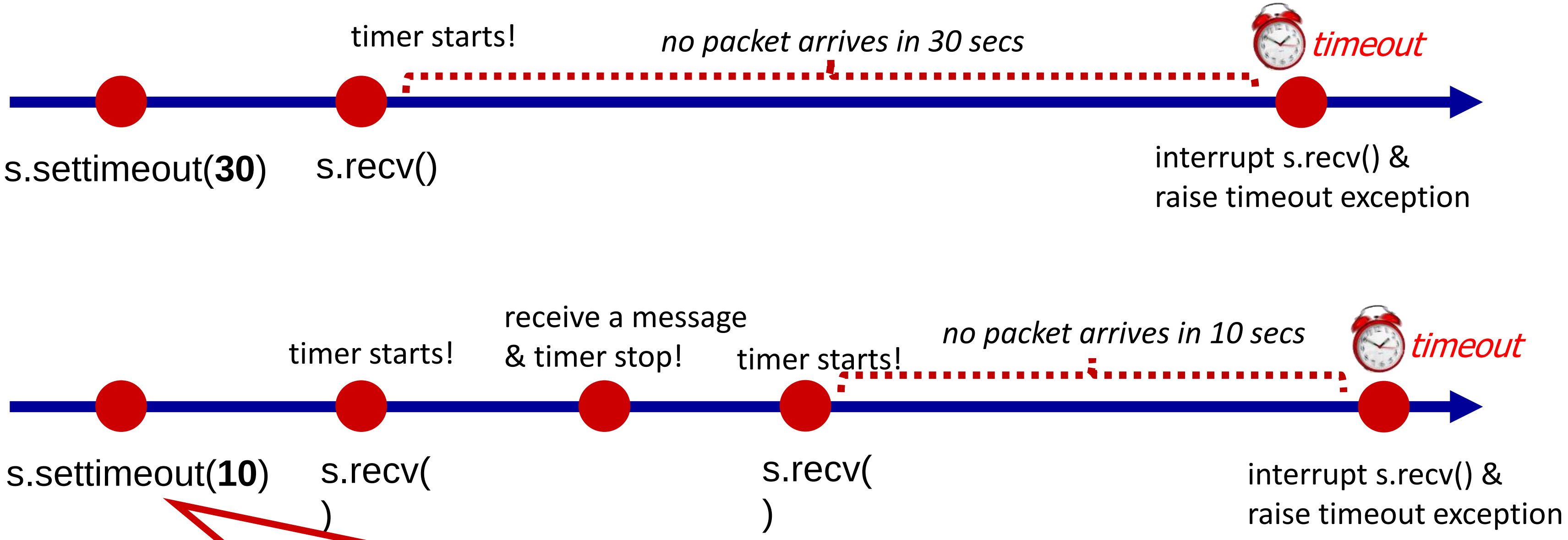
Note: this code update (2023) to Python 3

Socket programming: waiting for multiple events

- sometimes a program must wait for one of several events to happen, e.g.,:
  - wait for either (i) a reply from another end of the socket, or (ii) timeout: timer
  - wait for replies from several different open sockets: select(), multithreading
- timeouts are used extensively in networking
- using timeouts with Python socket:



How Python socket.settimeout() works?



Set a timeout on all future socket operations of that specific socket!

Python try-except block

Execute a block of code, and handle “exceptions” that may occur when executing that block of code

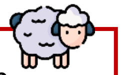
```
try:
    <do something>
except <exception>:
    <handle the exception>
```

Executing this try code block may cause exception(s) to catch. If an exception is raised, execution jumps from jumps directly into except code block

this except code block is only executed *if an <exception> occurred* in the try code block (note: except block is *required* with a try block)

Socket programming: socket timeouts

Toy Example:



- A shepherd boy tends his master’s sheep.
- If he sees a wolf, he can send a message to villagers for help using a TCP socket.
- The boy found it fun to connect to the server without sending any messages. But the villagers don’t think so.
- And they decided that if the boy connects to the server and doesn’t send the wolf location **within 10 seconds for three times**, they will **stop listening** to him forever and ever.

Python TCPServer (Villagers)

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind(('',serverPort))
serverSocket.listen(1)
counter = 0
while counter < 3:
    connectionSocket, addr = serverSocket.accept()
    connectionSocket.settimeout(10)
    try:
        wolf_location =
connectionSocket.recv(1024).decode()
        send_hunter(wolf_location) # a villager function
        connectionSocket.send('hunter sent')
    except timeout:
        counter += 1
    connectionSocket.close()
```

set a 10-seconds timeout on all future socket operations

timer starts when recv() is called and will raise timeout exception if there is no message within 10 seconds.

catch socket timeout exception

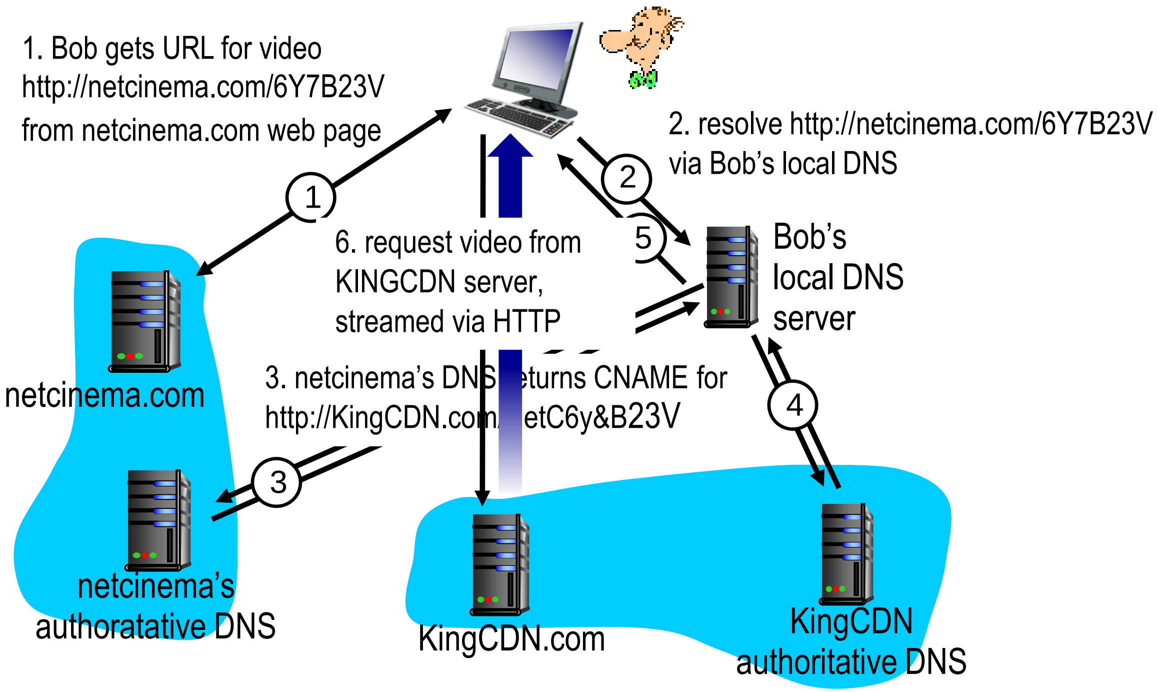
Sample SMTP interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250  Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

CDN content access: a closer look

Bob (client) requests video http://netcinema.com/6Y7B23V

- video stored in CDN at http://KingCDN.com/NetC6y&B23V



Case study: Netflix