Sockets and Client/Server Communication

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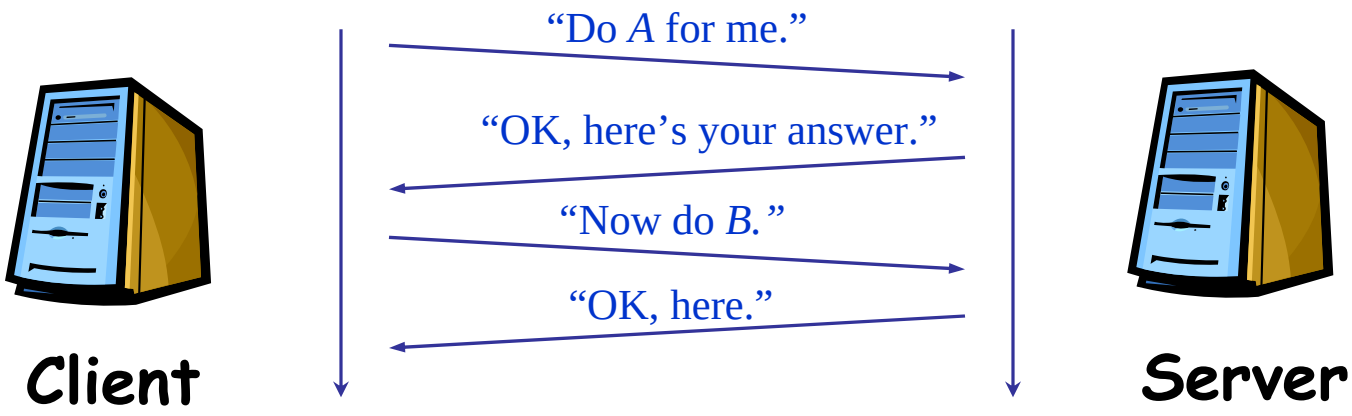
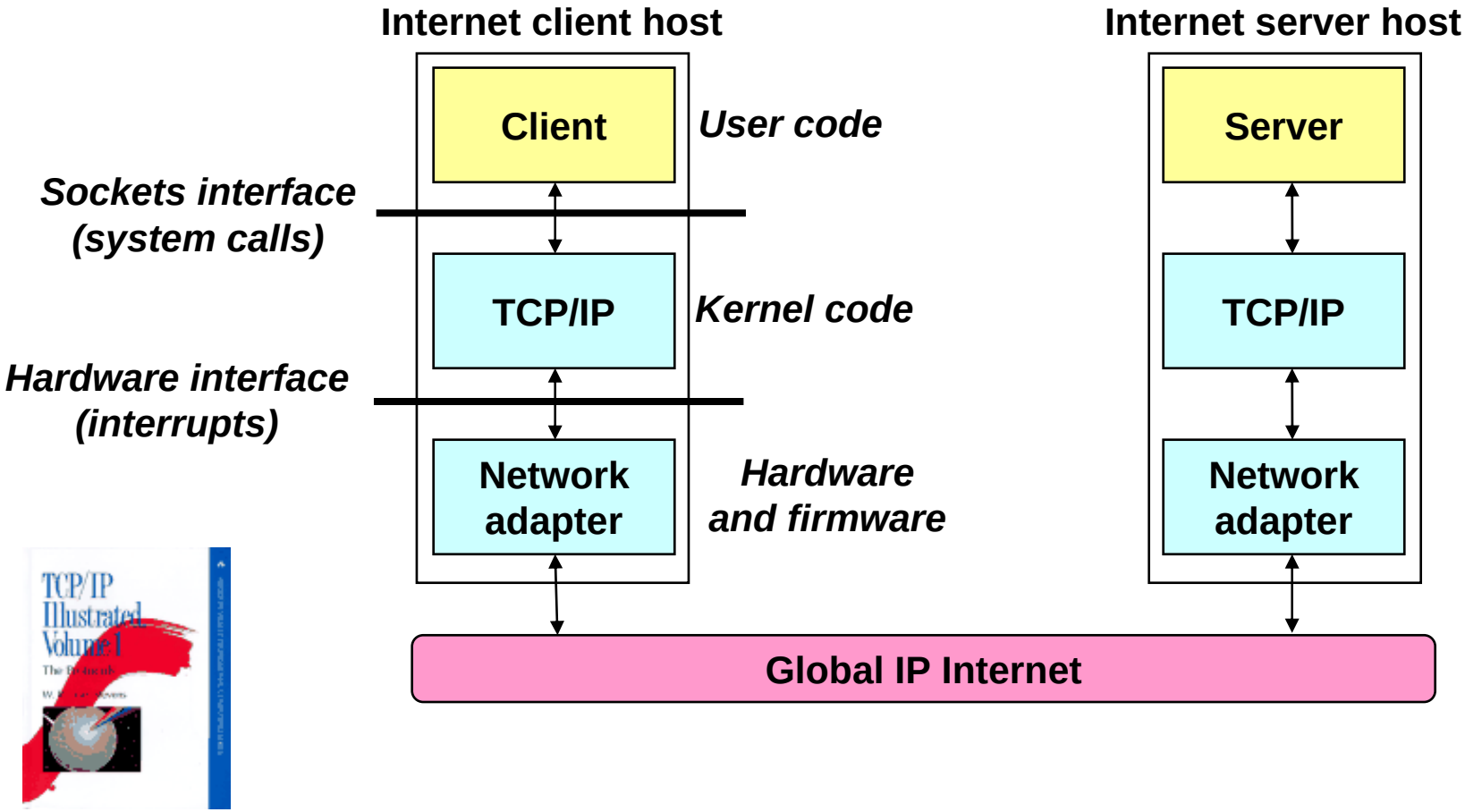
Services



request/response paradigm ==> *client/server roles*

- Remote Procedure Call (RPC)
- object invocation, e.g., Remote Method Invocation (RMI)
- HTTP (the Web)
- device protocols (e.g., SCSI)

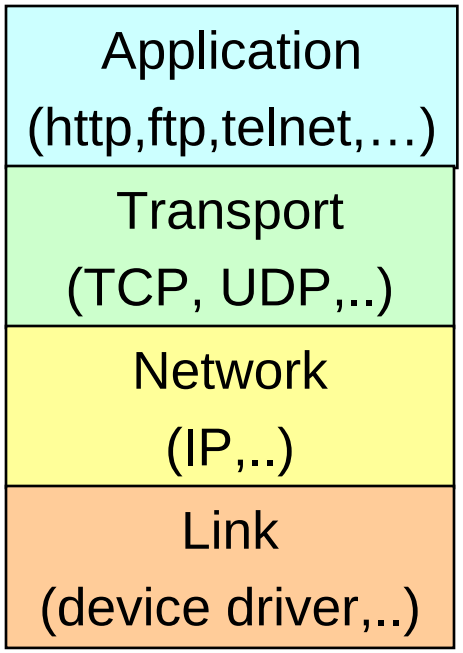
An Internet Application



[CMU 15-213]

Networking Basics

- Applications Layer
  - Standard apps
    - HTTP
    - FTP
    - Telnet
  - User apps
- Transport Layer
  - TCP
  - UDP
  - Programming Interface:
    - Sockets
- Network Layer
  - IP
- Link Layer
  - Device drivers



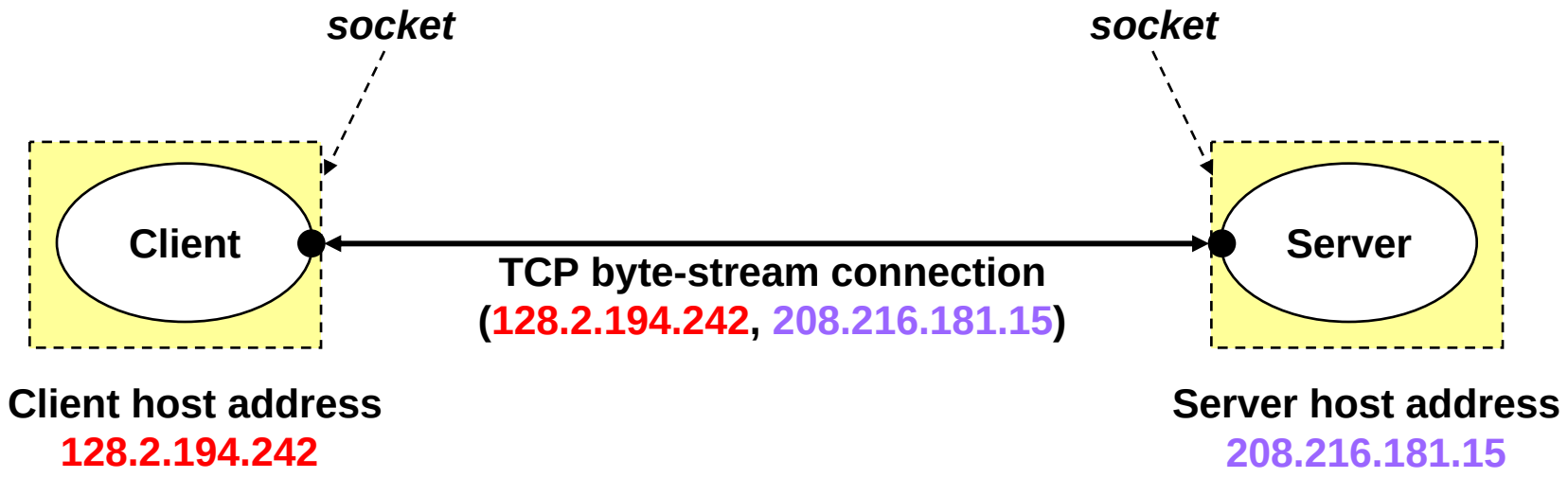
[Buyya]

A Programmer's View of the Internet

- Hosts are mapped to a set of 32-bit *IP addresses*.
  - 128.2.203.179
- The set of IP addresses is mapped to a set of identifiers called Internet *domain names*.
  - 128.2.203.179 is mapped to www.cs.cmu.edu
- A process on one Internet host can communicate with a process on another Internet host over a *connection*.

Internet Connections

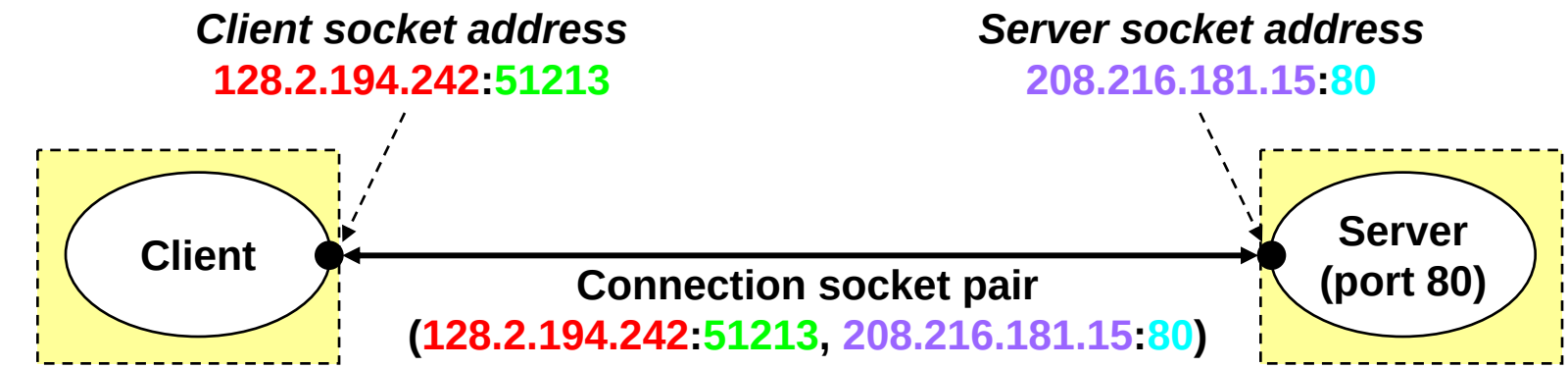
- Most clients and servers communicate by sending streams of bytes over *connections*
  - E.g., using TCP, the Transmission Control Protocol
- *A socket* is an endpoint of a connection between two processes.
  - Unix and Windows system calls, Java APIs



[adapted from CMU 15-213]

Sockets: the rest of the story

- A host might have many open connections, possibly held by different processes.
- A *port* is a unique communication endpoint on a host, named by a 16-bit integer, and associated with a process.



Client host address
128.2.194.242

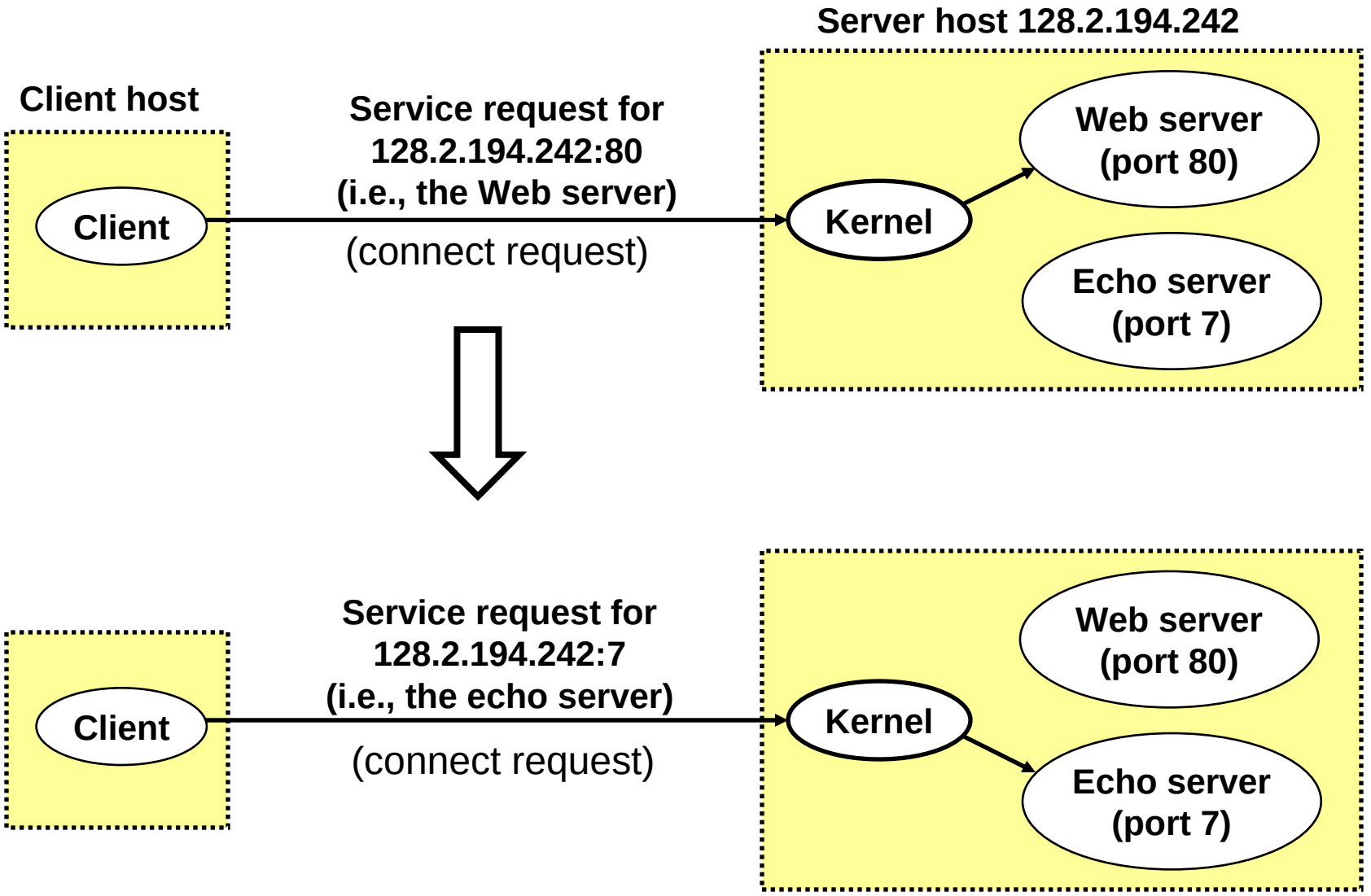
Note: 51213 is an ephemeral port allocated by the kernel

Server host address
208.216.181.15

Note: 80 is a well-known port associated with Web servers

[CMU 15-213]

Using Ports to Identify Services



[CMU 15-213]

More on Ports

- This port abstraction is an Internet Protocol concept.
  - Source/dest port is named in every packet.
  - Kernel looks at port to demultiplex incoming traffic.
- The term is commonly used to refer to a communication endpoint in other contexts.
- How do clients know what port number to connect to?
  - We have to agree on well-known ports for common services: ICAAN again
  - Look at /etc/services
  - Ports 1023 and below are 'reserved'
- Clients need a return port, but it can be an ephemeral port assigned dynamically by the kernel.

Berkeley Sockets

- Networking protocols are implemented as part of the OS
  - The networking API exported by most OS's is the *socket interface*
  - Originally provided by BSD 4.1c ~1982.
- The principal abstraction is a socket
  - Point at which an application attaches to the network
  - Defines operations for creating connections, attaching to network, sending/receiving data, closing.

[Paul Barford]

Datagrams and Streams

Communication over the Internet uses a selected transport-layer protocol (layer 4) built above the common IP packet protocol.

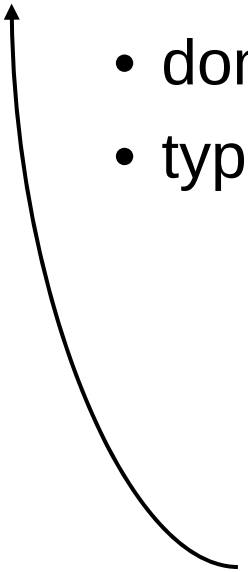
- Point-to-point communication with a socket/port at either end.
- UDP = User Datagram Protocol (AF_INET/SOCK_DGRAM)
  - Send/receive messages up to 8KB (plus)
  - Unreliable: messages may be lost or reordered
  - Connectionless: no notion or cost of 'establishing a connection'
- TCP = Transmission Control Protocol (AF_INET/SOCK_STREAM)
  - Send/receive byte streams of arbitrary length (like a pipe)
  - All bytes delivered are correct and delivered in order
  - Masks transient packet loss
  - Connection setup/maintenance: other end is notified if one end closes or resets the connection, or if the connection breaks.

Unix Sockets I

- Creating a socket

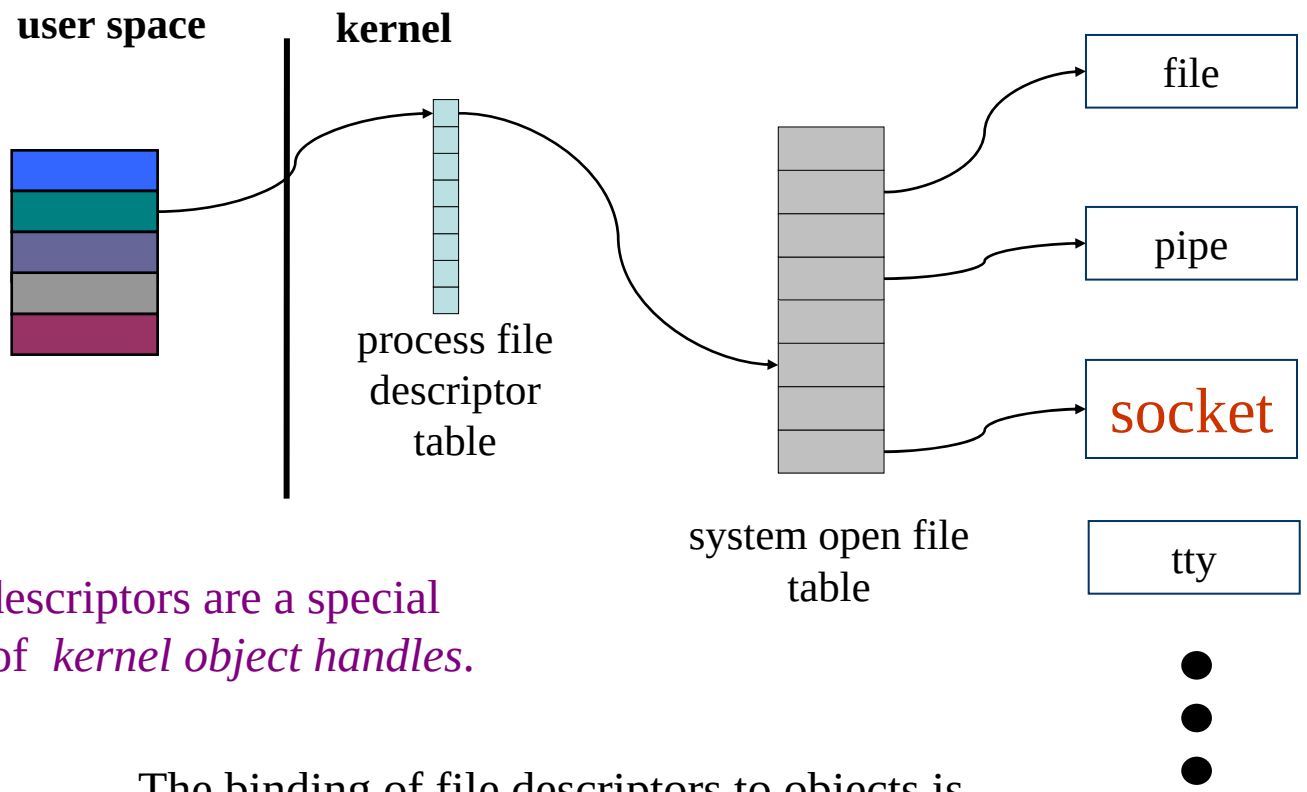
  int socket(int domain, int type, int protocol)

  - domain = AF_INET, AF_UNIX
  - type = SOCK_STREAM, SOCK_DGRAM



What is this integer that is returned?

Unix File Descriptors Illustrated



File descriptors are a special case of *kernel object handles*.

The binding of file descriptors to objects is specific to each process, like the virtual translations in the virtual address space.

Disclaimer: this drawing is oversimplified.

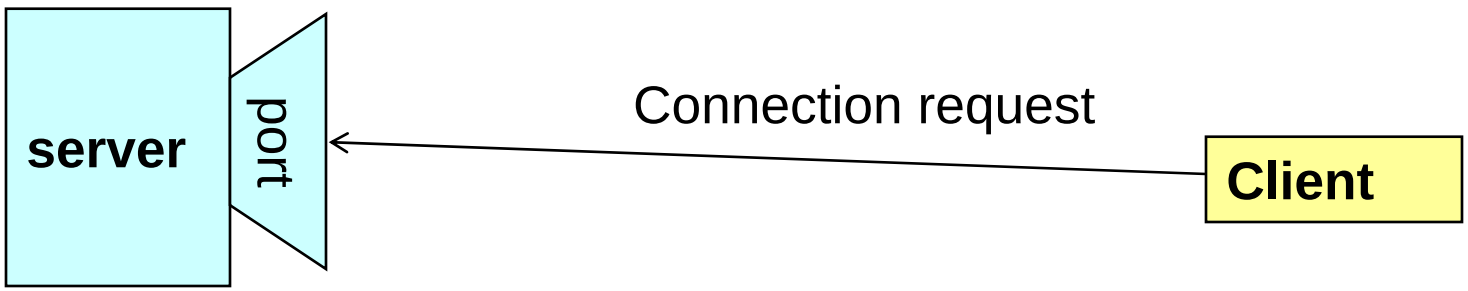
Sending/Receiving

- Use read/write system calls and variants to transmit/receive byte-stream data.
  - "Just like files"!
  - Close works too
- Alternative syscalls for sending/receiving messages
- Variants of:

```
int send(int socket, char *msg, int mlen, int flags)
int recv(int socket, char *buf, int blen, int flags)
```

Listening for a Connection

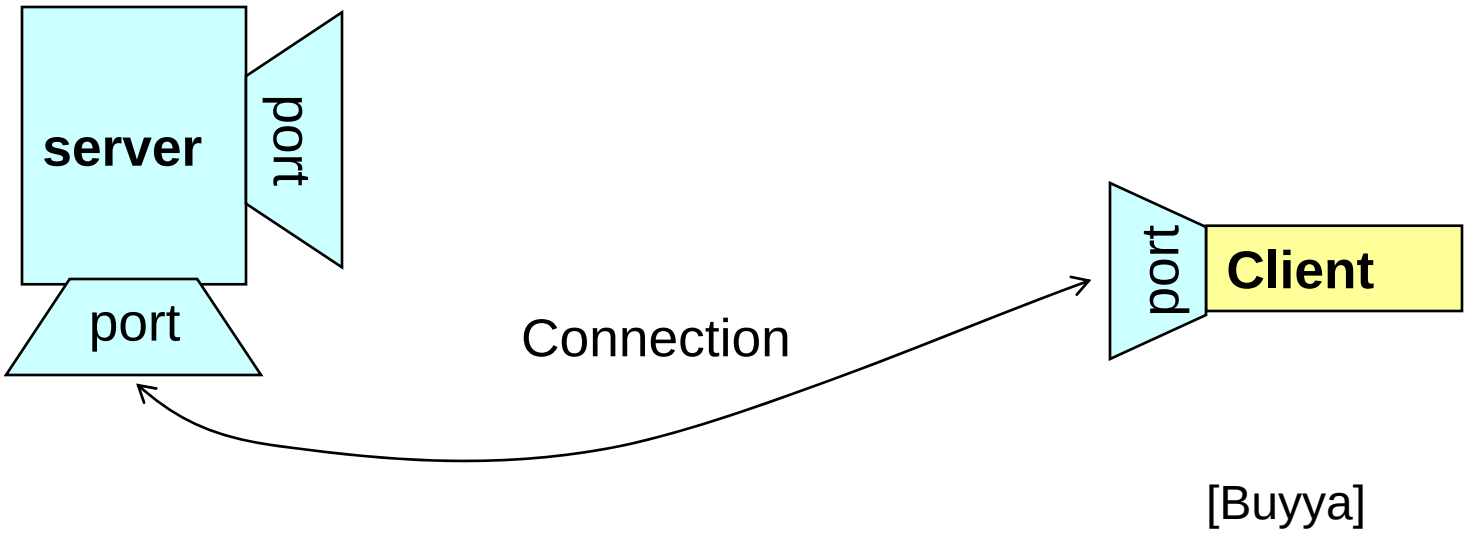
- A server (program) runs on a specific computer and has a socket that is bound to a specific port. The server waits and listens to the socket for a client to make a connection request.



[Buyya]

Making a Connection

- If everything goes well, the server accepts the connection.
- Upon acceptance, the server gets a new socket bound to a different port.
  - It needs a new socket (consequently a different port number) so that it can continue to listen to the original socket for connection requests while serving the connected client.



[Buyya]

Server-Side Sockets

- Bind socket to IP address/port

  int bind(int socket, struct sockaddr *addr, int addr_len)

- Mark the socket as accepting connections

  int listen(int socket, int backlog)

- "Passive open" accepts connection

  int accept(int socket, struct sockaddr *addr, int addr_len)

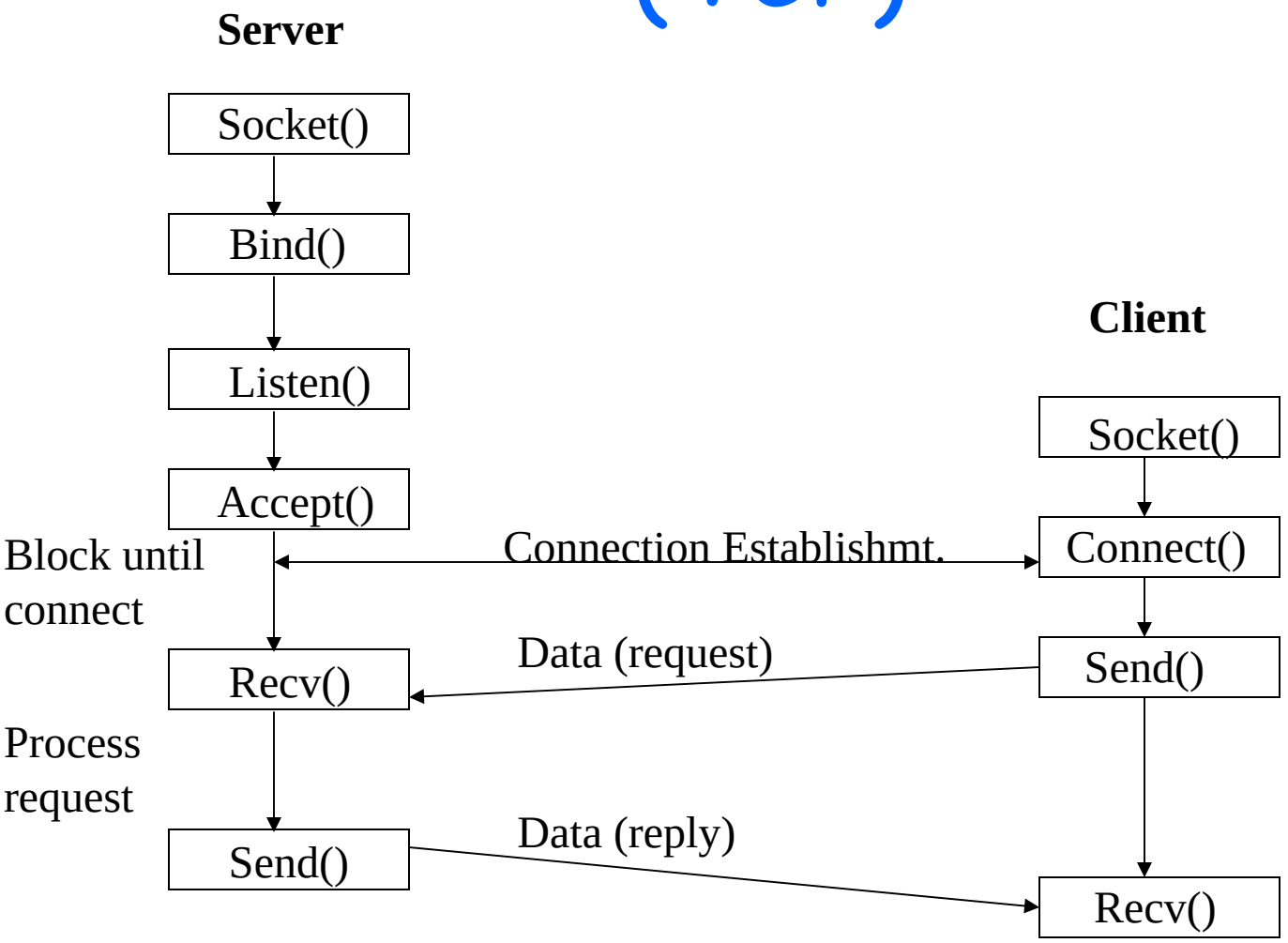
  (returns a new socket to talk to the client)

Client Socket

- Active Open (on client)

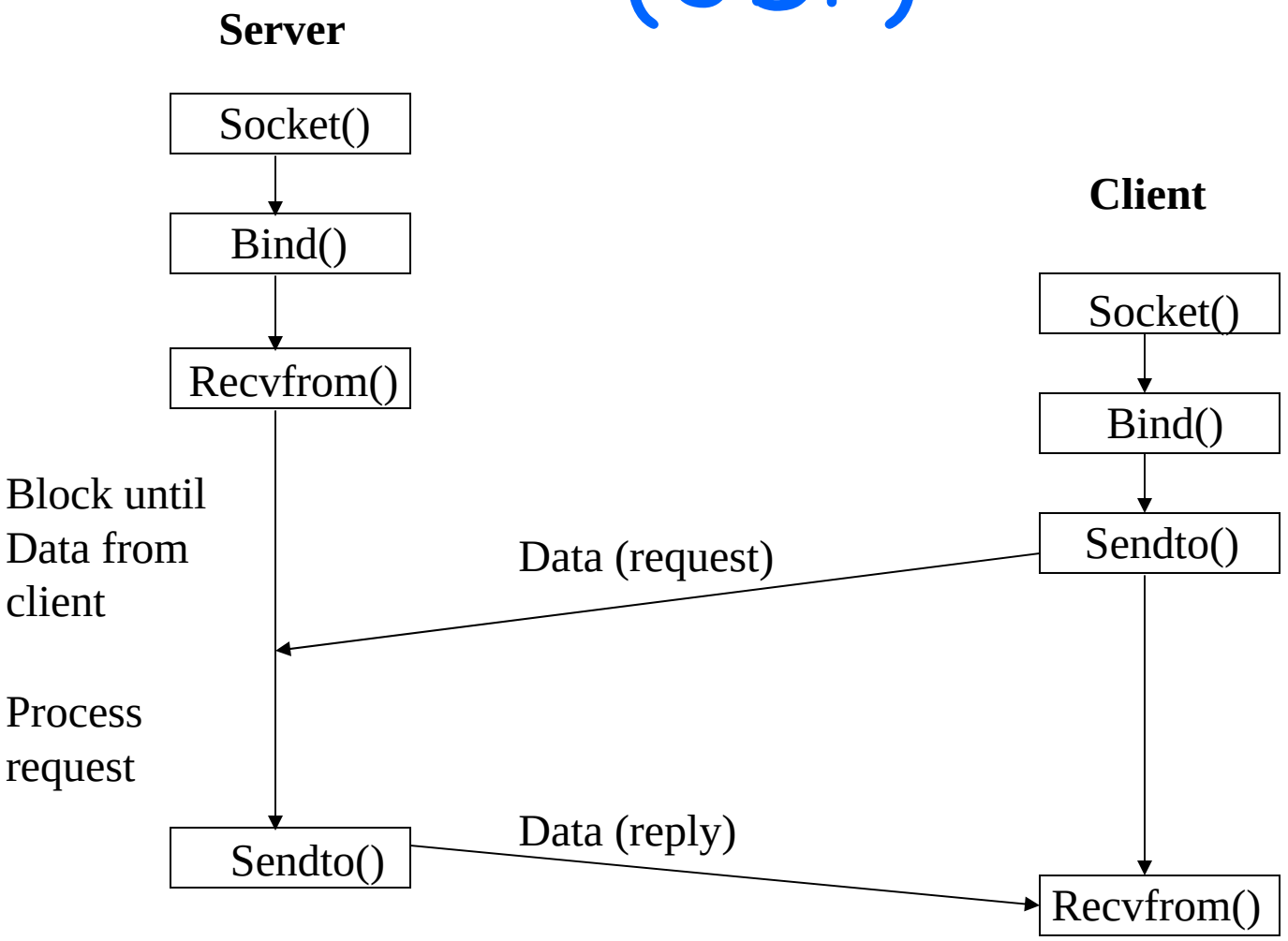
  int connect(int socket, struct sockaddr *addr,
  int addr_len)

Connection-oriented example (TCP)



[Paul Barford]

Connectionless example (UDP)



[Paul Barford]

Socket call

- Means by which an application attached to the network
- int socket(int family, int type, int protocol)
- *Family*: address family (protocol family)
  - AF_UNIX, AF_INET, AF_NS, AF_IMPLINK
- *Type*: semantics of communication
  - SOCK_STREAM, SOCK_DGRAM, SOCK_RAW
  - Not all combinations of family and type are valid
- *Protocol*: Usually set to 0 but can be set to specific value.
  - Family and type usually imply the protocol
- Return value is a *handle* for new socket

[Paul Barford]

Bind call

- Binds a newly created socket to the specified address
- Int bind(int socket, struct sockaddr *address, int addr_len)
- *Socket*: newly created socket handle
- *Address*: data structure of address of *local* system
  - IP address and port number (demux keys)
  - Same operation for both connection-oriented and connectionless servers
    - Can use well known port or unique port

[Paul Barford]

Listen call

- Used by connection-oriented servers to indicate an application is willing to receive connections
- Int(int socket, int backlog)
- *Socket*: handle of newly creates socket
- *Backlog*: number of connection requests that can be queued by the system while waiting for server to execute accept call.

[Paul Barford]

Accept call

- After executing *listen,* the accept call carries out a *passive open* (server prepared to accept connects).
- Int accept(int socket, struct sockaddr *address, int addr_len)
- It blocks until a remote client carries out a connection request.
- When it does return, it returns with a *new* socket that corresponds with new connection and the address contains the clients address

[Paul Barford]

Connect call

- Client executes an *active open* of a connection
- Int connect(int socket, struct sockaddr *address, int addr_len)
- Call does not return until the three-way handshake (TCP) is complete
- Address field contains remote system's address
- Client OS usually selects random, unused port

[Paul Barford]

Send(to), Recv(from)

- After connection has been made, application uses send/recv to data
- Int send(int socket, char *message, int msg_len, int flags)
  - Send specified message using specified socket
- Int recv(int scoket, char *buffer, int buf_len, int flags)
  - Receive message from specified socket into specified buffer

[Paul Barford]

Implementing a Server (Java)

1. Open the Server Socket:

```
ServerSocket server;
DataOutputStream os;
DataInputStream is;
server = new ServerSocket( PORT );
```

2. Wait for the Client Request:

```
Socket client = server.accept();
```

3. Create I/O streams for communicating to the client

```
is = new DataInputStream( client.getInputStream() );
os = new DataOutputStream( client.getOutputStream() );
```

4. Perform communication with client

```
Receive from client: String line = is.readLine();
Send to client: os.writeBytes("Hello\n");
```

5. Close sockets: `client.close();`

[Buyya]

Implementing a Client (Java)

1. Create a Socket Object:
   ```
   client = new Socket( server, port_id );
   ```
2. Create I/O streams for communicating with the server.
   ```
   is = new DataInputStream(client.getInputStream() );
   os = new DataOutputStream( client.getOutputStream() );
   ```
3. Perform I/O or communication with the server:
   - Receive data from the server:
     ```
     String line = is.readLine();
     ```
   - Send data to the server:
     ```
     os.writeBytes("Hello\n");
     ```
4. Close the socket when done:
   ```
   client.close();
   ```

[Buyya]

A simple server (simplified code)

```
// SimpleServer.java: a simple server program
import java.net.*;
import java.io.*;
public class SimpleServer {
  public static void main(String args[]) throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    Socket s1=s.accept(); // Wait and accept a connection
    // Get a communication stream associated with the socket
    OutputStream s1out = s1.getOutputStream();
    DataOutputStream dos = new DataOutputStream (s1out);
    // Send a string!
    dos.writeUTF("Hi there");
    // Close the connection, but not the server socket
    dos.close();
    s1out.close();
    s1.close();
  }
}
```

[Buyya]

A simple client (simplified code)

```
// SimpleClient.java: a simple client program
import java.net.*;
import java.io.*;
public class SimpleClient {
  public static void main(String args[]) throws IOException {
    // Open your connection to a server, at port 1234
    Socket s1 = new Socket("mundroo.cs.mu.oz.au",1234);
    // Get an input file handle from the socket and read the input
    InputStream s1In = s1.getInputStream();
    DataInputStream dis = new DataInputStream(s1In);
    String st = new String (dis.readUTF());
    System.out.println(st);
    // When done, just close the connection and exit
    dis.close();
    s1In.close();
    s1.close();
  }
}
```

[Buyya]

ServerSocket & Exceptions

- public **ServerSocket**(int port) throws IOException
  - Creates a server socket on a specified port.
  - A port of 0 creates a socket on any free port. You can use **getLocalPort**() to identify the (assigned) port on which this socket is listening.
  - The maximum queue length for incoming connection indications (a request to connect) is set to 50. If a connection indication arrives when the queue is full, the connection is refused.
- Throws:
  - IOException - if an I/O error occurs when opening the socket.
  - SecurityException - if a security manager exists and its checkListen method doesn't allow the operation.

[Buyya]

How does the Web work?

- The canonical example in your Web browser

  Click here

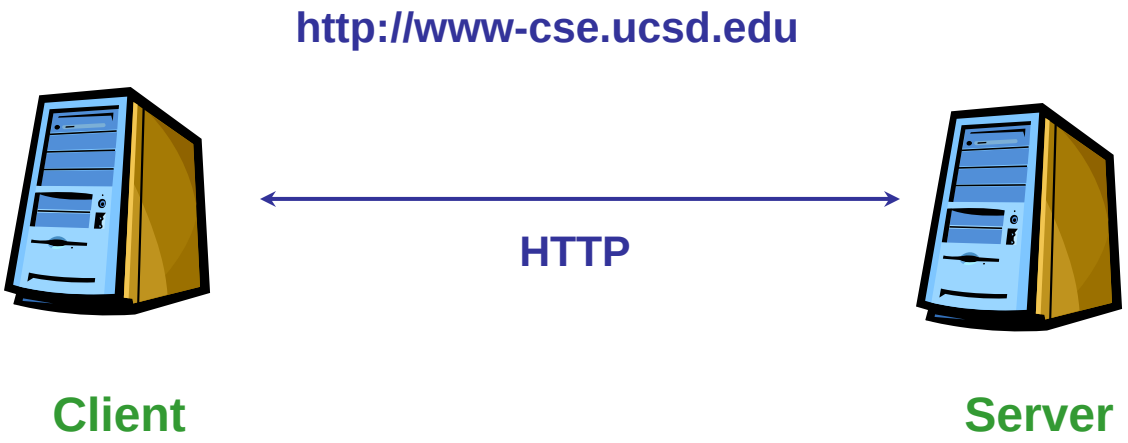
- "here" is a Uniform Resource Locator (URL)

  http://www-cse.ucsd.edu

- It names the location of an object (document) on a server.

[Geoff Voelker]

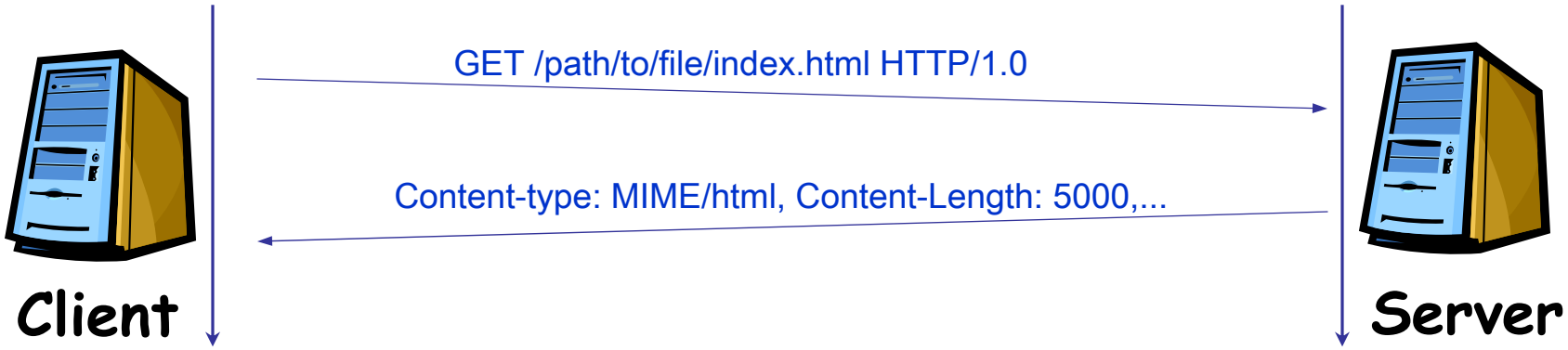
In Action…



- Client uses DNS to resolves name of server (*www-cse.ucsd.edu*)
- Establishes an HTTP connection with the server over TCP/IP
- Sends the server the name of the object (null)
- Server returns the object

[Voelker]

HTTP in a Nutshell



HTTP supports request/response message exchanges of arbitrary length.

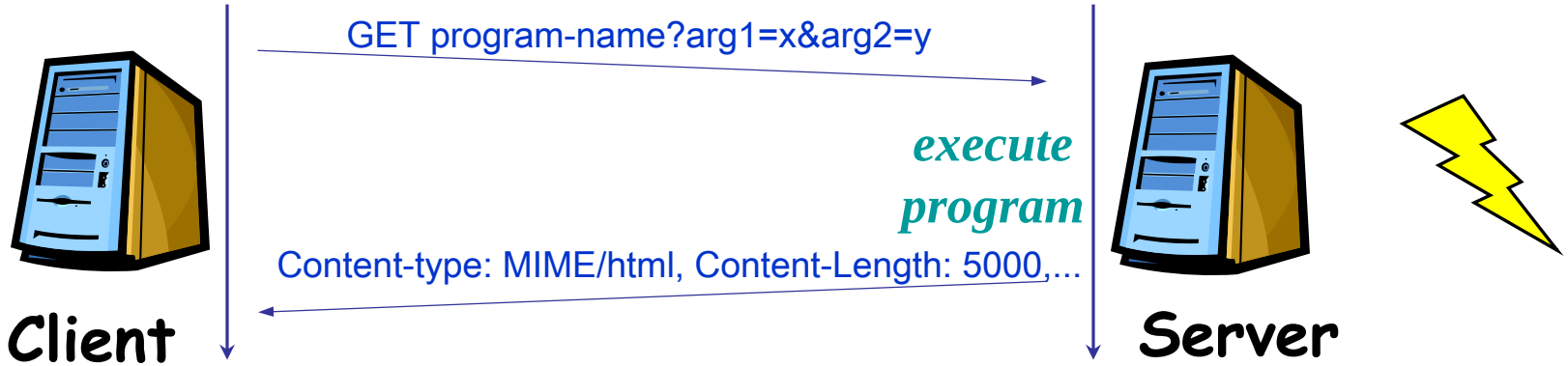
Small number of request types: basically GET and POST, with supplements.

- object name, + content for POST
- optional *query string*
- optional *request headers*

Responses are self-typed objects (*documents*) with attributes and tags.

- optional *cookies*
- optional *response headers*

The Dynamic Web



HTTP began as a souped-up FTP that supports hypertext URLs.

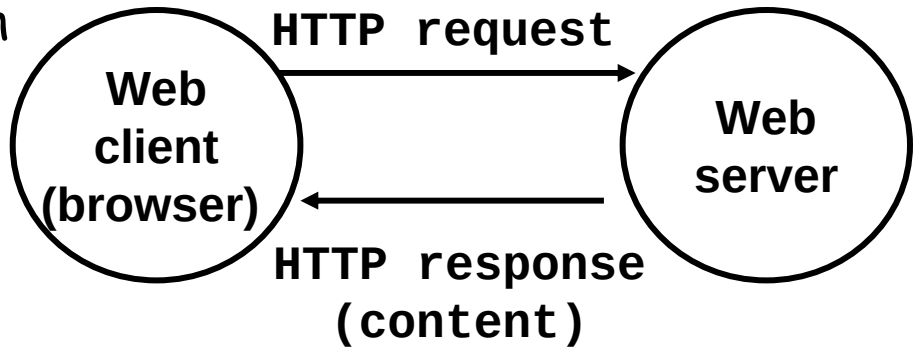
Service builders rapidly began using it for dynamically-generated content.

Web servers morphed into *Web Application Servers*.

- Common Gateway Interface (CGI)
- Java Servlets and JavaServer Pages (JSP)
- Microsoft Active Server Pages (ASP)
- "Web Services"

Web Servers

- Clients and servers communicate using the HyperText Transfer Protocol (HTTP)
  - Client and server establish TCP connection
  - Client requests content
  - Server responds with requested content
  - Client and server close connection (usually)
- E.g., HTTP/1.1
  - IETF RFC 2616, June, 1999.



Web Content

- Web servers return *content* to clients
  - *content:* a sequence of bytes with an associated MIME (Multipurpose Internet Mail Extensions) type
- Example MIME types
  - `text/html` HTML document
  - `text/plain` Unformatted text
  - `application/postscript` Postcript document
  - `image/gif` Binary image encoded in GIF format
  - `image/jpeg` Binary image in JPEG format

Static and Dynamic Content

- The content returned in HTTP responses can be either *static* or *dynamic*.
  - Static content: content stored in files and retrieved in response to an HTTP request
    - Examples: HTML files, images, audio clips.
  - Dynamic content: content produced on-the-fly in response to an HTTP request
    - Example: content produced by a program executed by the server on behalf of the client.
- Bottom line: *All Web content is associated with a file that is managed by the server.*

URLs

- Each file managed by a server has a unique name called a URL (Universal Resource Locator)
- URLs for static content:
  - `http://www.cs.cmu.edu:80/index.html`
  - `http://www.cs.cmu.edu/index.html`
  - `http://www.cs.cmu.edu`
    - Identifies a file called `index.html`, managed by a Web server at `www.cs.cmu.edu` that is listening on port 80.
- URLs for dynamic content:
  - `http://www.cs.cmu.edu:8000/cgi-bin/adder?15000&213`
    - Identifies an executable file called `adder`, managed by a Web server at `www.cs.cmu.edu` that is listening on port 8000, that should be called with two argument strings: `15000` and `213`.

How Clients and Servers Use URLs

- Example URL: `http://www.aol.com:80/index.html`
- Clients use *prefix* (`http://www.aol.com:80`) to infer:
  - What kind of server to contact (Web server)
  - Where the server is (`www.aol.com`)
  - What port it is listening on (80)
- Servers use *suffix* (`/index.html`) to:
  - Determine if request is for static or dynamic content.
    - No hard and fast rules for this.
    - Convention: executables reside in `cgi-bin` directory
  - Find file on file system.
    - Initial "/" in suffix denotes home directory for requested content.
    - Minimal suffix is "/", which all servers expand to some default home page (e.g., `index.html`).

Anatomy of an HTTP Transaction

```
unix> telnet www.aol.com 80          Client: open connection to server
Trying 205.188.146.23...             Telnet prints 3 lines to the terminal
Connected to aol.com.
Escape character is '^]'.
GET / HTTP/1.1                       Client: request line
host: www.aol.com                    Client: required HTTP/1.1 HOST header
                                     Client: empty line terminates headers.
HTTP/1.0 200 OK                      Server: response line
MIME-Version: 1.0                    Server: followed by five response headers
Date: Mon, 08 Jan 2001 04:59:42 GMT
Server: NaviServer/2.0 AOLserver/2.3.3
Content-Type: text/html              Server: expect HTML in the response body
Content-Length: 42092                Server: expect 42,092 bytes in the resp body
                                     Server: empty line ("\r\n") terminates hdrs
<html>                               Server: first HTML line in response body
...                                  Server: 766 lines of HTML not shown.
</html>                              Server: last HTML line in response body
Connection closed by foreign host.   Server: closes connection
unix>                                Client: closes connection and terminates
```

HTTP Requests

- HTTP request is a *request line*, followed by zero or more *request headers*

- Request line: `<method> <uri> <version>`
  - `<version>` is HTTP version of request (`HTTP/1.0` or `HTTP/1.1`)
  - `<uri>` is typically URL for proxies, URL suffix for servers.
    - A URL is a type of URI (Uniform Resource Identifier)
    - See http://www.ietf.org/rfc/rfc2396.txt
  - `<method>` is either `GET`, `POST`, `OPTIONS`, `HEAD`, `PUT`, `DELETE`, or `TRACE`.

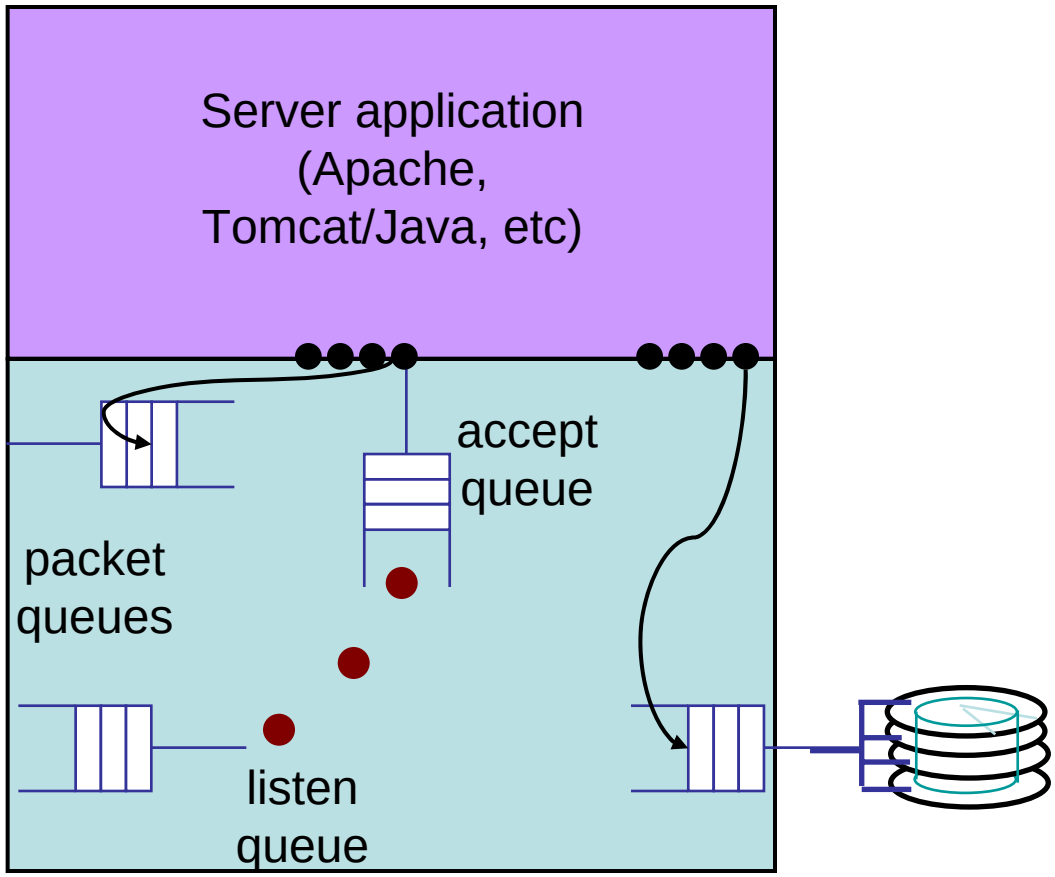
HTTP Responses

- HTTP response is a *response line* followed by zero or more *response headers*.
- Response line:
- `<version> <status code> <status msg>`
  - <version> is HTTP version of the response.
  - <status code> is numeric status.
  - <status msg> is corresponding English text.
    - 200 OK Request was handled without error
    - 403 Forbidden Server lacks permission to access file
    - 404 Not found Server couldn't find the file.
- Response headers: `<header name>: <header data>`
  - Provide additional information about response
  - `Content-Type:` MIME type of content in response body.
  - `Content-Length:` Length of content in response body.

HTTP Server

- HTTP Server
  - Creates a socket (*socket*)
  - *Binds* to an address
  - *Listens* to setup accept backlog
  - Can call *accept* to block waiting for connections
  - (Can call *select* to check for data on multiple socks)
- Handle request
  - GET /index.html HTTP/1.0\n
    <optional body, multiple lines>\n
    \n

Inside your server



Measures
offered load
response time
throughput
utilization

Web Server Processing Steps