Server Design

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Topics

- Types of servers
- Server algorithms
  - Iterative, connection-oriented servers
  - Iterative, connectionless servers
  - Iterative, connectionless servers
  - Concurrent, connection-oriented servers
- Server design issues

Server examples based on BSD-compatible socket functions and POSIX Threads.

Need for Concurrency in Servers

- **A simple server**
  - **Server creates a socket, binds address, and makes it passive**
  - **Server accepts a connection, services the request, the connection is closed, and this is repeated indefinitely**
- **Simple server is inadequate for most applications since the request may take arbitrarily long to service**
  - **Other clients are blocked from service**

Concurrent versus Iterative Servers

- **An *iterative* server services one request at a time**
- **A *concurrent* server services multiple requests at the same time**
  - **The actual implementation may or may not be concurrent**
  - **More complex than iterative servers**

Three Dimensions of Server Design

- **Iterative versus concurrent**
  - **Truly a server design issue as it is independent of the application protocol**
- **Connection-oriented versus connectionless**
  - **Usually constrained by the application protocol**
- **Stateless versus stateful**
  - **Usually constrained by the application protocol**

Four Classes of Servers

	Connectionless	Connection-Oriented
Concurrent	-	++
Iterative	+	-

- **Concurrent, connection-oriented is the most common server design**

Iterative, Connection-Oriented (1)

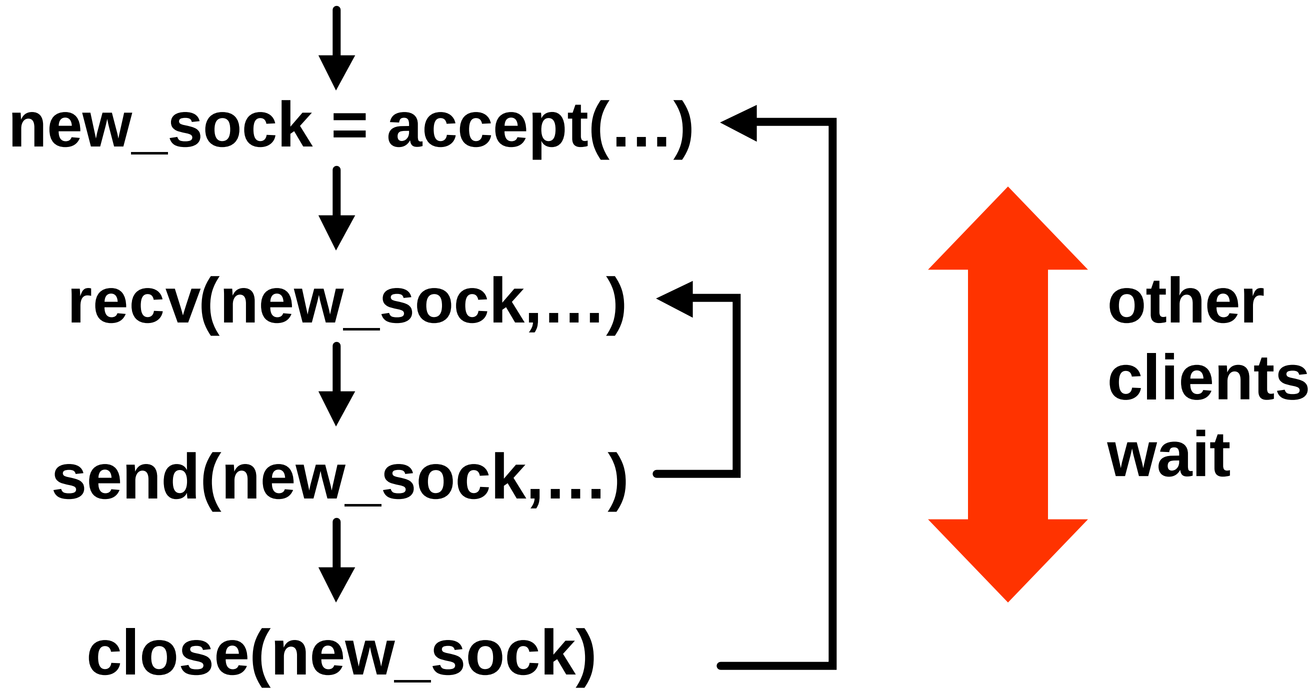
1) Create a socket
   – sock = socket(PF_INET, SOCK_STREAM, 0)
2) Bind to well-known address
   – bind(sock, localaddr, addrlen)
   – For port number, server can use getservbyname(name, protocol)
   – For host IP address, “wild card” address is usually used: INADDR_ANY
3) Place socket in passive mode
   – listen(sock, queuelen)
   – Need to establish queue length (maximum is implementation dependent)

Iterative, Connection-Oriented (2)

4) **Accept a connection from a client**
   - **new_socket = accept(sock, addr, addrlen)**
   - **accept() blocks until there is at least one connection request**
   - **Based on the queue length value in listen(), connection requests may be “accepted” by the operating system and queued to be accepted later by the server with the accept() call**
5) **Interact with client**
   - **recv(new_socket, …)**
   - **send(new_socket, …)**

Iterative, Connection-Oriented (3)

6) **Close connection and return to accept() call (step 4)**
   - **close(new_socket)**



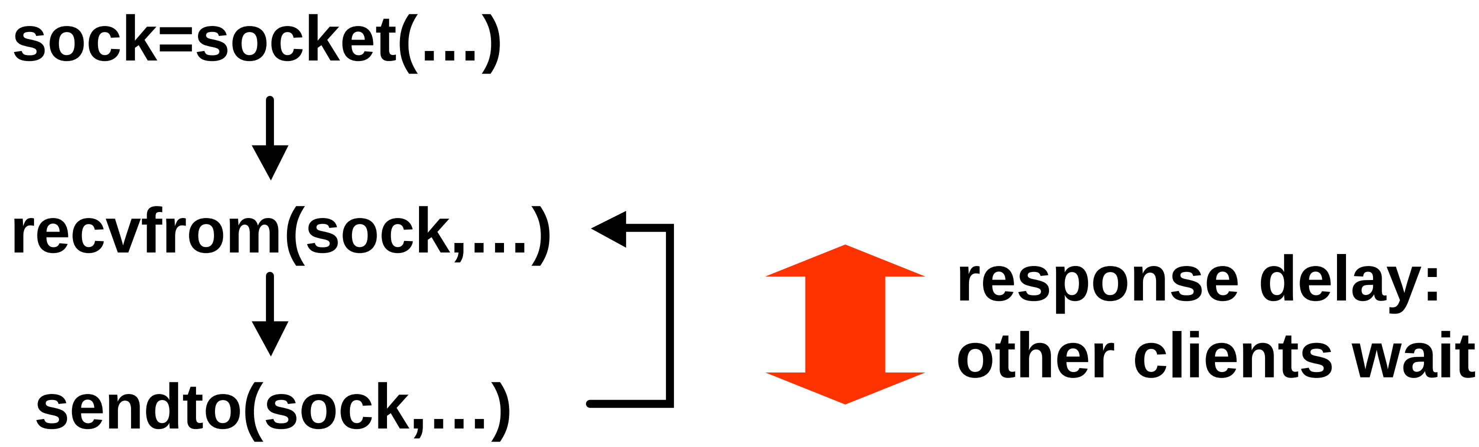
Iterative, Connection-Oriented (4)

- **Only one connection at a time is serviced by an iterative, connection-oriented server**
  - **Others wait in queue to be accepted**
  - **Or, their connection is refused**
- **TCP provides reliable transport, but there is overhead in making and breaking the connection**
  - **Simplifies application design**
  - **At the expense of a performance penalty**

Iterative, Connectionless Server (1)

1) **Create socket**
   - **sock = socket(PF_INET, SOCK_DGRAM)**
2) **Interact with one or more clients**
   - **recvfrom(sock, buf, buflen, flags, from_addr, from_addrlen)**
     - **Each subsequent recvfrom() can receive from a different client**
     - **fromaddr parameter lets server identify the client**
   - **sendto(sock, buf, buflen, flags, to_addr, to_addrlen)**
     - **to_addr is usually from_addr of preceding recvfrom()**

Iterative, Connectionless Server (2)



- Other clients block while one *request* is processed, not for a full connection time
- UDP is not reliable, but there is no connection overhead

Concurrent, Connectionless (1)

- **Concurrency is on a *per request* basis for a connectionless server**
- **There are two way to achieve concurrency**
  - **Create a new process, e.g. using fork() or exec()**
  - **Create a new thread, using pthread_create()**
- ***"Master" thread* uses pthread_create() to create a *"slave" thread* for each request**

Concurrent, Connectionless (2)

Master

M1) Create socket

- **sock = socket(PF_INET, SOCK_DGRAM)**

M2) Read request

- **recvfrom(sock,…)**

M3) Create thread

- **pthread_create()**
- **Thread knows:**
  - **IP address and port of client**
  - **Request information**
  - **Global data and socket**

Return to M2

Concurrent, Connectionless (3)

Slave

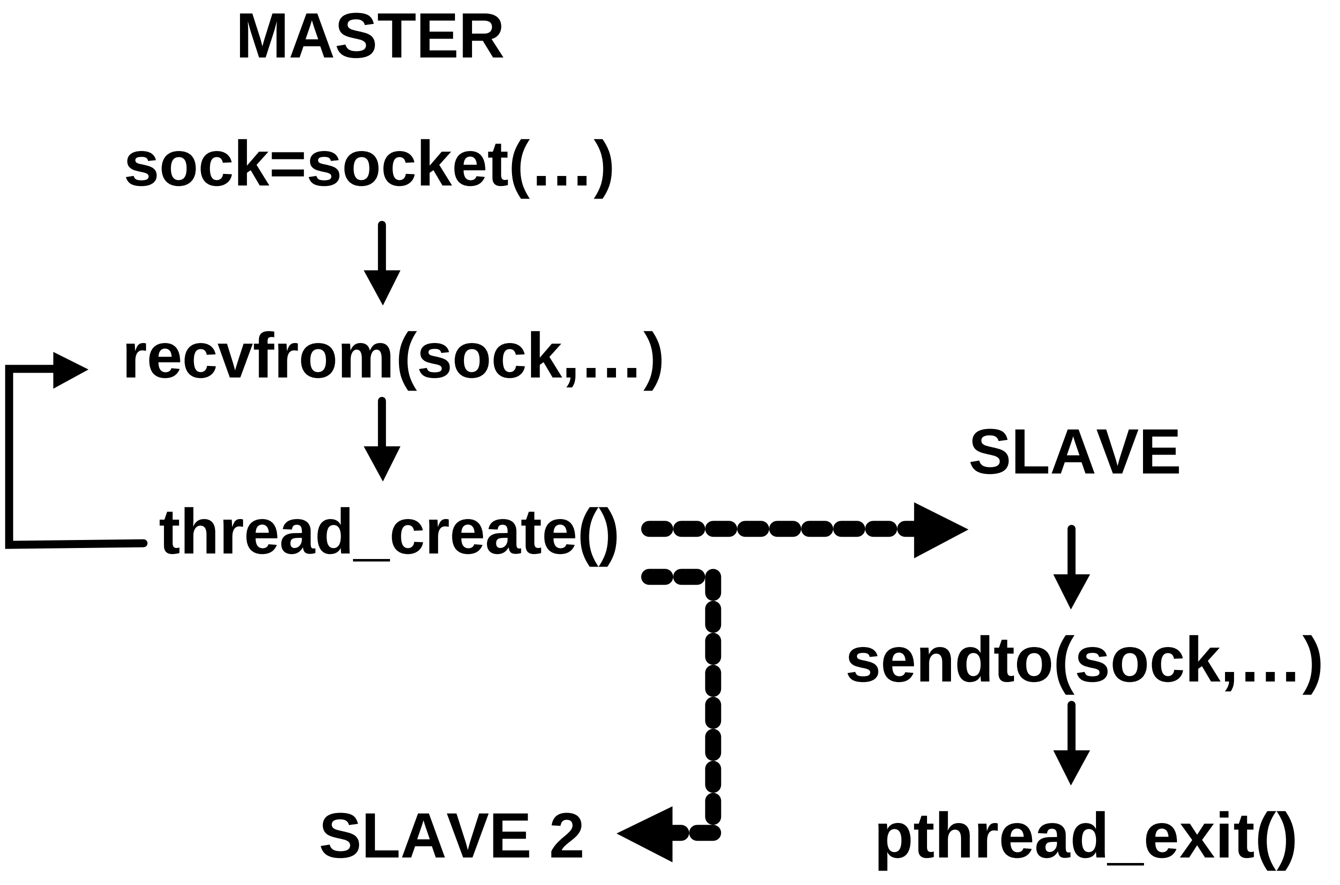
S1) Respond to request

- **sendto(sock,…)**

S2) Terminate

- **pthread_exit()**

Concurrent, Connectionless (4)



Concurrent, Connectionless (5)

- **Requests from multiple clients (or multiple requests from a single client) can be serviced concurrently**
  - **No long blocking periods**
- **pthread_create() does have overhead**
  - **Thread overhead can dominate if time to respond to request is small**
  - **Concurrent, connectionless server is a good design choice only if average processing time is long relative to thread overhead**
- **UDP offers no reliability, has no connection overhead**

Concurrent, Connection-Oriented (1)

- **Concurrency is on a *per connection* basis for a connection-oriented server**
  - **Depending on application, additional concurrency may also be possible**
- **There are three ways to achieve concurrency**
  - **Create a new process -- high overhead**
  - **Create a new thread -- lower overhead**
  - **Use *apparent concurrency* within a single thread**
    - **Lowest overhead**
    - **Based on select() call for *asynchronous* operation**

Concurrent, Connection-Oriented (2)

Master, using thread

M1) Create socket
- sock = socket(PF_INET, SOCK_STREAM)

M2) Bind address
- bind(sock, …)

M3) Put socket in passive mode
- listen(sock, …)

Concurrent, Connection-Oriented (3)

Master, using threads (continued)

M4) Accept a new connection

- **new_sock = accept(sock,…)**

M5) Create thread

- **pthread_create()**
- **Thread knows:**
  - **New socket -- new_sock**
  - **Global data**

Return to M4

Concurrent, Connection-Oriented (4)

Slave, using threads

S1) Interact with client

- **recv(new_sock,…)**
- **send(new_sock,…)**

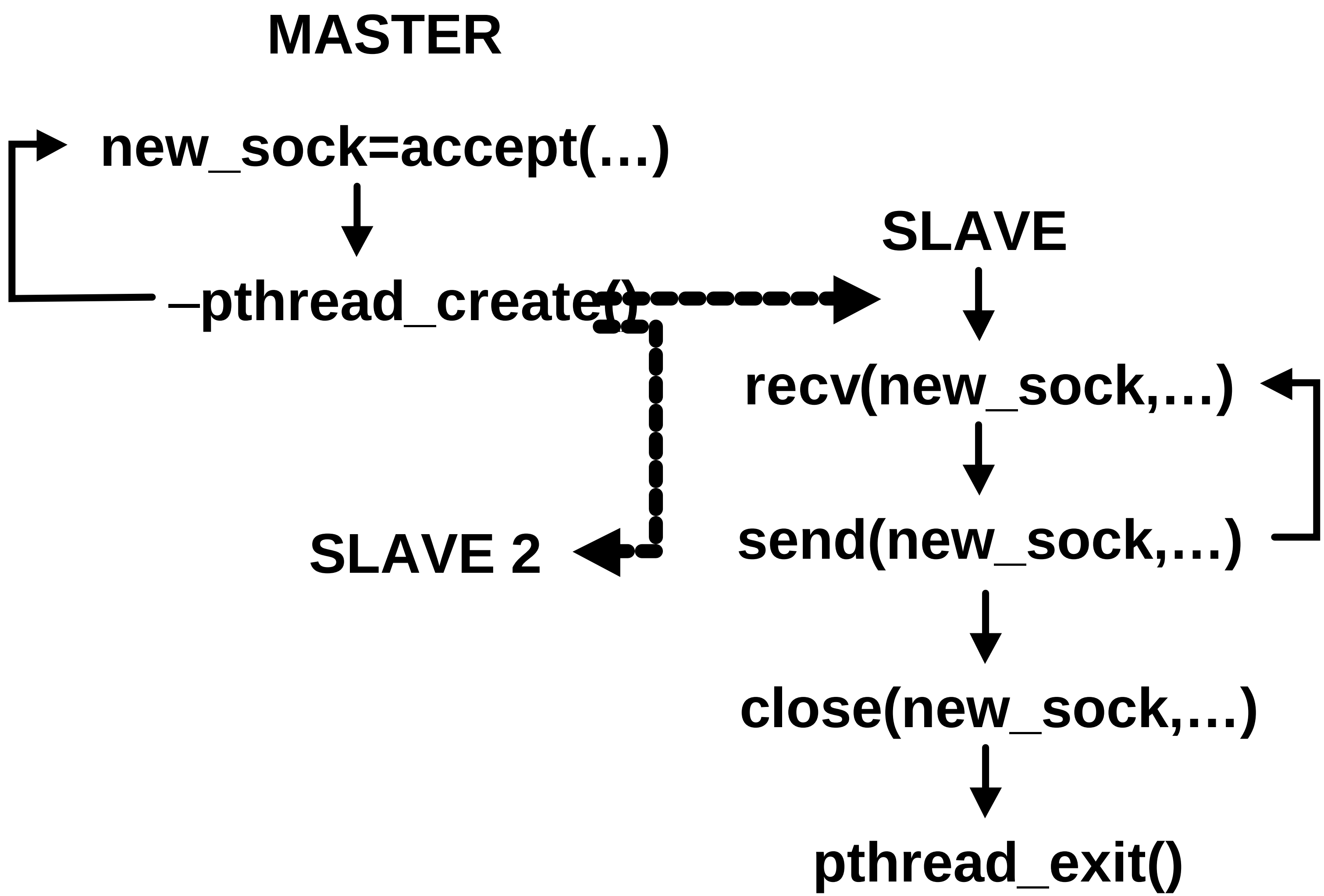
S3) Close socket

- **close(new_sock,…)**

S2) Terminate

- **pthread_exit()**

Concurrent, Connection-Oriented (5)

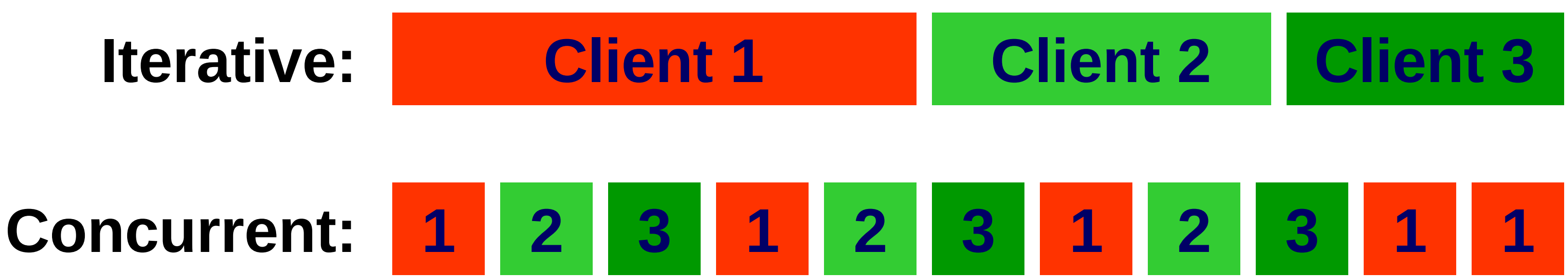


Concurrent, Connection-Oriented (6)

- **Clients do not block while other clients are connected**
  - **One thread per client**
  - **Could have additional threads per client, but based on particular features of the application**
- **pthread_create() has overheads**
  - **Thread overhead can dominate if connection time is small**
  - **Concurrent, connection-oriented server is a good design choice only if average client connection time is long relative to thread overhead**

Concurrent, Connection-Oriented (7)

- **Except on a true multiprocessor, “concurrency” from threads does *not* generally increase throughput!**
  - **Transactions per second do *not* increase**
  - **Delay for first service and variance for service time *do* decrease**



Concurrent, Connection-Oriented (8)

- **May be able to increase throughput for some applications, e.g. by overlapping disk I/O with processing in the CPU**
- **TCP provides reliability at the expense of connect/disconnect overhead**

Apparent Concurrency (1)

0) **Maintain a set of socket descriptors (SOCKETS) using the fd_set structure**
   - **Initialize SOCKETS = { } (empty)**
1) **Create socket**
   - **sock = socket(PF_INET, SOCK_STREAM)**
   - **SOCKETS = { sock }**
2) **Bind address**
   - **bind(sock, …)**
3) **Put socket in passive mode**
   - **listen(sock, …)**

Apparent Concurrency (2)

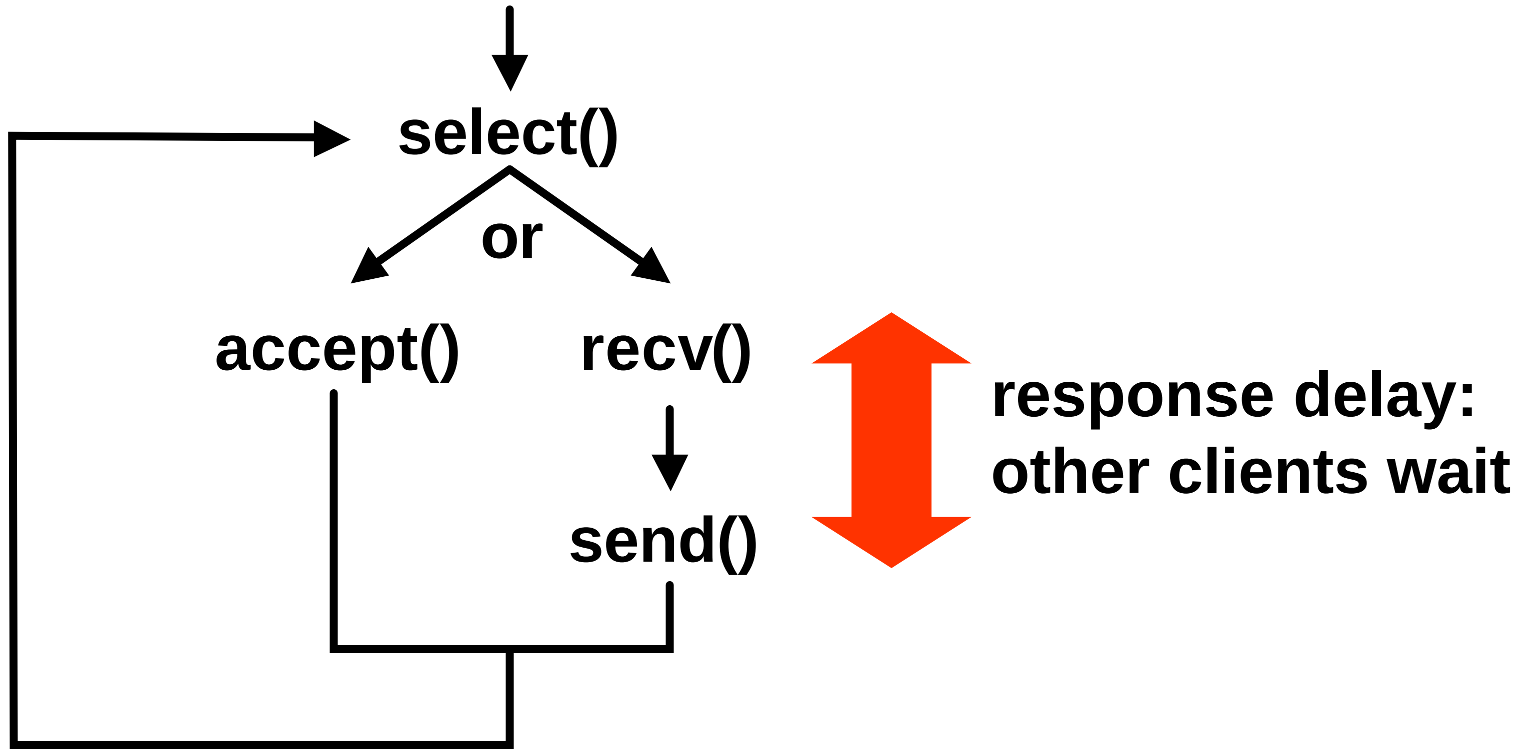
4) **Use select() to determine sockets that have activity (are ready for “service”)**
   - **ret = select(maxfd, rdfds, wrfds, exfds, time)**

5a) **If select() indicates main socket (sock) is ready, accept a new connection**
   - **new_sock = accept(sock,…)**
   - **SOCKETS = SOCKETS È { new_sock }**

5b) **If select() indicates another socket (ready) is ready**
   - **recv(ready,…) to read request, and then**
   - **send(read,…) to send response**

Return to step 4

Apparent Concurrency (3)



- **While another connection is accepted or while one *request* from another client is serviced**
- **Clients do not wait full connection time**

Apparent Concurrency (4)

- **Data can be conveniently (or dangerously) shared between different clients**
  - **Not easy with multiple threads**

Server Design Factors (1)

- **Time per request**
  - **If high, a multithreaded design is best**
  - **If low, thread overhead may dominate performance and an iterative server or a server using apparent concurrency is best**
- **Time per connection (connection-oriented)**
  - **If high, a concurrent (threaded or apparent) server is best**
  - **If low, an iterative server is best**
- **Number of active clients**
  - **If high, concurrent server is best**
  - **If low, iterative server is best**

Server Design Factors (2)

- **Overhead for thread creation**
  - **Trade-offs for connection time and request response time are relative to thread creation time**
  - **Operating systems with low overhead thread creation increase opportunities to use multithreaded design**
- **Need to share information between clients**
  - **Easier in an iterative server or a server with apparent concurrency**
  - **More complex in a multithreaded server**

Server Design Factors (3)

- **LAN- versus WAN-based application**
  - **TCP's reliability is more important in a WAN where packet loss and out-of-order delivery is more likely**
  - **LAN-based applications may be able to provide reliability with less "expense" using UDP than TCP**
- **Inherent reliability in the application**
  - **May eliminate the need to use TCP**

Simple Deadlock

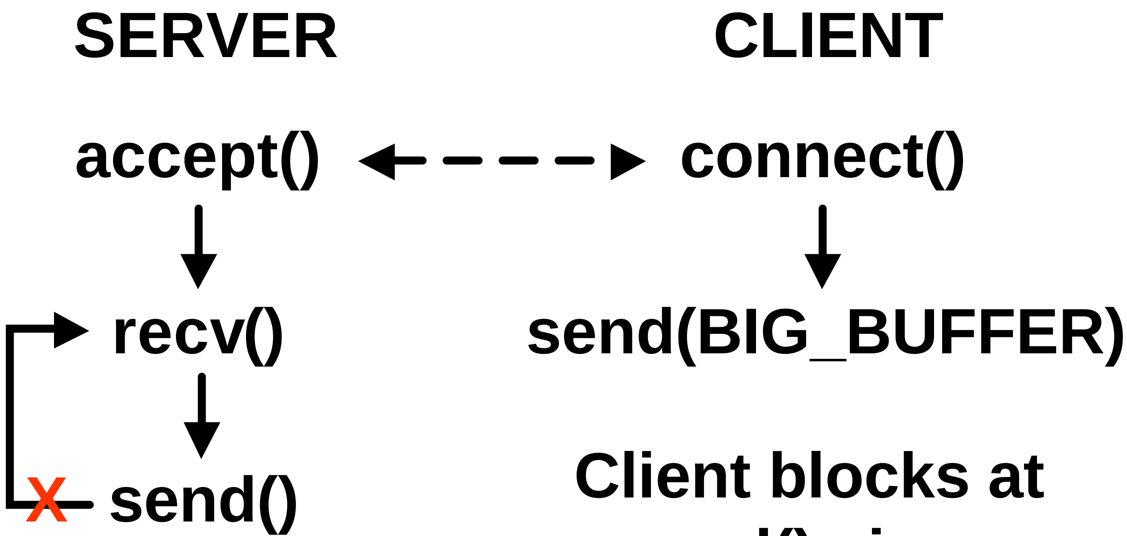
- **Deadlock occurs when**
  - **Client is blocked waiting on server**
  - **Server is blocked waiting on client**
- **Simple example of server deadlock**

SERVER		**CLIENT**
accept()	←– – – →	**connect()**
↓		↓
recv()		**never_never_land()**

Server is blocked waiting for data from the client ☹

More Subtle Deadlock (1)

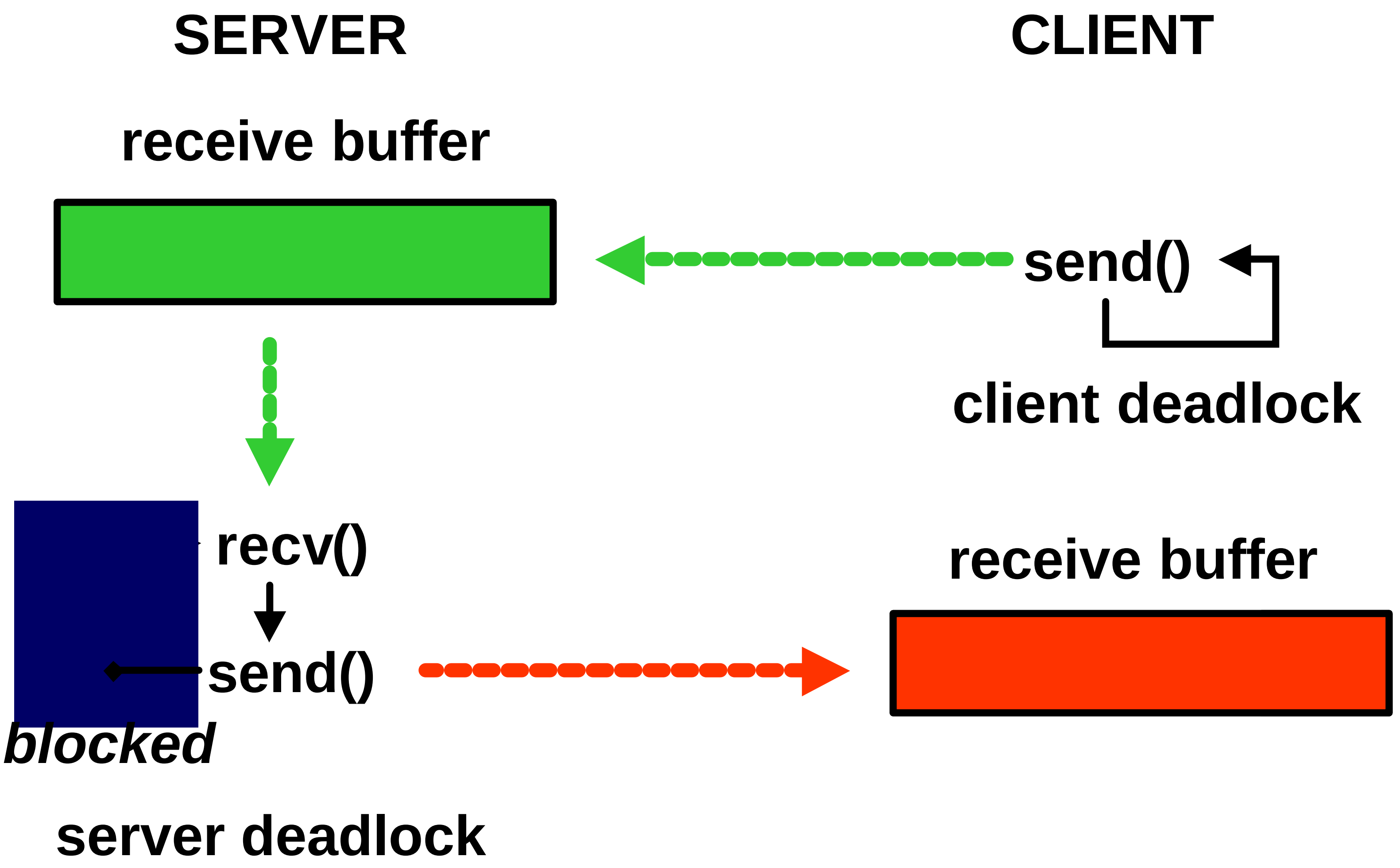
- **Deadlock may be much more subtle**



Server eventually blocks at send() since client never receives ☹

Client blocks at send() since server is not receiving ☹

More Subtle Deadlock (2)



Terminating a Connection (1)

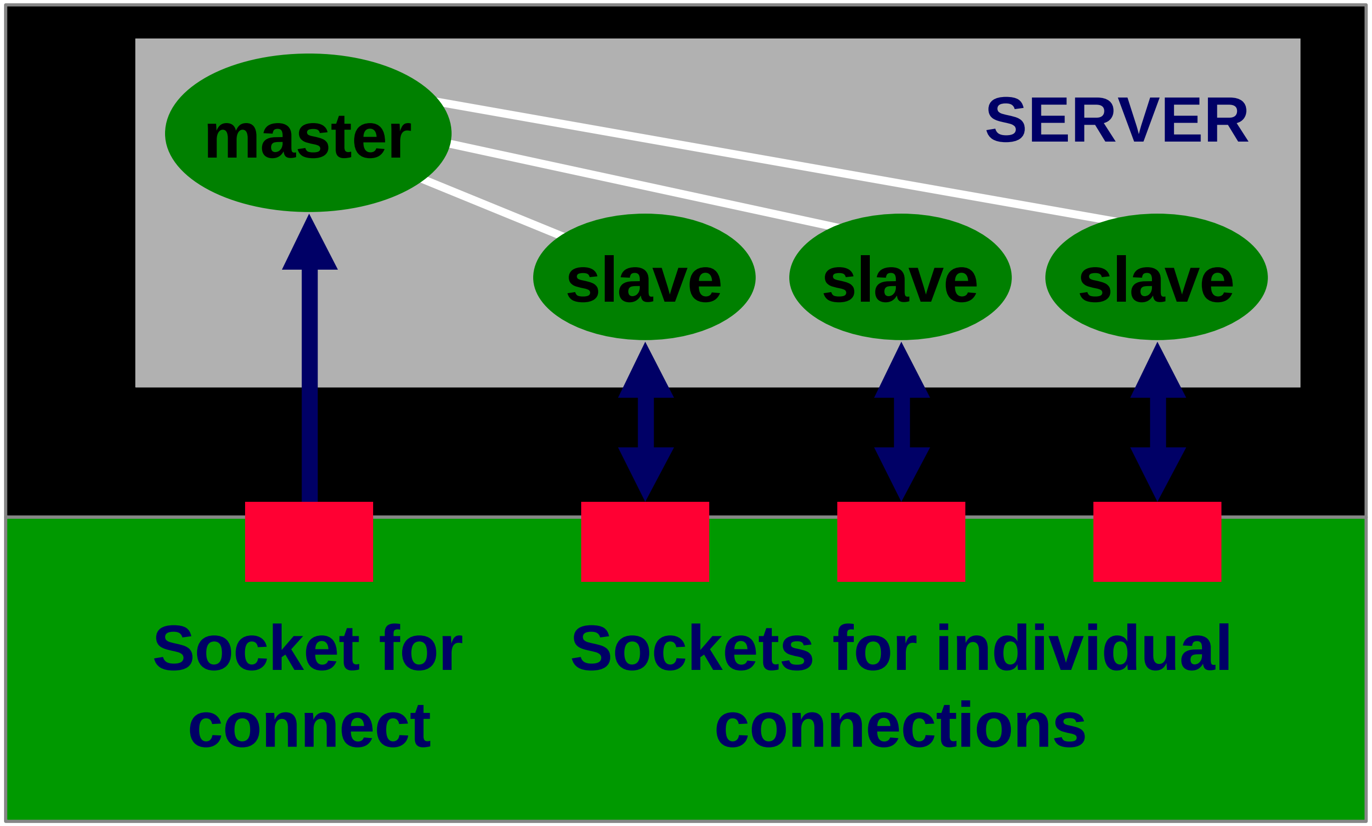
- **The application protocol determines when a connection should be closed**
- **Client may know when transaction is done**
  - **Examples:**
    - **FTP**
    - **HTTP 1.1 (persistent connections)**
  - **A “misbehaving” client can keep connections open, consuming server resources**
  - **Solutions**
    - **Time-out for the session (connect, idle, etc.)**
    - **Trusted clients**

Terminating a Connection (2)

- **Even if the server controls connection termination, there may still be problems**
  - **Operating system maintains connection information for 2´MSL (maximum segment life)**
    - **Allows OS to reject delayed, duplicate packets**
    - **Uses OS resources**
  - **Client can make lots of requests and consume resources faster than the server can free them**
- **Vulnerability to *denial of service attacks***

Example: Threaded ECHO Server (1)

- **Multiple-threaded concurrent, connection-oriented design**

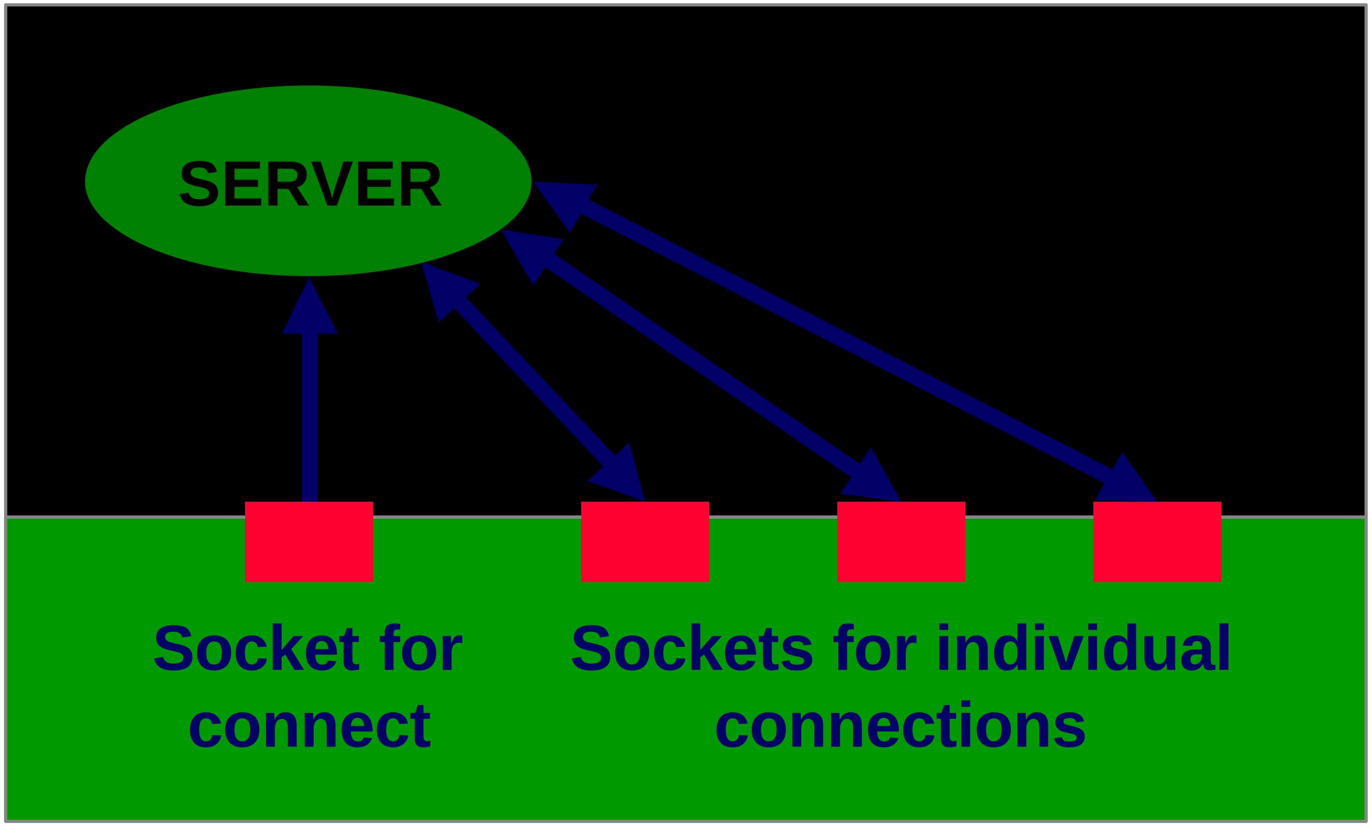


Example: Concurrent ECHO Server (2)

- **Operation of concurrent ECHO server**
  - **pthread_create() called for each new connection**
  - **TCPechod() invoked for each thread**
    - **recv() and send() repeated until client closes the connection**
    - **Note that TCPechod() does *not* call exit() to exit the process if there's an error -- just the thread terminates I.e. the thread calls pthread_exit.**
    - **Calling exit will terminate all threads and the process, a bad idea in this case**

Example: Asynch ECHO Server (1)

- **Single-thread concurrent, connection-oriented**



Example: Asynch ECHO Server (2)

- **Uses select() call**
  - **select() indicates which sockets are ready for service**
    - **Input or connection for ECHO server**
  - **fd_set structures record the sets of sockets**

```
typedef struct fd_set {
  u_int  fd_count;
  SOCKET fd_array[FD_SETSIZE];
}
```

Example: Asynch ECHO Server (3)

- **fd_set structures manipulated with macros**
  - **FD_CLR(fd, set): remove fd from set**
  - **FD_SET(fd, set): add fd to set**
  - **FD_ZERO(set): empty set**
  - **FD_ISSET(fd, set): test if fd is in set**

```
FD_ZERO(&afds);          // empty afds
FD_SET(msock, &afds); // add msock
```

Example: Asynch ECHO Server (4)

- **select()**
  - **Checks all sockets in sets**
    - **set for input and connection request**
    - **set for output**
    - **set for exceptions**
  - **Blocks until at least one of the sockets is ready or time-out**
  - **Returns with the set changed to contain just the sockets ready for service**

```
select(FD_SETSIZE, &rfds,
  (fd_set *)0, (fd_set *)0,
  (struct timeval *)0)
```

Example: Asynch ECHO Server (5)

- **Operation**
  - **Steps through all active sockets and checks to see if socket is ready**
  - **Accepts a new connection and adds to set if master server socket (msock) is ready**
  - **Calls echo() to echo new data if client connection socket is ready**
- **There may be several sockets ready for service**

You should now be able to …

- **Identify the three dimensions of server design**
- **Identify factors and application requirements that affect design choice**
- **Select server design based on factors application requirements**
- **Design, implement, and test servers based on the four classes**
- **Recognize causes of deadlock**