CSE 333

Lecture 18 -- fork, pthread_create

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Previously

We implemented an echo server, but it was sequential

- it processed requests one at a time, in spite of client interactions blocking for arbitrarily long periods of time
  - this led to terrible performance

Servers should be concurrent

- process multiple requests simultaneously
  - issue multiple I/O requests simultaneously
  - overlap the I/O of one request with computation of another
  - utilize multiple CPUs / cores

Today

We'll go over three versions of the 'echo' server

- sequential
- concurrent
  - processes [**fork( )**]
  - threads [**pthread_create( )**]

Next time: non-blocking, event driven version

- non-blocking I/O [**select( )**]

Sequential

pseudocode:

```
listen_fd = Listen(port);
while(1) {
  client_fd = accept(listen_fd);
  buf = read(client_fd);
  write(client_fd, buf);
  close(client_fd);
}
```

look at ***echo_sequential.cc***

Whither sequential?

Benefits

- super simple to build

Disadvantages

- incredibly poorly performing
  - one slow client causes **all** others to block
  - poor utilization of network, CPU

fork( )

```
pid_t fork(void);
```

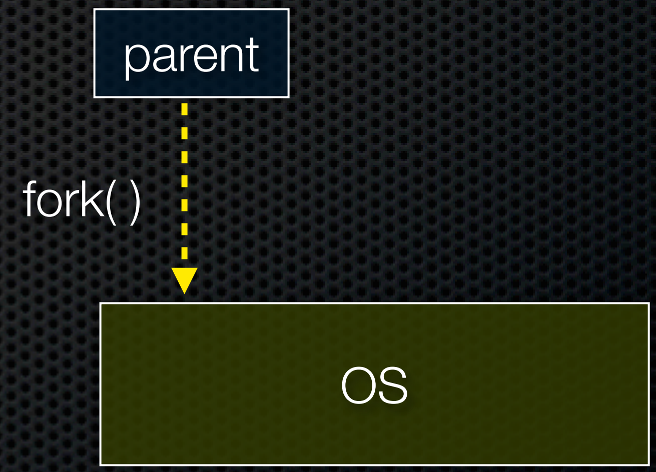
Fork is used to create a new process (the “child”) that is an exact clone of the current process (the “parent”)

- everything is cloned (except threads)
  - all variables, file descriptors, open sockets, etc.
  - the heap, the stack, etc.
- primarily used in two patterns
  - servers: fork a child to handle a connection
  - shells: fork a child, which then exec’s a new program

fork( )

fork( ) has peculiar semantics

- the parent invokes fork( )
- the operating system clones the parent
- **both** the parent and the child return from fork
  - parent receives child's pid
  - child receives a "0" as pid



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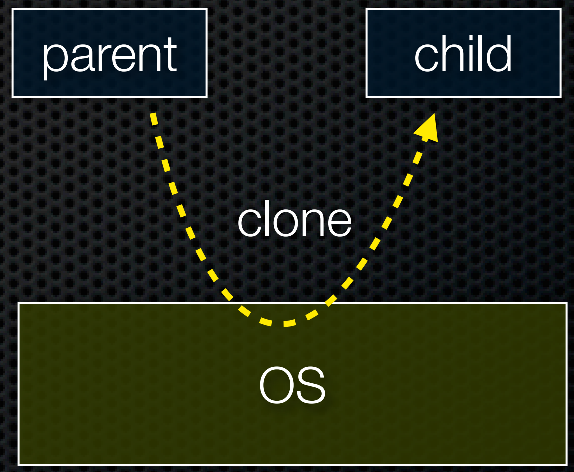

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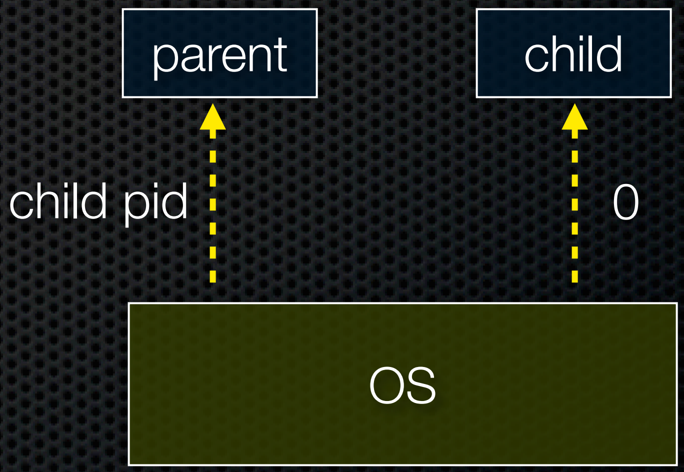


fork( )

fork_example.cc

Concurrency with processes

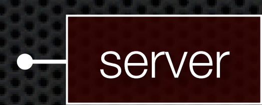
The ***parent*** process blocks on **accept( )**, waiting for a new client to connect

- when a new connection arrives, the parent calls **fork( )** to create a ***child*** process
- the child process handles that new connection, and **exit( )**’s when the connection terminates

Remember that children become “zombies” after death

- option a) parent calls wait( ) to “reap” children
- option b) use the double-fork trick

Graphically



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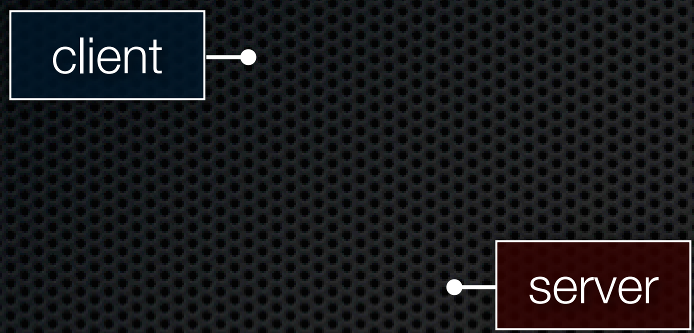

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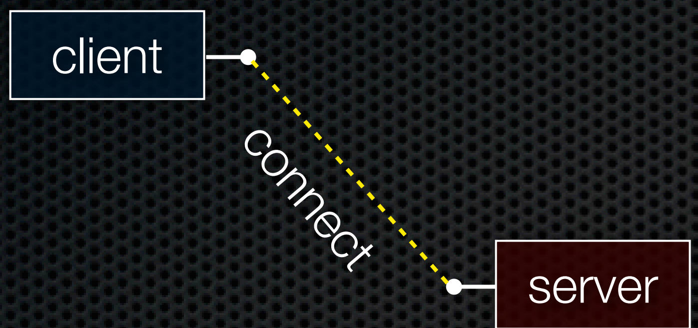

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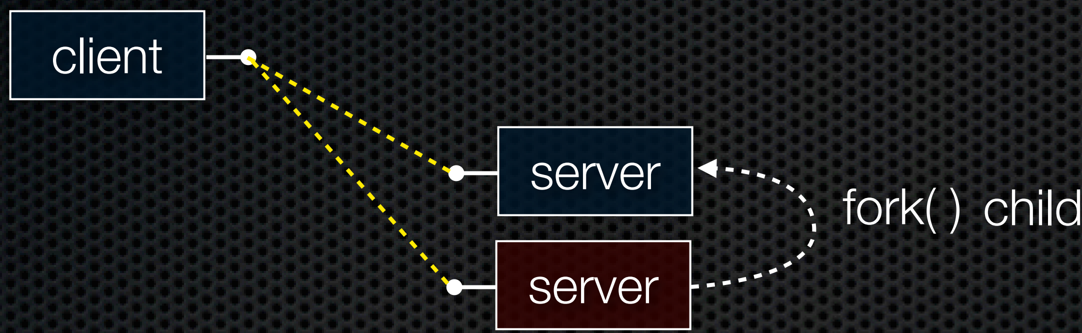

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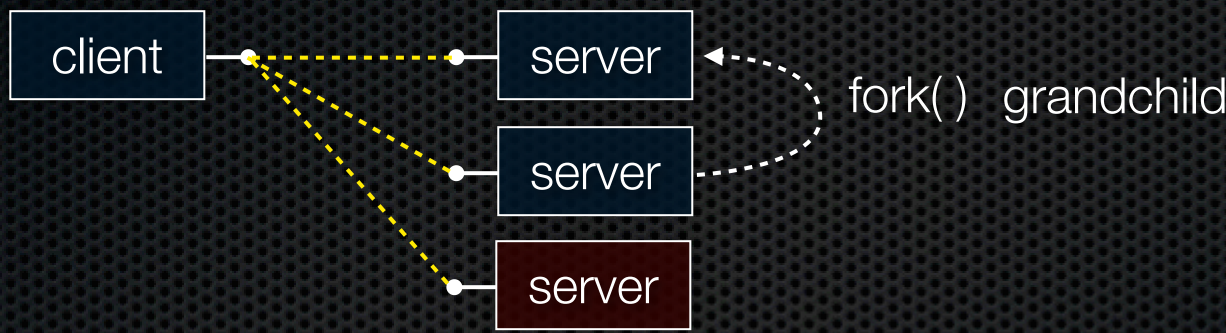

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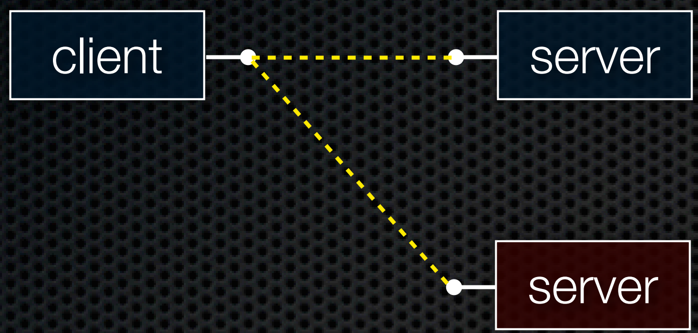
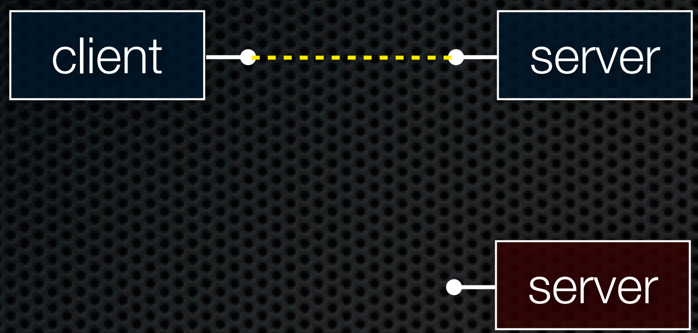


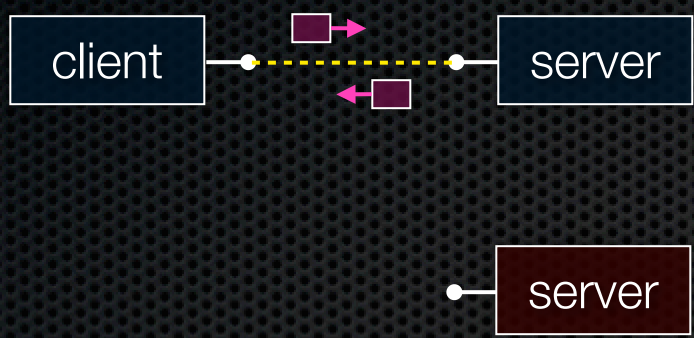
child exit( )'s / parent wait( )'s

Graphically



parent closes its
client connection

Graphically



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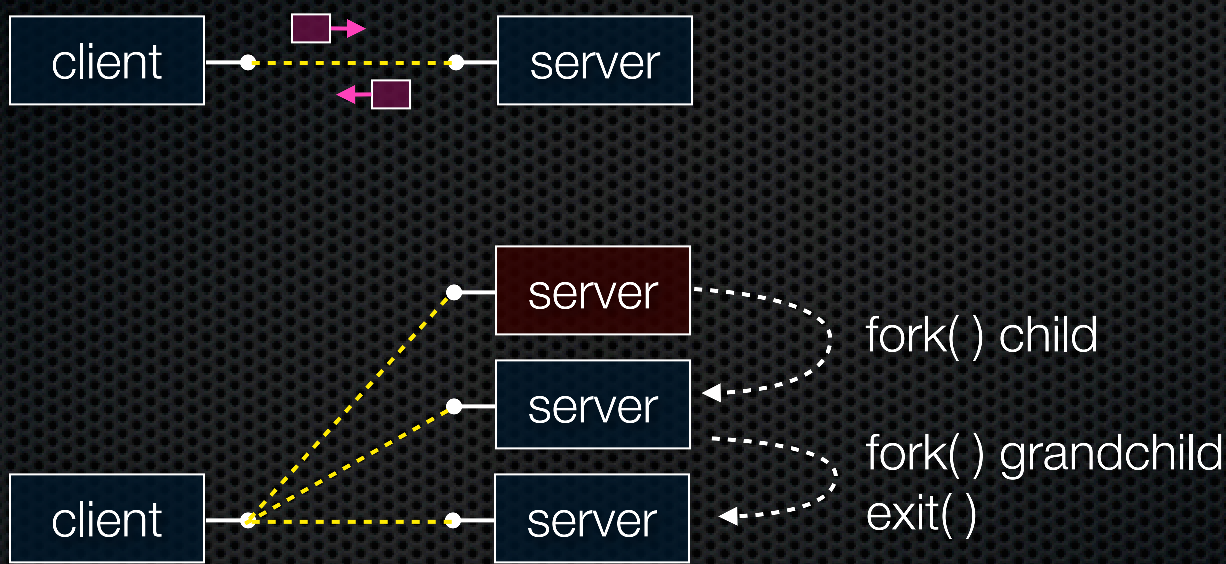

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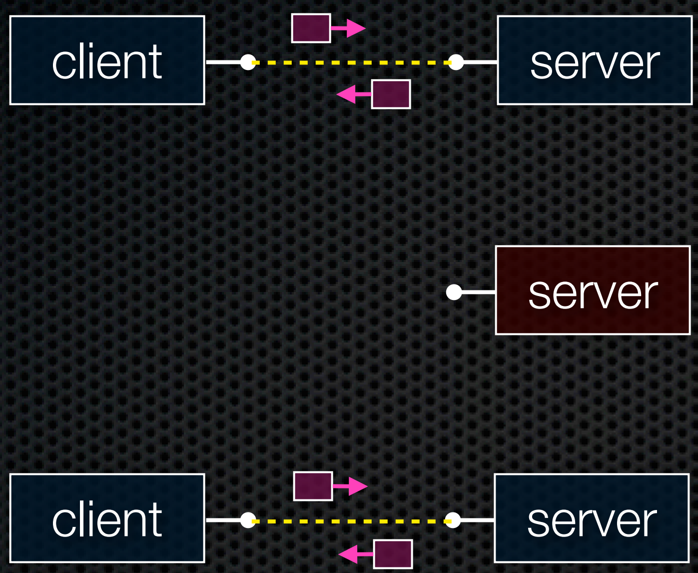

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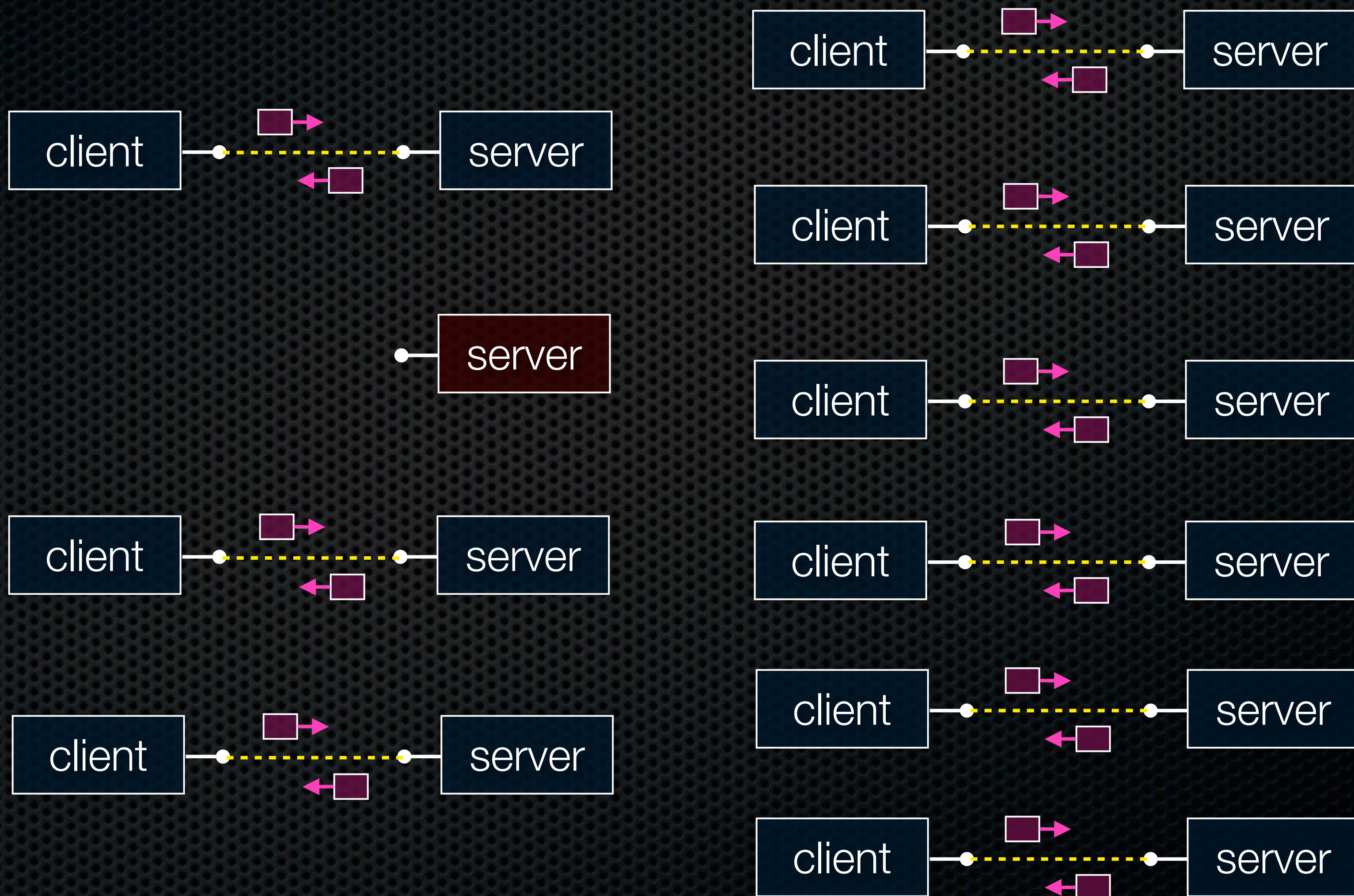


Concurrent with processes

look at ***echo_concurrent_processes.cc***

Whither concurrent processes?

Benefits

- almost as simple as sequential
  - in fact, most of the code is identical!
- parallel execution; good CPU, network utilization

Disadvantages

- processes are heavyweight
  - relatively slow to fork
  - context switching latency is high
- communication between processes is complicated

How slow is fork?

run ***forklatency.cc***

Implications?

0.31 ms per fork

- maximum of (1000 / 0.31) = 3,500 connections per second per core
- ~0.5 billion connections per day per core
    - fine for most servers
    - too slow for a few super-high-traffic front-line web services
        - Facebook serves O(750 billion) page views per day
        - guess ~1-20 HTTP connections per page
        - would need 3,000 -- 60,000 cores just to handle fork( ), i.e., without doing any work for each connection!

threads

Threads are like lightweight processes

- like processes, they execute concurrently
  - multiple threads can run simultaneously on multiple cores/CPUs
- unlike processes, threads cohabit the same address space
  - the threads within a process see the same heap and globals
    - threads can communicate with each other through variables
    - but, threads can interfere with each other: need synchronization
  - each thread has its own stack

threads

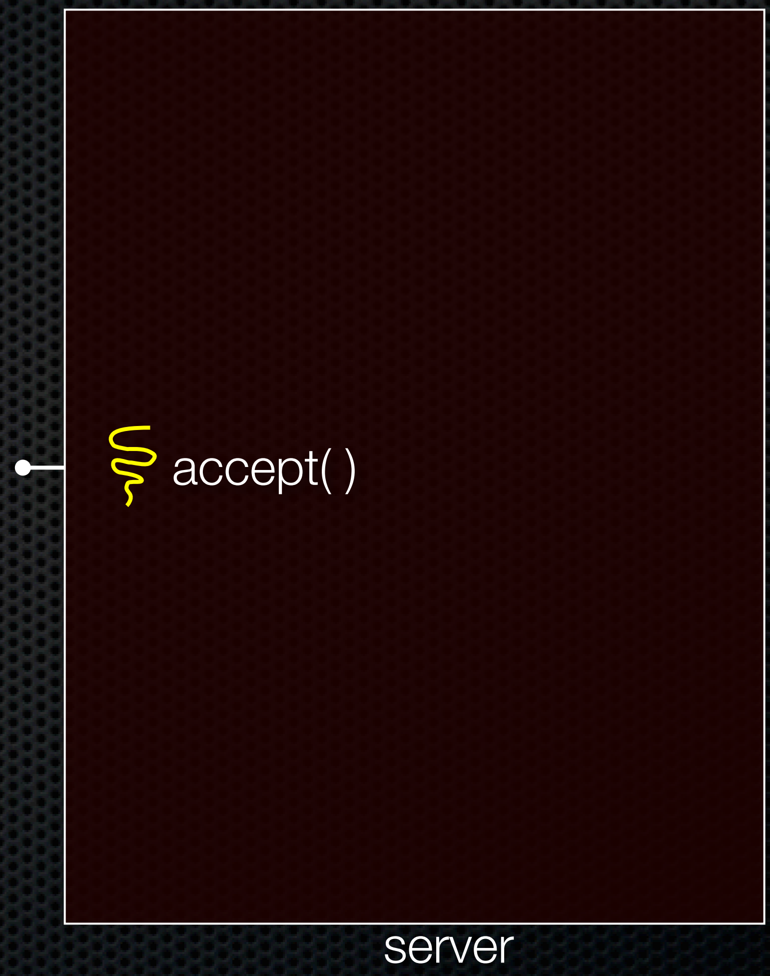
see thread_example.cc

Concurrency with threads

A single ***process*** handles all of the connections

- but, a parent ***thread*** forks (or dispatches) a new thread to handle each connection
- the child thread:
  - handles the new connection
  - exits when the connection terminates

Graphically



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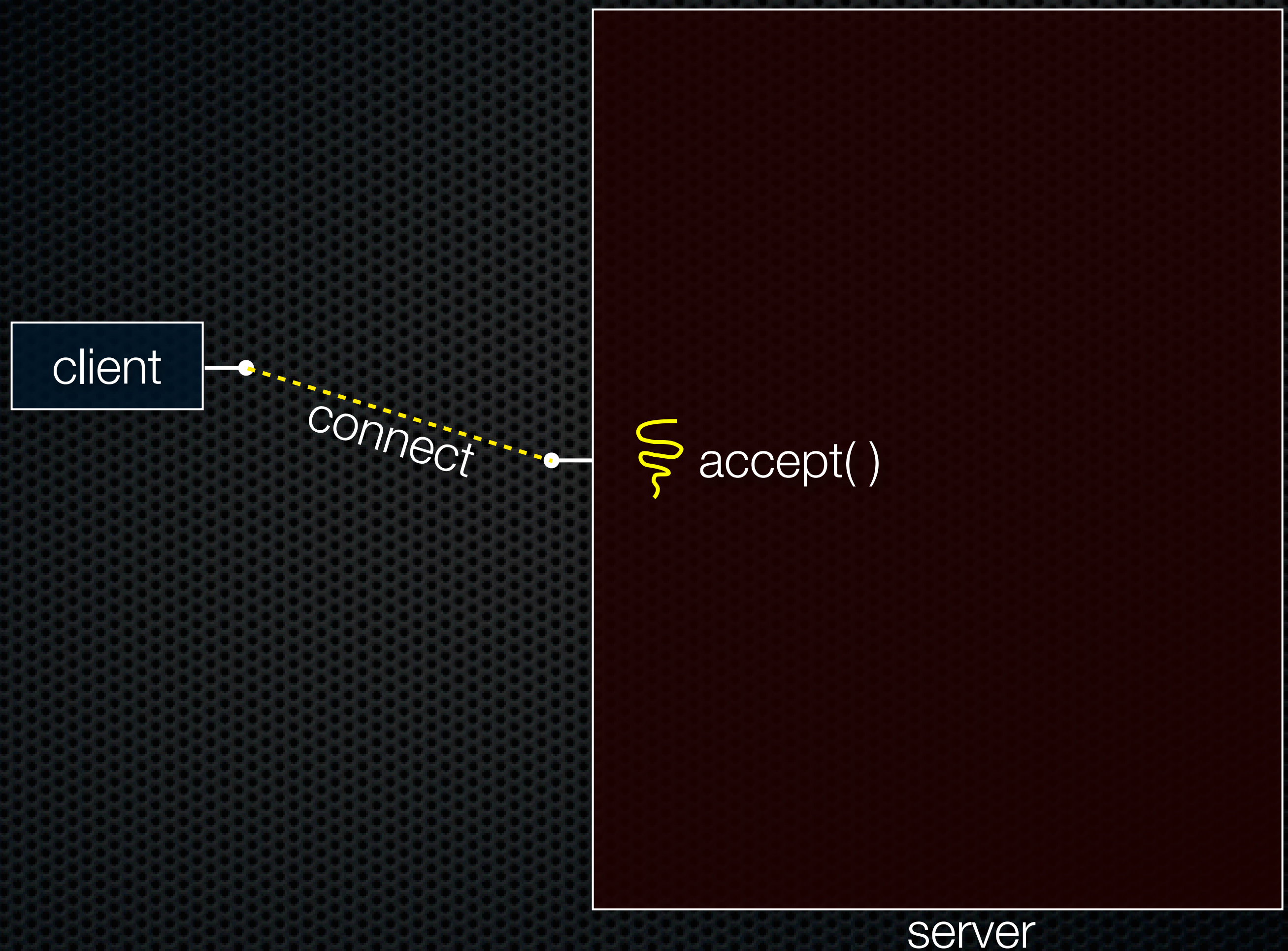

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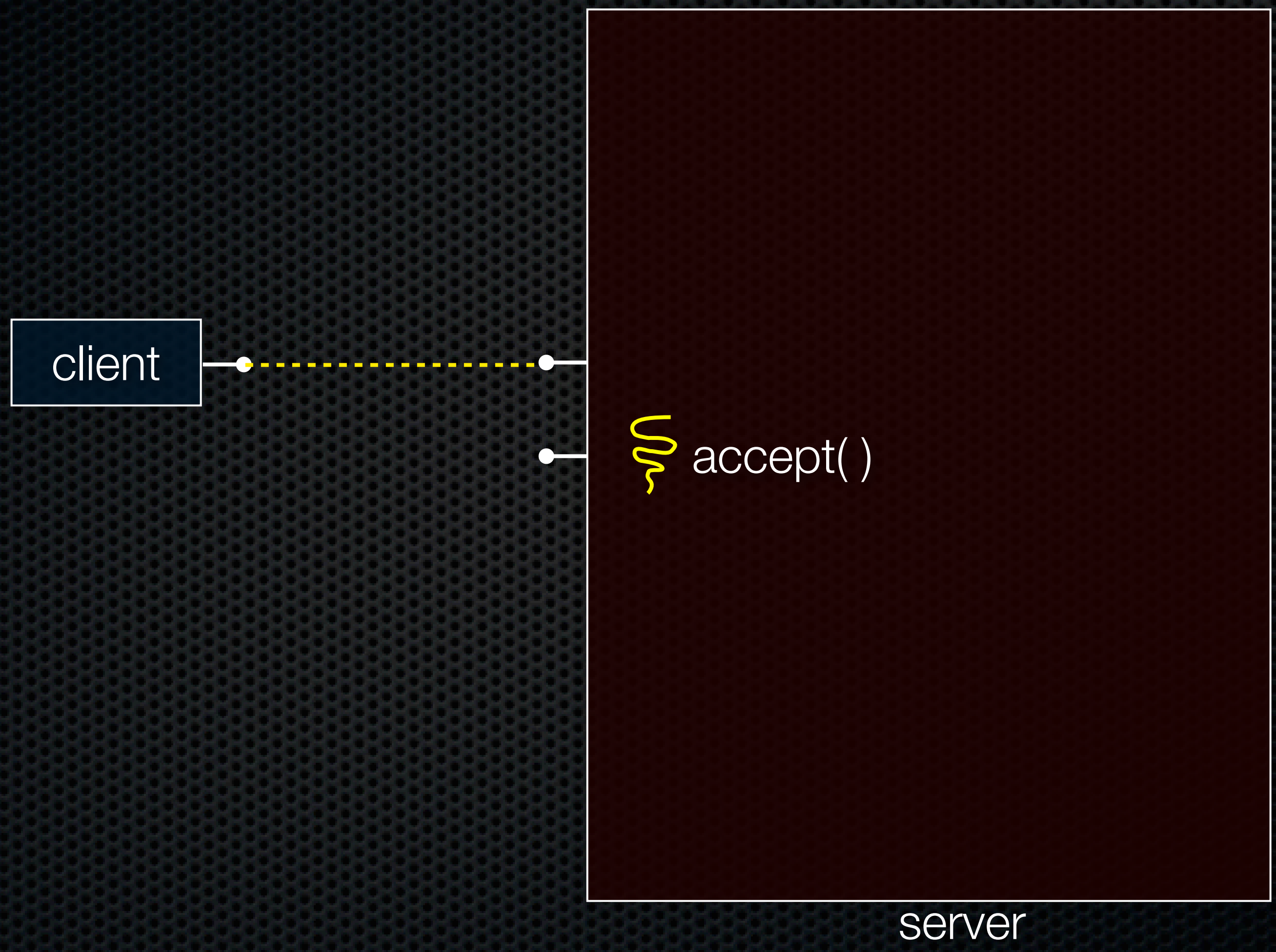

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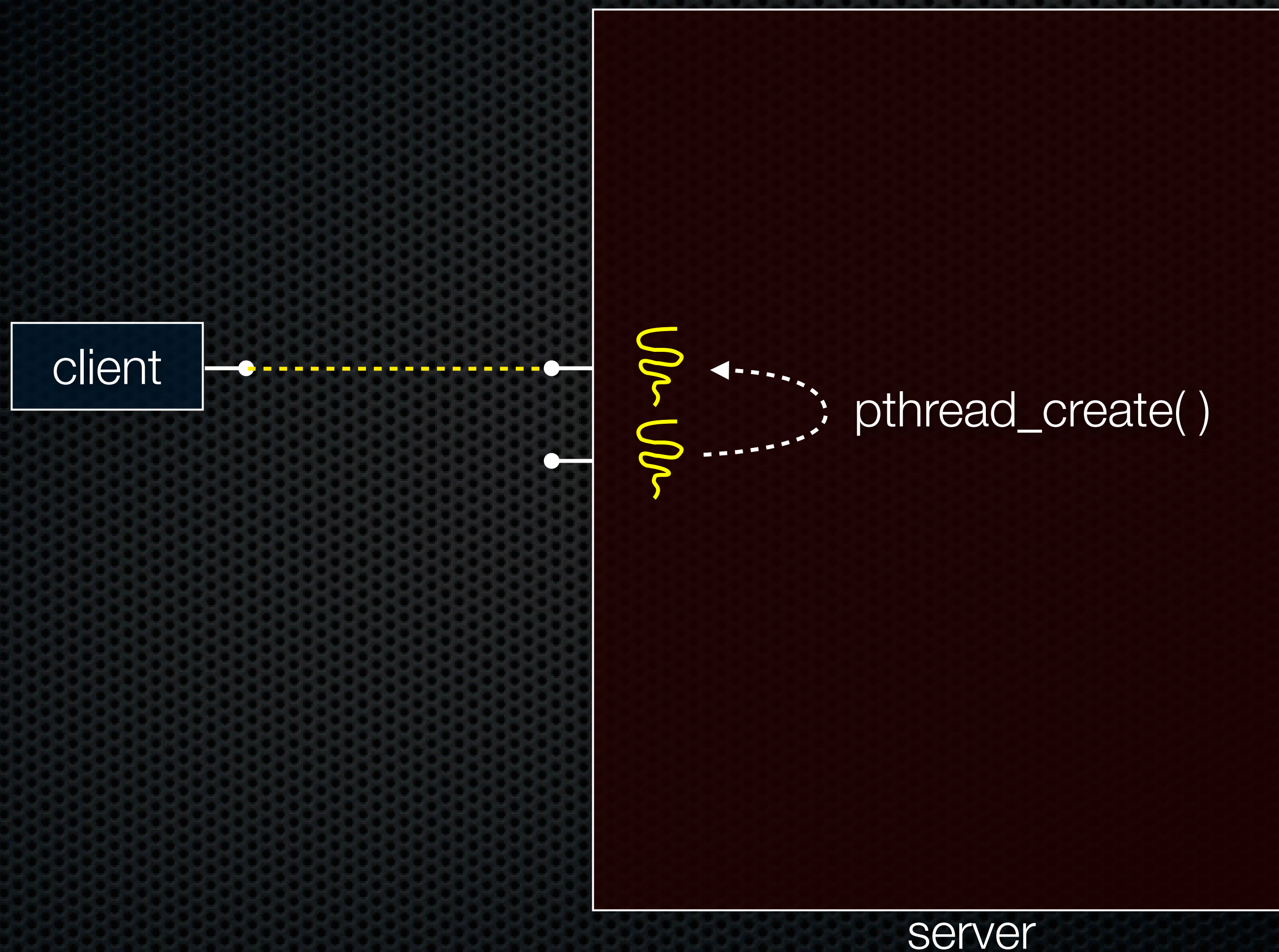

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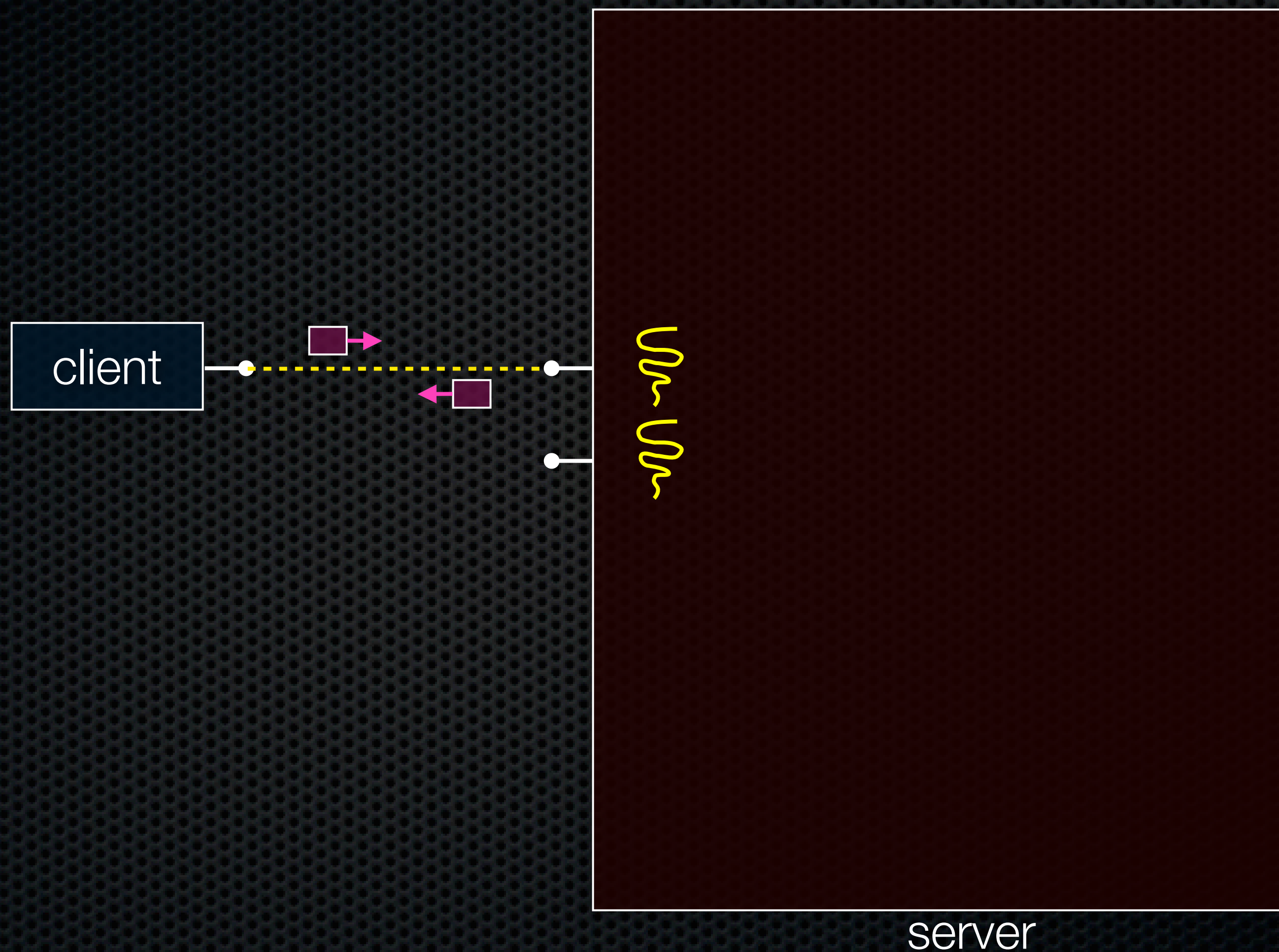

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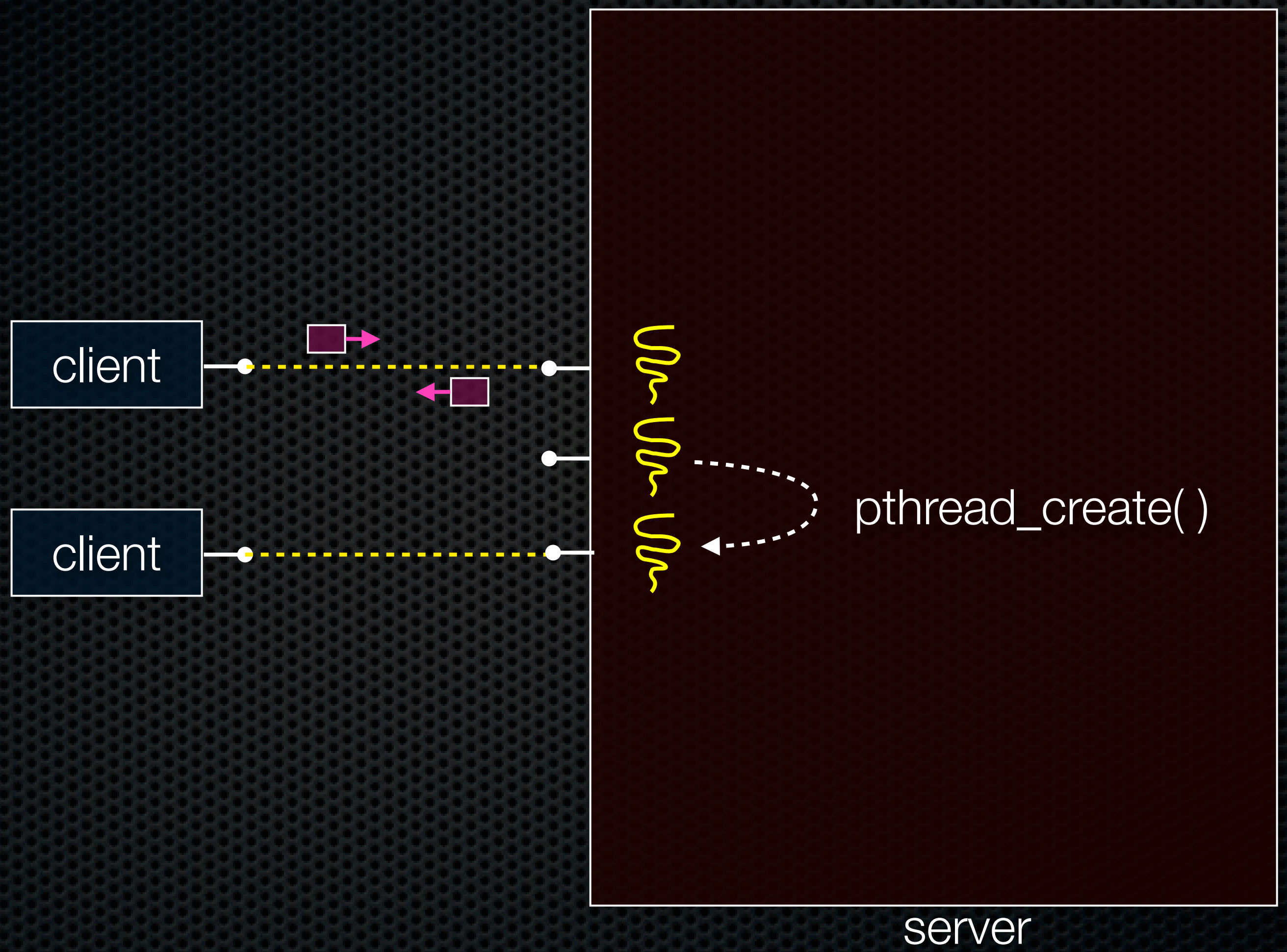

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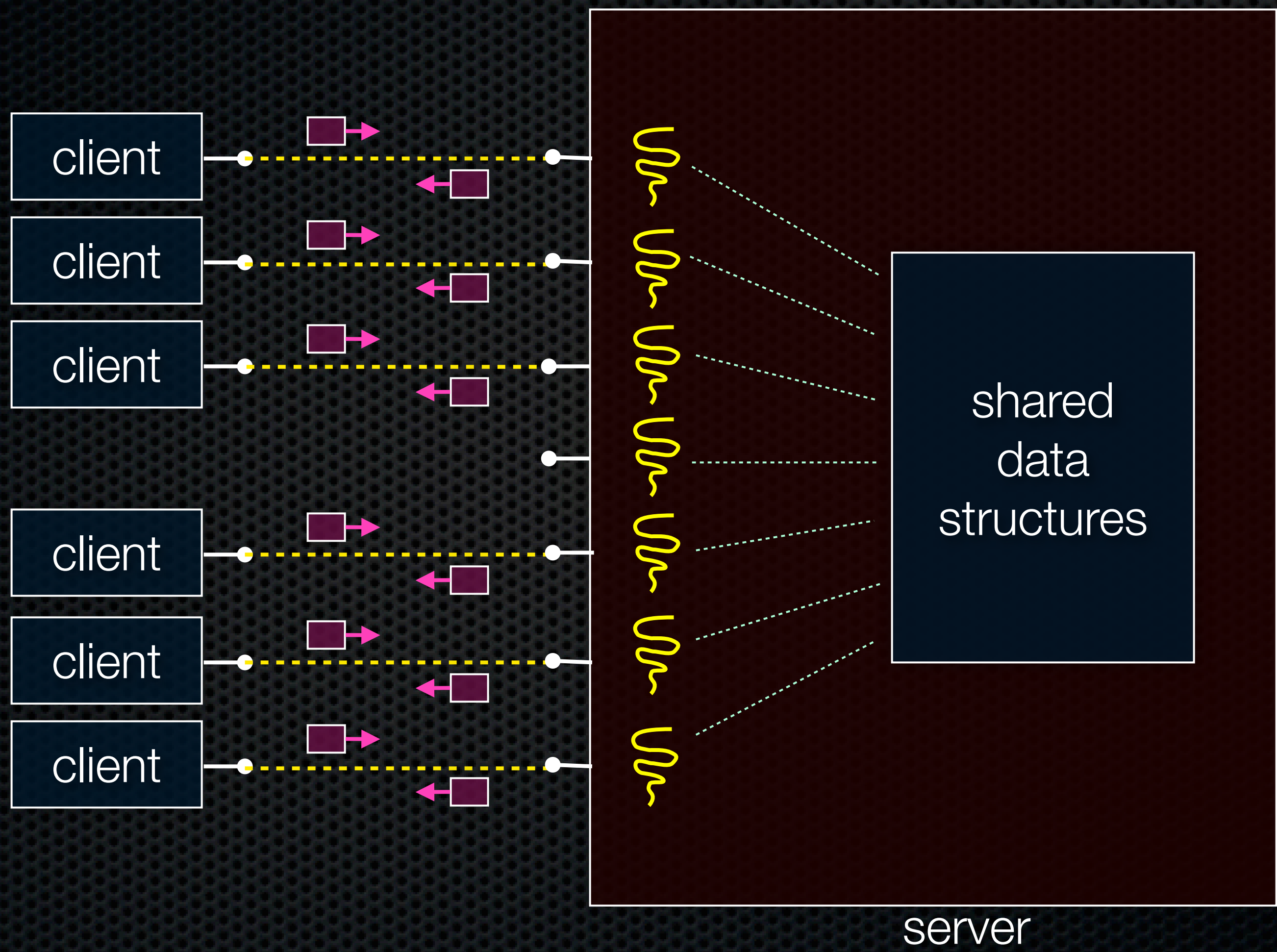

Concurrent with threads

look at ***echo_concurrent_threads.cc***

Whither concurrent threads?

Benefits

- straight-line code, line processes or sequential
  - still the case that much of the code is identical!
- parallel execution; good CPU, network utilization
  - lower overhead than processes
- shared-memory communication is possible

Disadvantages

- synchronization is complicated
- shared fate within a process; one rogue thread can hurt you badly

How fast is pthread_create?

run ***threadlatency.cc***

Implications?

0.036 ms per thread create; ~10x faster than process forking

- maximum of (1000 / 0.036) = ~30,000 connections per second
- ~5 billion connections per day per core
    - much better

But, writing safe multithreaded code can be serious voodoo

See you on Wednesday!

Exercise 1

Write a simple "proxy" server

- forks a process for each connection
- reads an HTTP request from the client
    - relays that request to www.cs.washington.edu
- reads the response from www.cs.washington.edu
    - relays the response to the client, closes the connection

Try visiting your proxy using a web browser :)

Exercise 2

Write a client program that:

- loops, doing "requests" in a loop. Each request must:
  - connect to one of the echo servers from the lecture
  - do a network exchange with the server
  - close the connection
- keeps track of the latency (time to do a request) distribution
- keeps track of the throughput (requests / s)
- prints these out