Concurrency: Processes

CSE 333

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Outline

- `searchserver`
  - Sequential
  - Concurrent via forking threads – `pthread_create()`
  - **Concurrent via forking processes – `fork()`**
  - *Concurrent via non-blocking, event-driven I/O – `select()`*
    - *We won't get to this ☹*

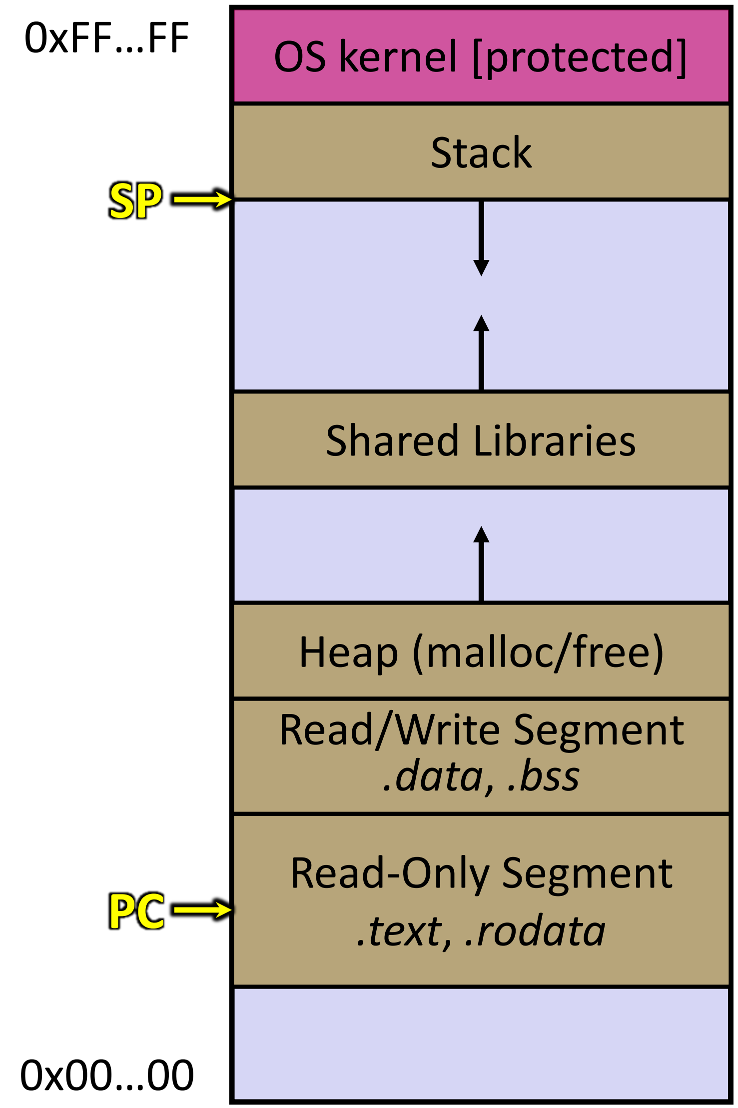
- Reference: *Computer Systems: A Programmer's Perspective*, Chapter 12 (CSE 351 book)

Creating New Processes

- `pid_t fork(void);`
  - Creates a new process (the "child") that is an *exact clone** of the current process (the "parent")
    - *Everything is cloned except threads; variables, file descriptors, open sockets, the virtual address space (code, globals, heap, stack), etc are all cloned
  - Primarily used in two patterns:
    - Servers: fork a child to handle a connection
    - Shells: fork a child that then exec's a new program

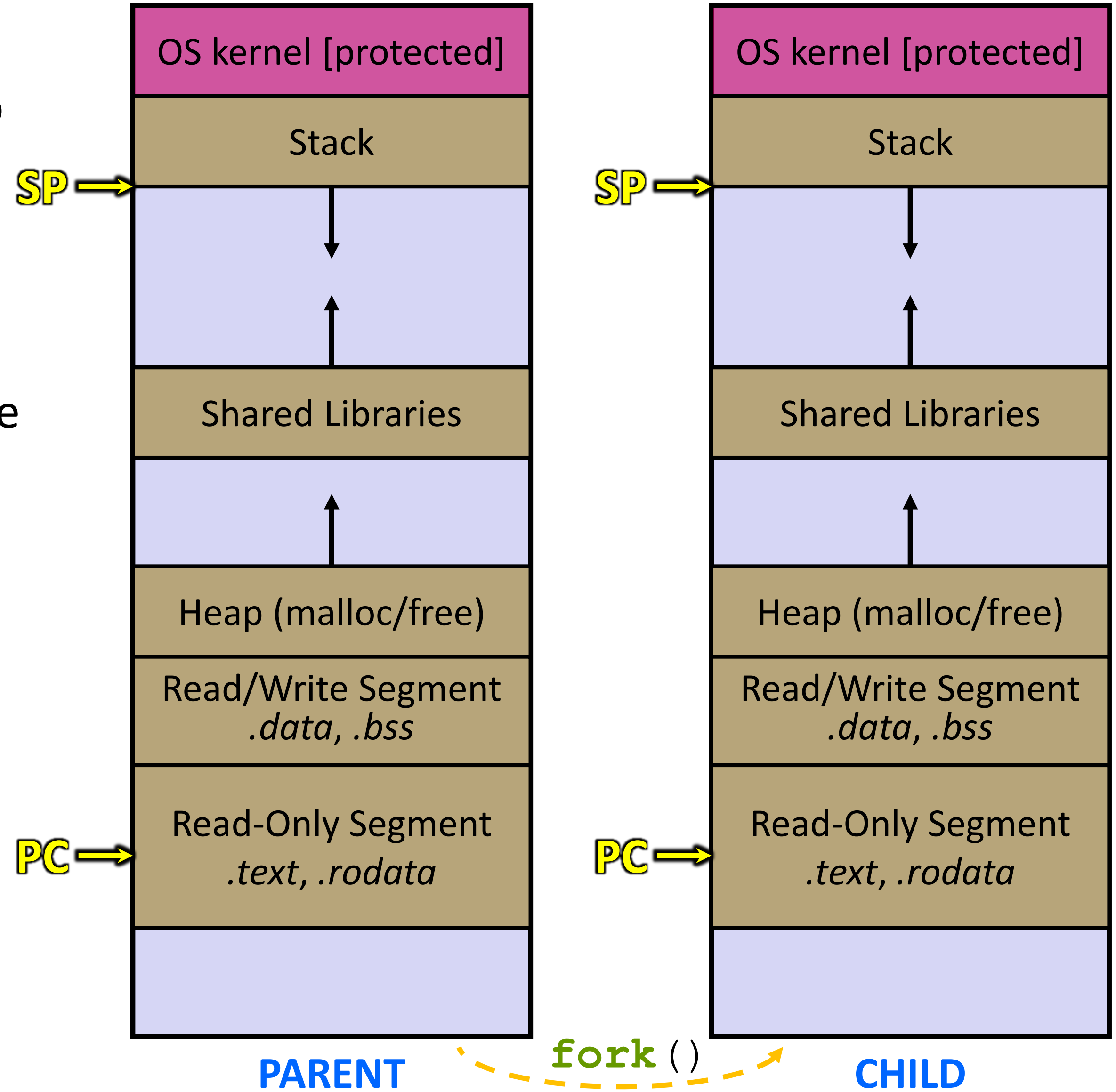
`fork()` and Address Spaces

- A process executes within an *address space*
  - Includes segments for different parts of memory
  - Process tracks its current state using the stack pointer (SP) and program counter (PC)



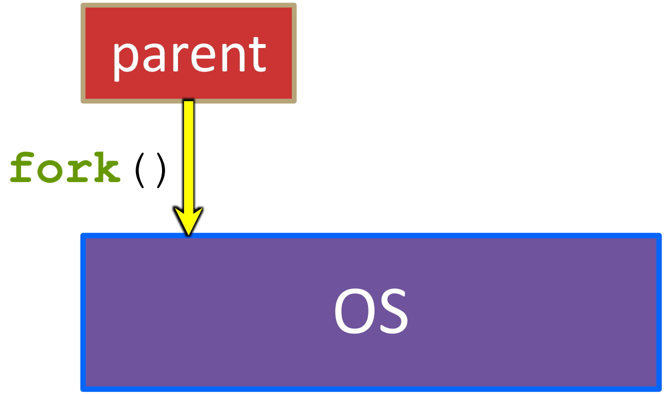
`fork()` and Address Spaces

- Fork cause the OS to clone the address space
  - The *copies* of the memory segments are (nearly) identical
  - The new process has *copies* of the parent's data, stack-allocated variables, open file descriptors, etc.



`fork()`

- `fork()` has peculiar semantics
  - The parent invokes `fork()`
  - The OS clones the parent
  - *Both* the parent and the child return from fork
    - Parent receives child's pid
    - Child receives a 0



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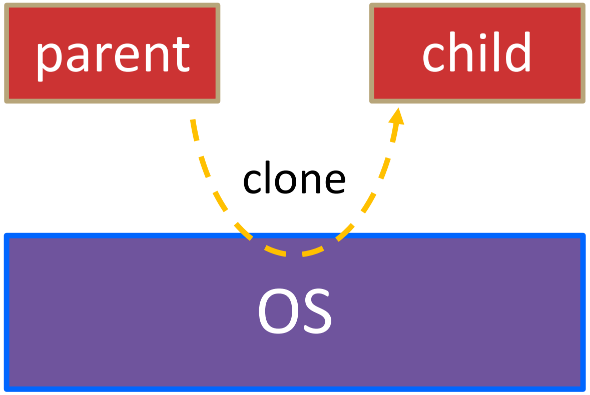

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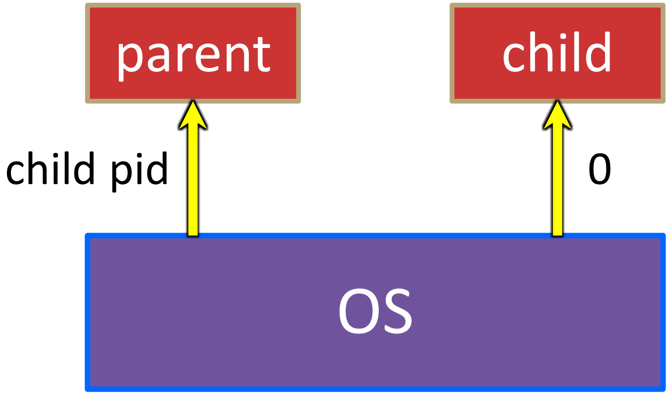

- See `fork_example.cc`

Poll Everywhere

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What happens when a grandchild process finishes?

A. Zombie until grandparent exits
B. Zombie until grandparent reaps
C. Zombie until `systemd` reaps
D. ZOMBIE FOREVER!!!
E. I'm not sure…

Concurrent Server 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 termination
  - Option A: Parent calls `wait()` to "reap" children
  - Option B: Use a double-fork trick

Double-fork Trick

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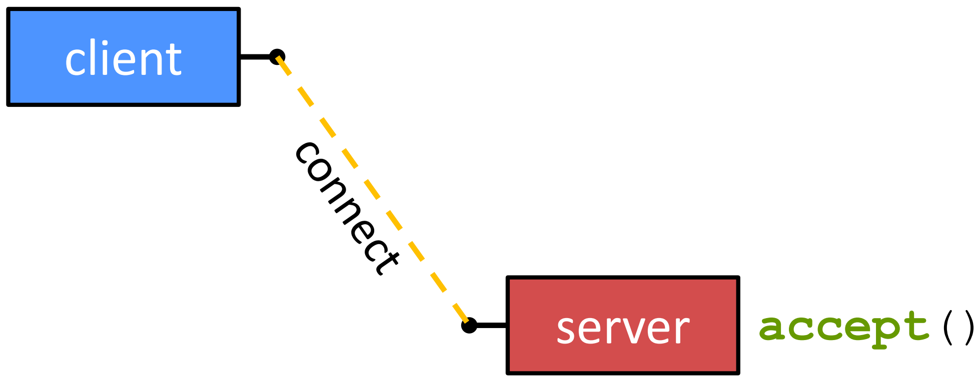
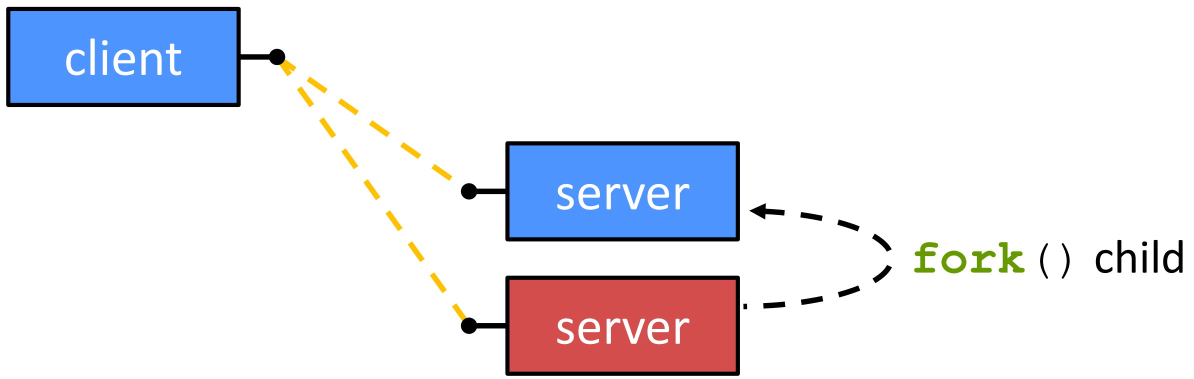


Double-fork Trick



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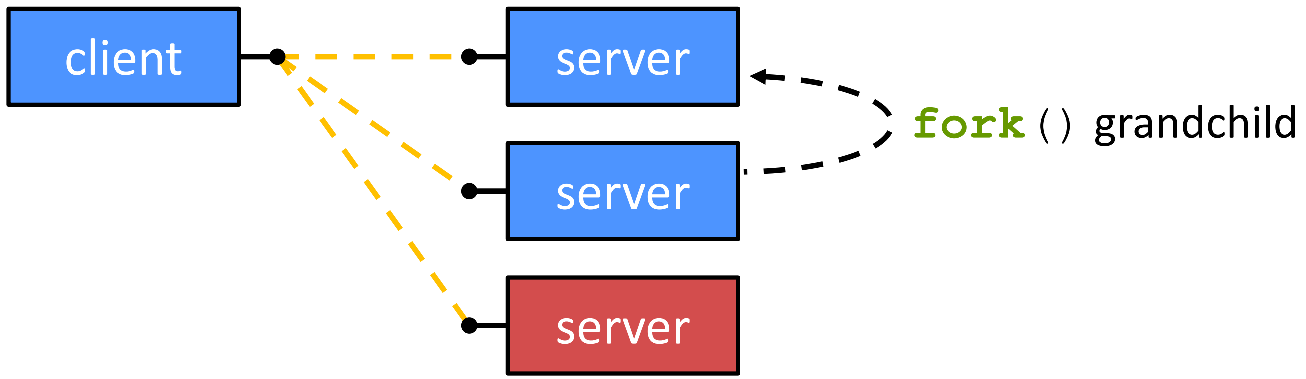

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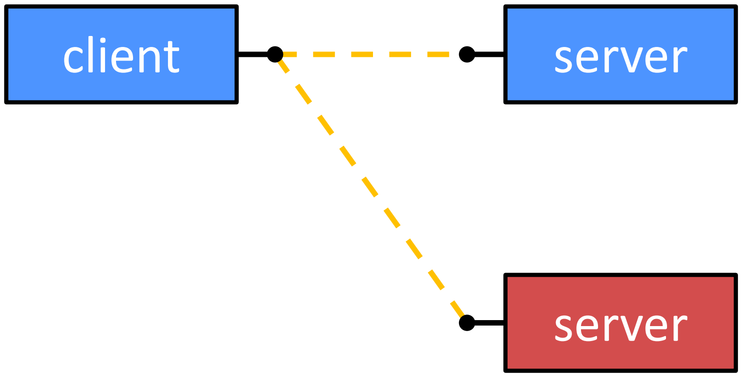
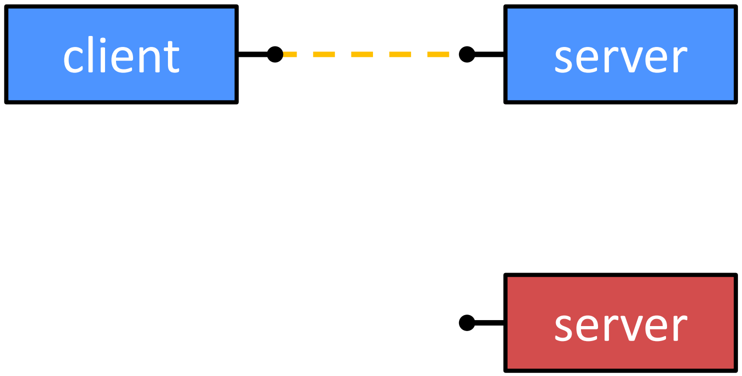


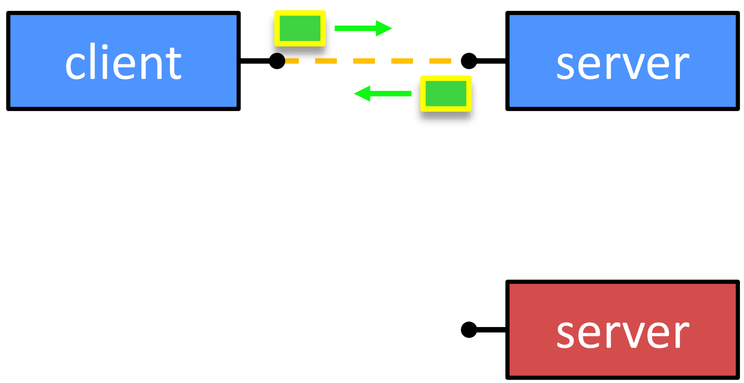
child **`exit`**`()`'s / parent **`wait`**`()`'s

Double-fork Trick



parent closes its
client connection

Double-fork Trick



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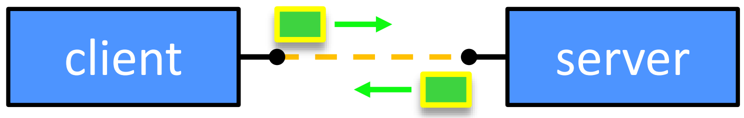

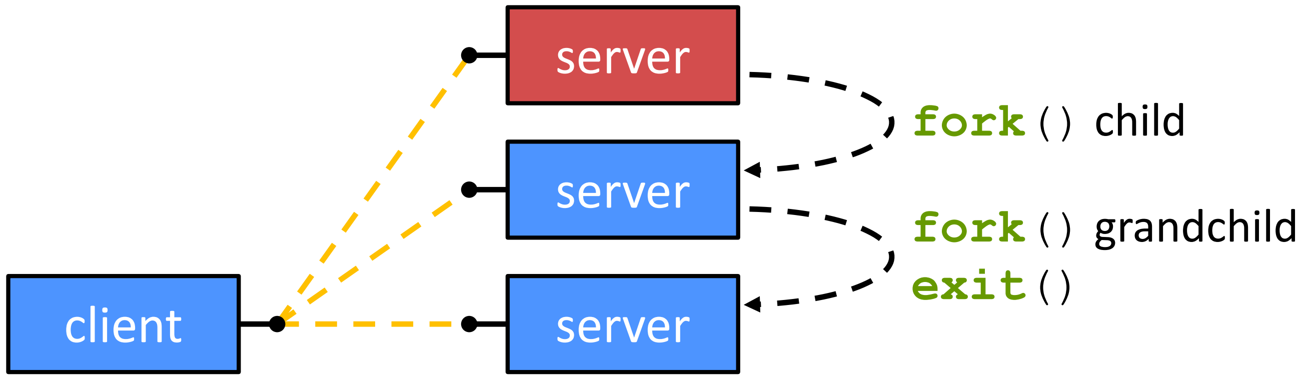

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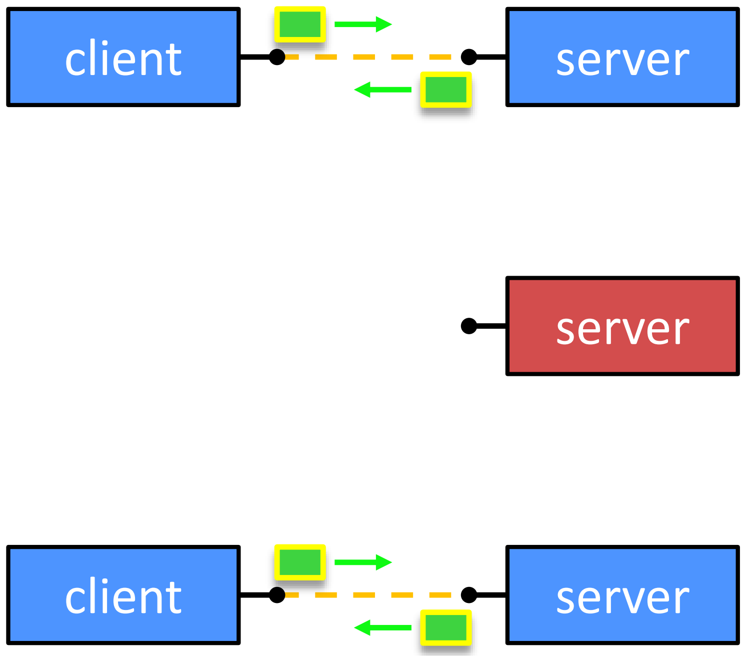

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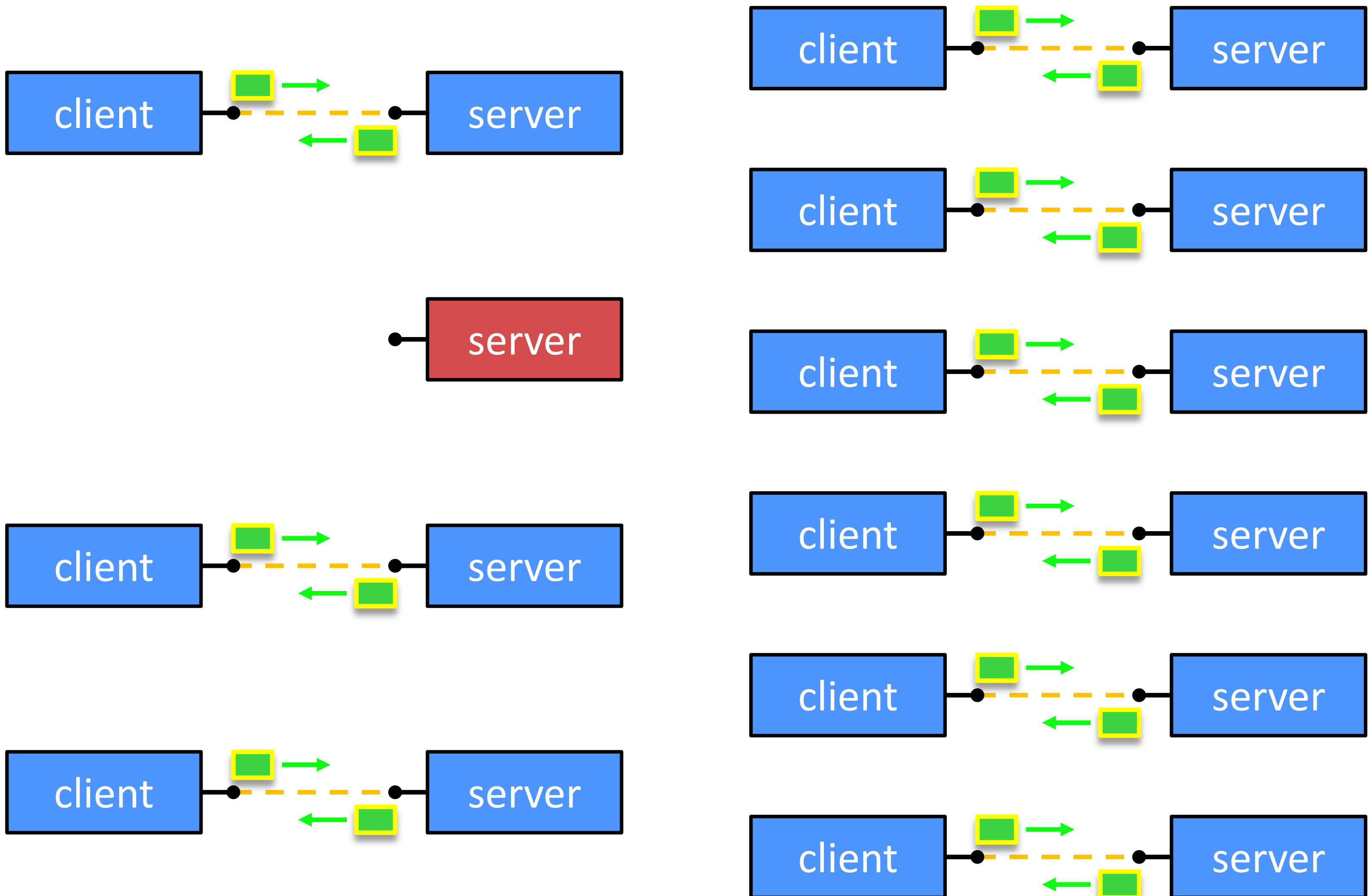

Poll Everywhere

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- Review code from L26 (concurrency via threads – May 22) and the networking "layer cake"

- What application protocol does searchserver use?

Concurrent with Processes

- See `searchserver_processes/`

Wherefore Concurrent Processes?

- Advantages:
  - Almost as simple to code as sequential
    - In fact, most of the code is identical!
  - Concurrent execution leads to better CPU, network utilization

- Disadvantages:
  - Processes are heavyweight
    - Relatively slow to fork
    - Context switching latency is high
  - Communication between processes is complicated

How Fast is `fork()`?

- See `forklatency.cc`

- ~ **0.25 ms** per fork*
  - ∴ maximum of (1000/0.25) = 4,000 connections/sec/core
  - ~350 million connections/day/core
    - This is fine for most servers
    - Too slow for super-high-traffic front-line web services
      - Facebook served ~ 750 billion page views per day in 2013! Would need 3-6k cores just to handle `fork()`, *i.e.* without doing any work for each connection

- *Past measurements are not indicative of future performance – depends on hardware, OS, software versions, …

How Fast is `pthread_create()`?

- See `threadlatency.cc`

- ~**0.036 ms** per thread creation*
  - ~10x faster than **`fork`**()
  - ∴ maximum of (1000/0.036) = 28,000 connections/sec
  - ~2.4 billion connections/day/core

- Much faster, but writing safe multithreaded code can be serious voodoo

- *Past measurements are not indicative of future performance – depends on hardware, OS, software versions, …, but will typically be an order of magnitude faster than fork()

Aside: Thread Pools

- In real servers, we'd like to avoid overhead needed to create a new thread or process for every request

- Idea: Thread Pools:
  - Create a fixed set of worker threads or processes on server startup and put them in a queue
  - When a request arrives, remove the first worker thread from the queue and assign it to handle the request
  - When a worker is done, it places itself back on the queue and then sleeps until dequeued and handed a new request

Why Sequential?

- Advantages:
  - Simple to write, maintain, debug
  - The default. Supported everywhere!

- Disadvantages:
  - Depending on application, poor performance
    - One slow client will cause *all* others to block
    - Poor utilization of resources (CPU, network, disk)

Why Concurrent Threads?

- Advantages:
  - Almost as simple to code as sequential
  - Concurrent execution with good CPU and network utilization
  - Threads can run in parallel if you have multiple CPUs/cores
  - Shared-memory communication is possible

- Disadvantages:
  - Need language and OS support for threads
  - If threads share data, you need locks or other synchronization
  - Threads can introduce overhead (technical + cognitive)
  - Threads have a “shared fate” (eg, “rogue” thread, shared limits)

Why Concurrent Processes?

- Advantages:
  - Almost as simple to code as sequential
  - Concurrent execution with good CPU and network utilization
  - Processes almost certainly run in parallel thanks to OS time-sharing
  - No need to synchronize access to in-memory structures

- Disadvantages:
  - Processes are heavyweight
    - Relatively slow to fork and context switching latency is high
  - Communication between processes is complicated — no shared memory
  - Fewer things to synchronize – but when you do need to synchronize, it's hard! — e.g., disk based locks? shared "master" to hold lock?

Why Events?

- Advantages:
  - For some kinds of programs – those with mostly-stateless, simple responses – leads to very simple and intuitive program
    - Eg, GUIs: one event handler for each UI event

- Disadvantages:
  - Can lead to very complex structure for some programs
    - Sequential logic gets broken up into a jumble of small event handlers
    - You have to package up all task state between handlers