Concurrency: Processes

CSE 333 Winter 2024

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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 ☹

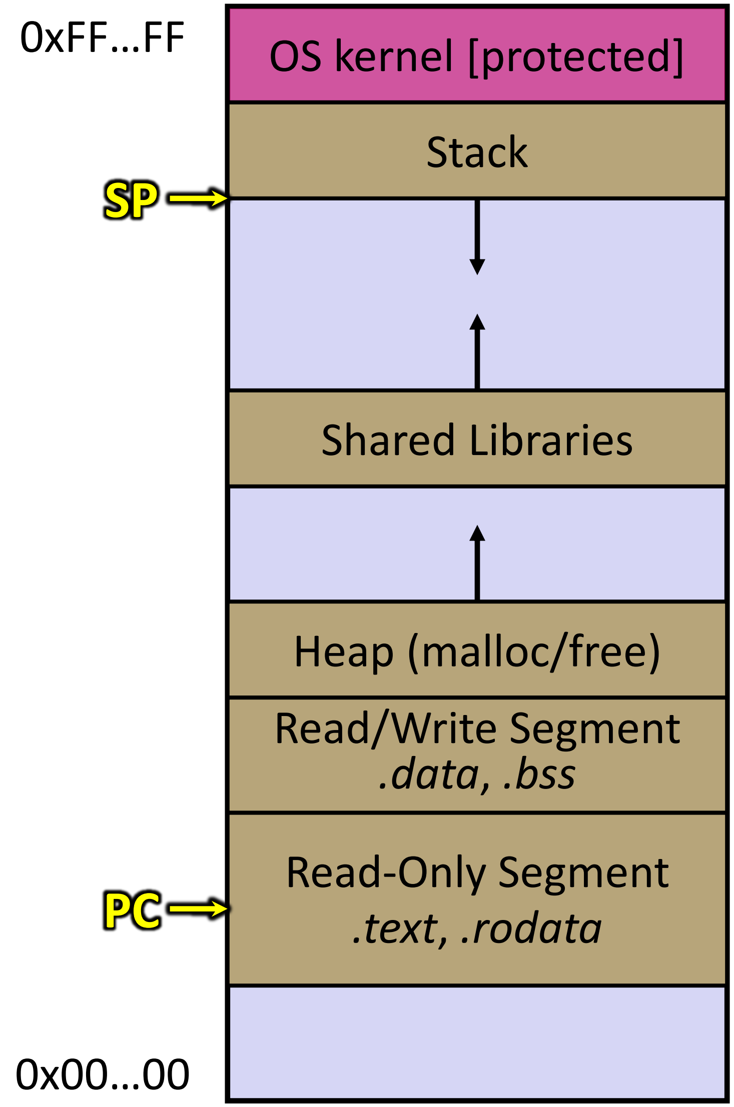
- Reference: *Computer Systems: A Programmer's Perspective*, Chapter 12 (CSE 351 book)

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.
  - Primarily used in two patterns:
    - Servers: fork a child to handle a connection
    - Shells: fork a child that then exec’s a new program

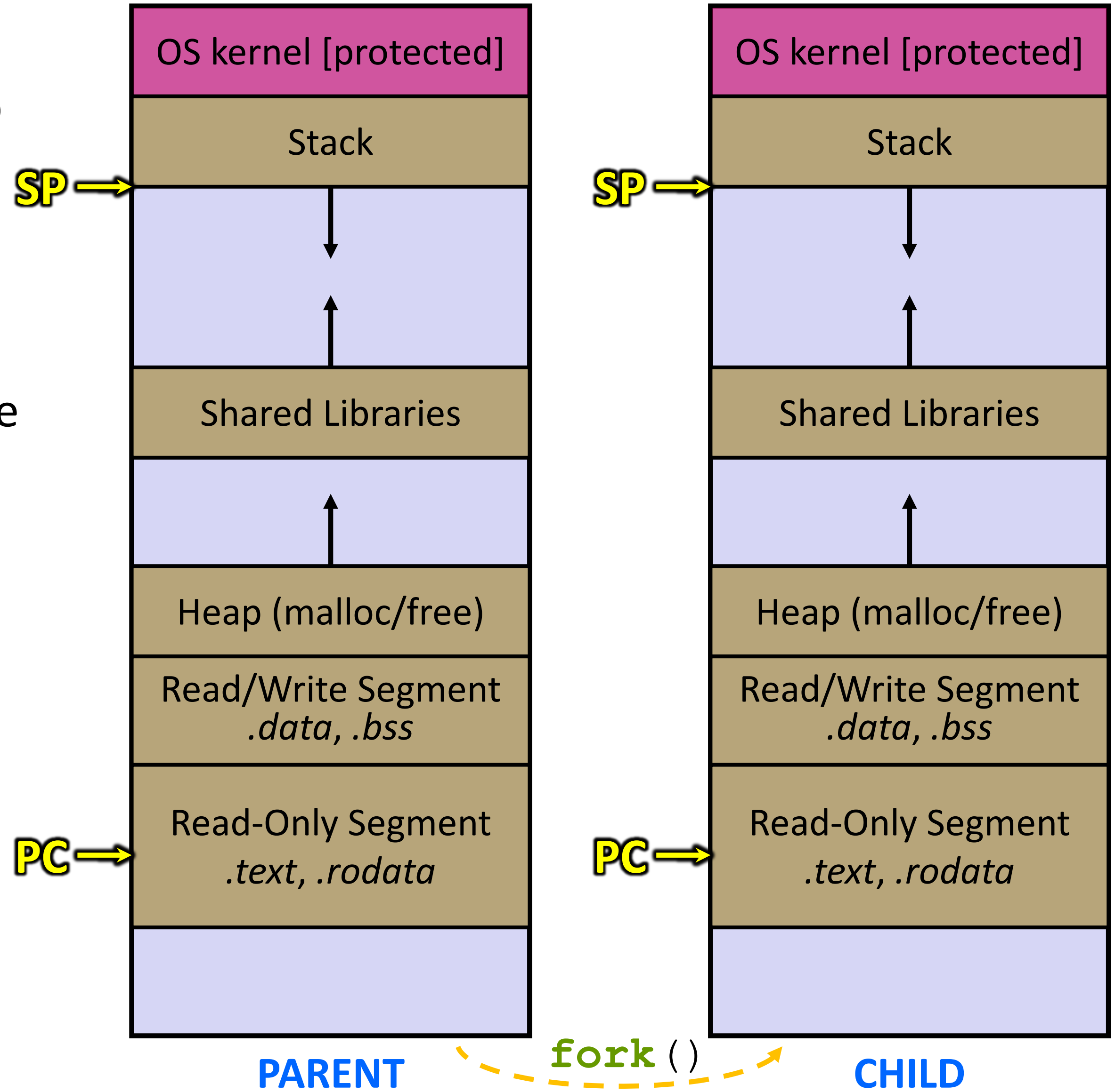
`fork()` and Address Spaces

- 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)



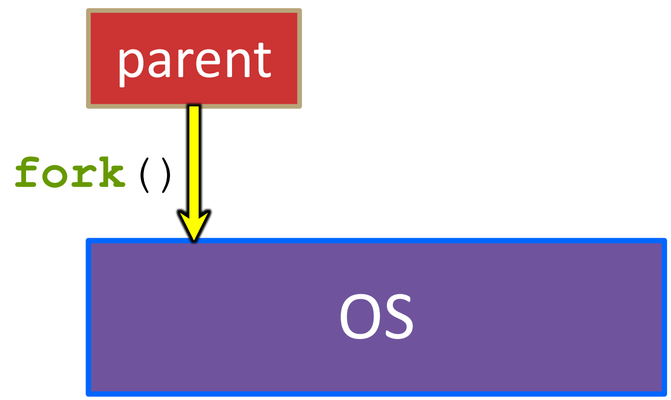
`fork()` and Address Spaces

- 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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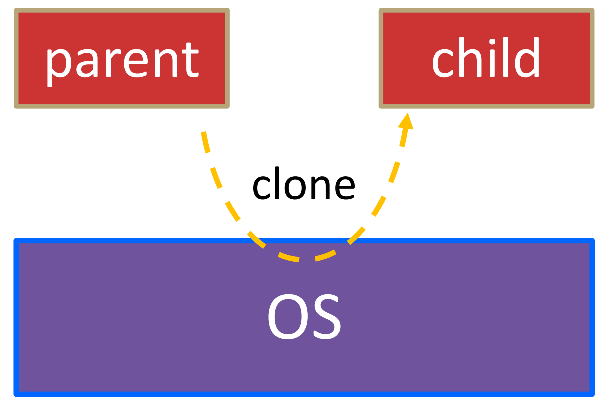

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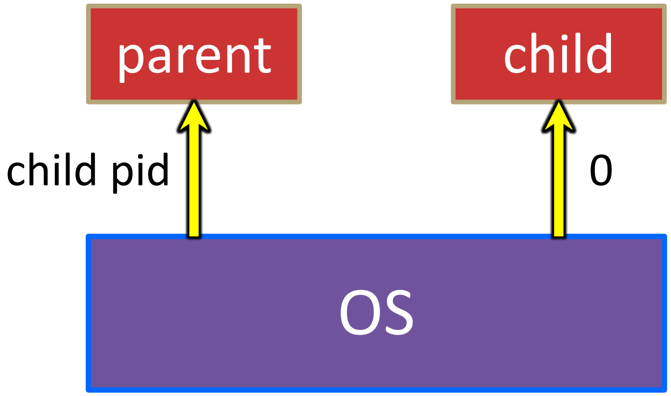

- See `fork_example.cc`

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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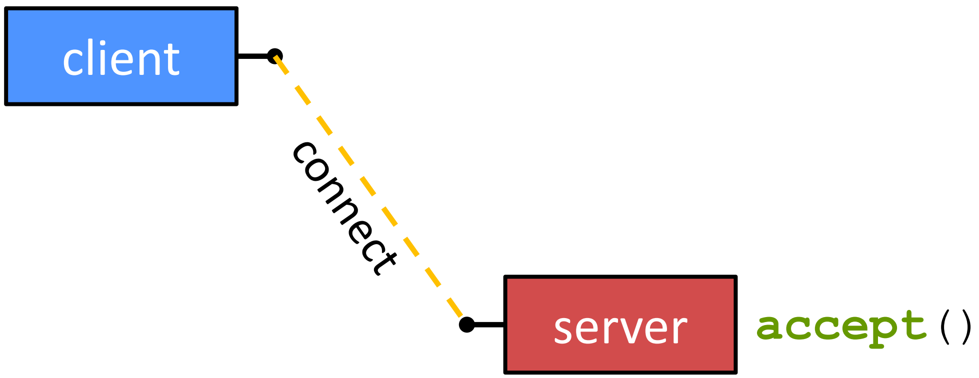

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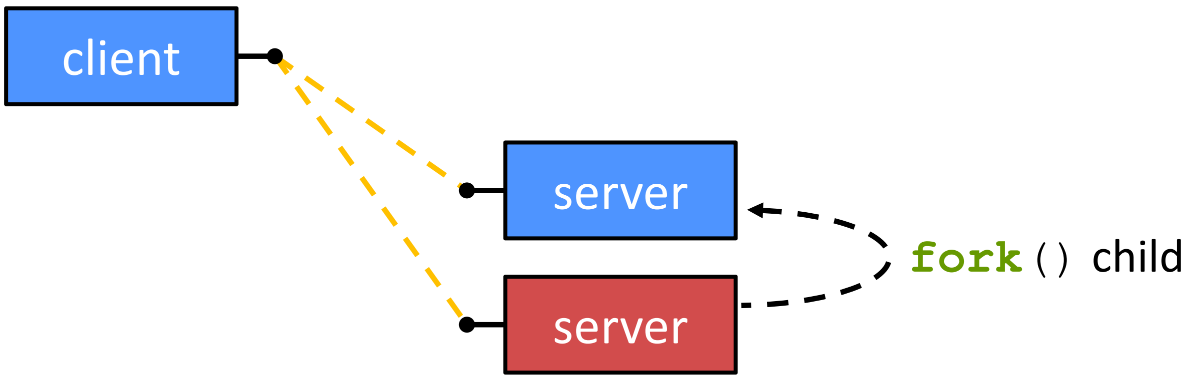

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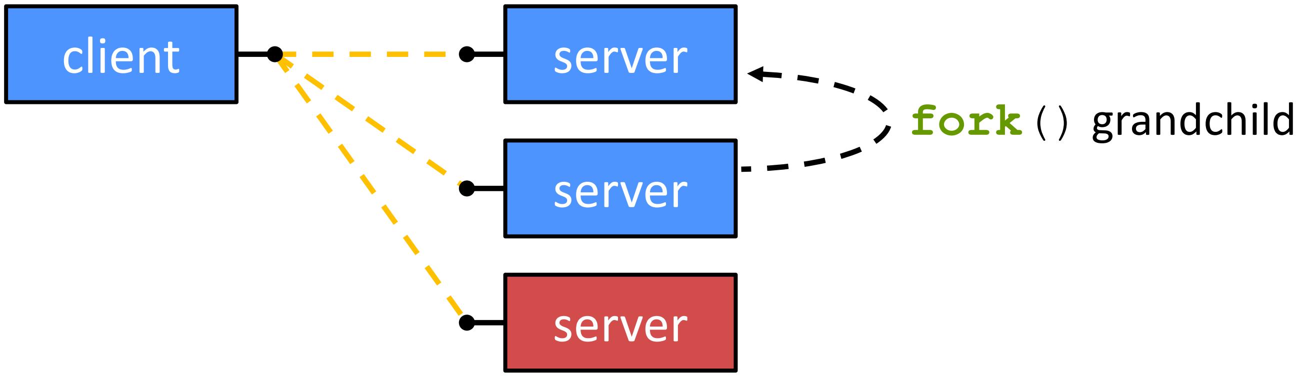

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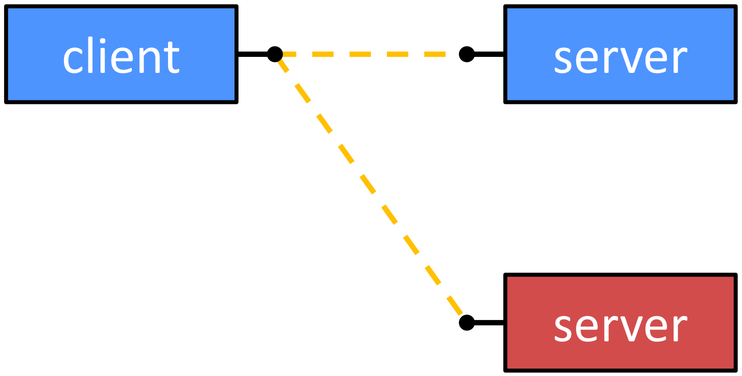
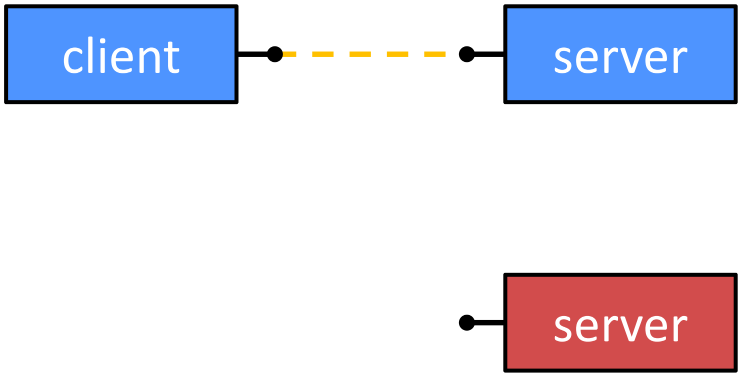


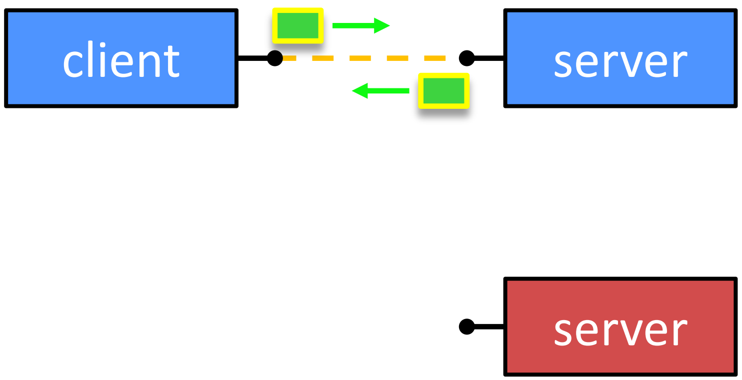
child `exit()`'s / parent `wait()`'s

Double-fork Trick



parent closes its
client connection

Double-fork Trick



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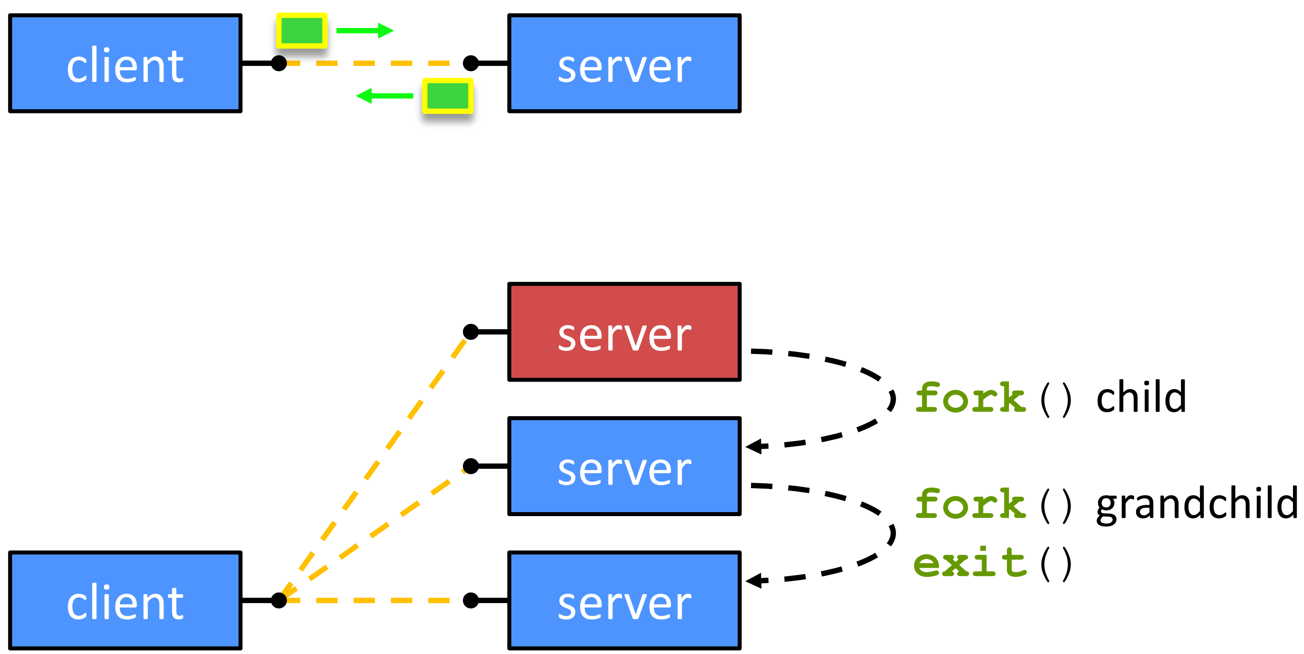

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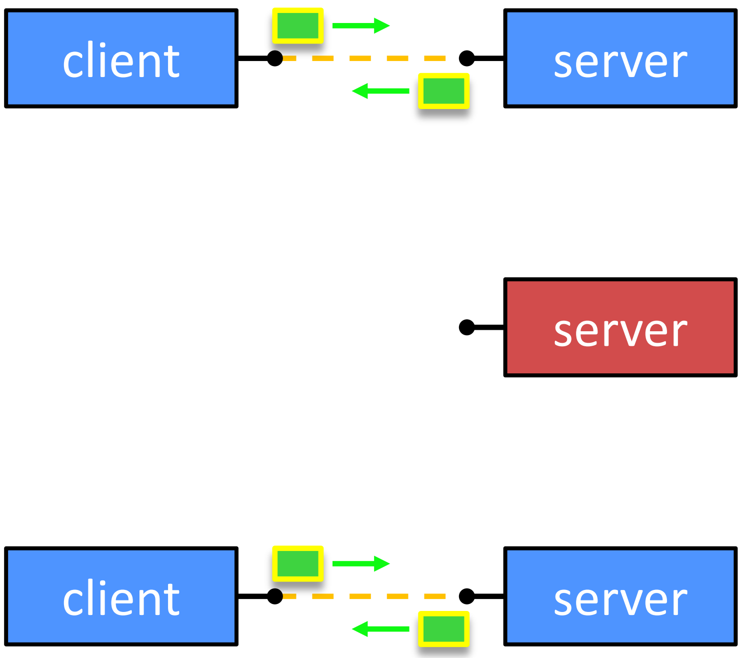

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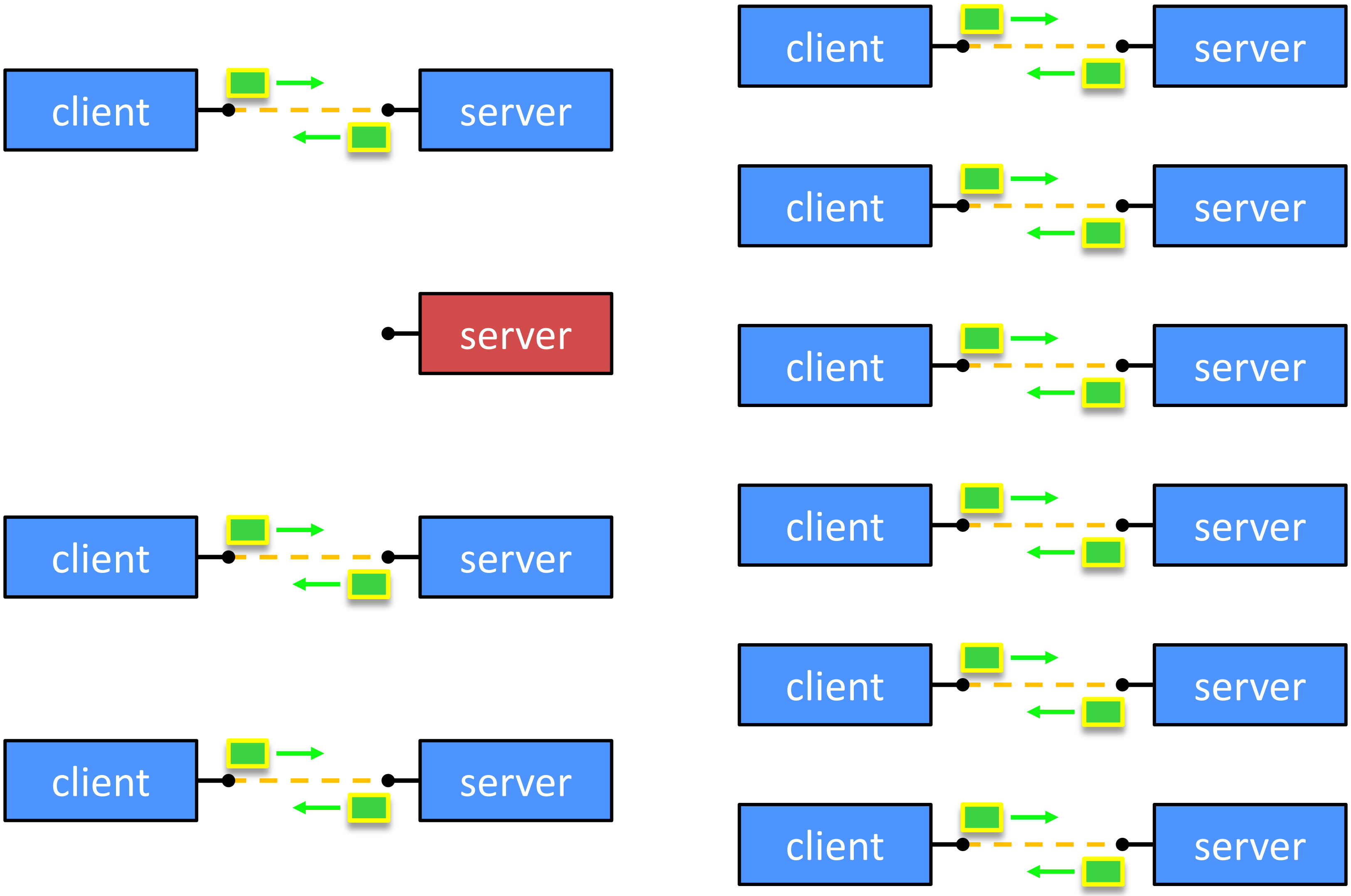

Concurrent with Processes

- See `searchserver_processes/`

Whither 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