Concurrency: Processes

CSE 333 Spring 2019

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Administrivia

- Classes have moved online to avoid virus transmission
  - Stay healthy everyone!
- **Final Exam is cancelled**
  - Grade weights will be updated, more info coming soon
- Lectures posted online through Panopto on Canvas
- Section will be online through Zoom
- Office Hours are online through Zoom

- hw4 due Thursday (3/12)
  - Submissions accepted through Sunday, as usual

- Course evaluations! (see Piazza)

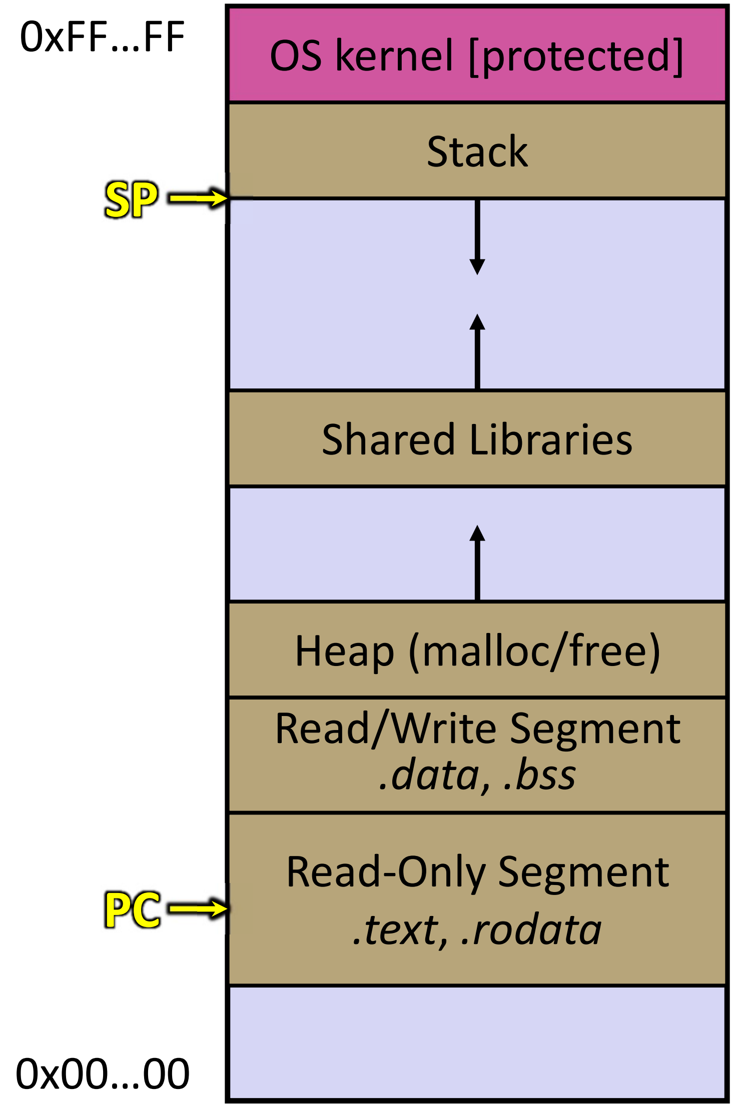
Outline

- `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)

Review: 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)



Creating New Processes

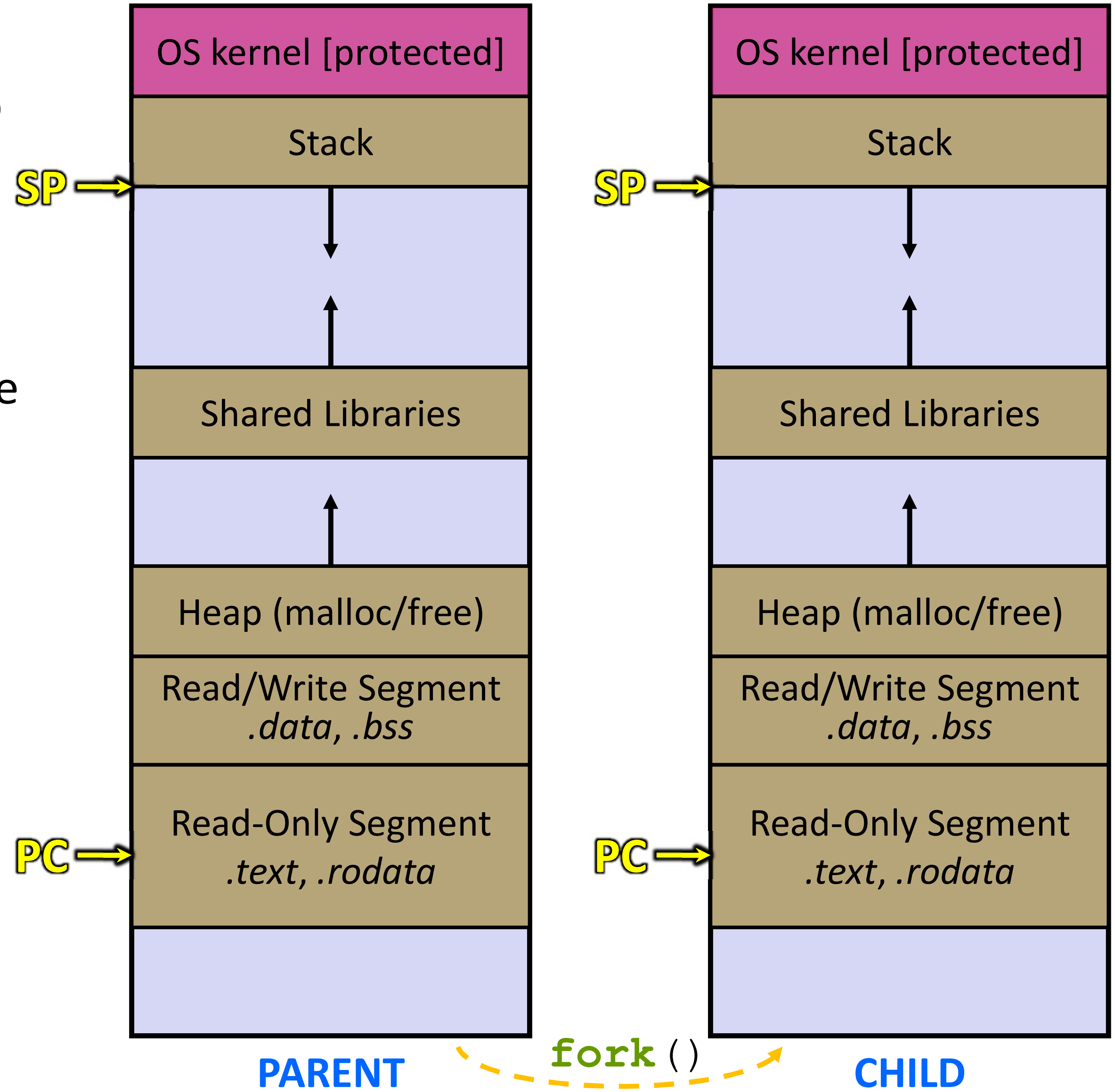
- `pid_t fork();`
  - Creates a new process (the “child”) that is an *exact clone** of the current process (the “parent”)
    - *Everything is cloned except threads
  - The new process has a separate virtual address space from the parent

Main Uses of `fork()`

- Fork a child to handle some work
  - Server forks to handle a new connection
  - Web browser forks to render a new website
    - Mainly for security purposes (separate address spaces)
- Fork a child that then exec's a new program
  - Shell forks and execs the program you want to run
  - 333 grading script forks and execs your executable
    - Using Python `subprocess`

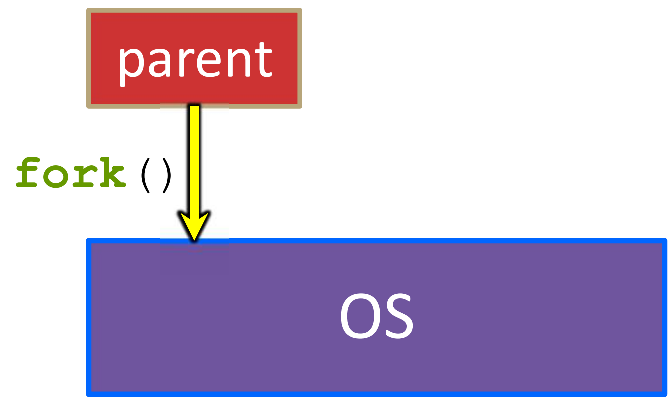
fork() and Address Spaces

- 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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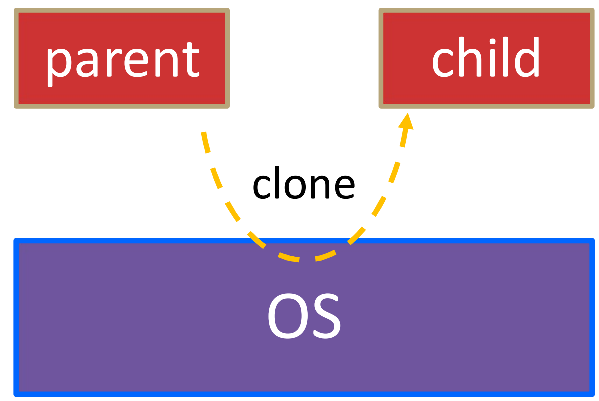

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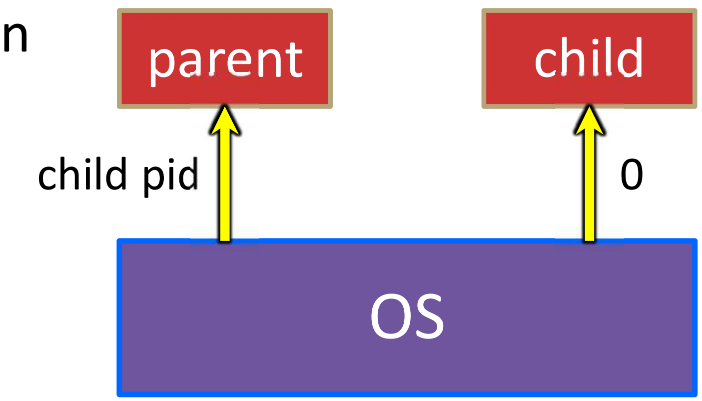

- See `fork_example.cc`

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

Double-fork Trick

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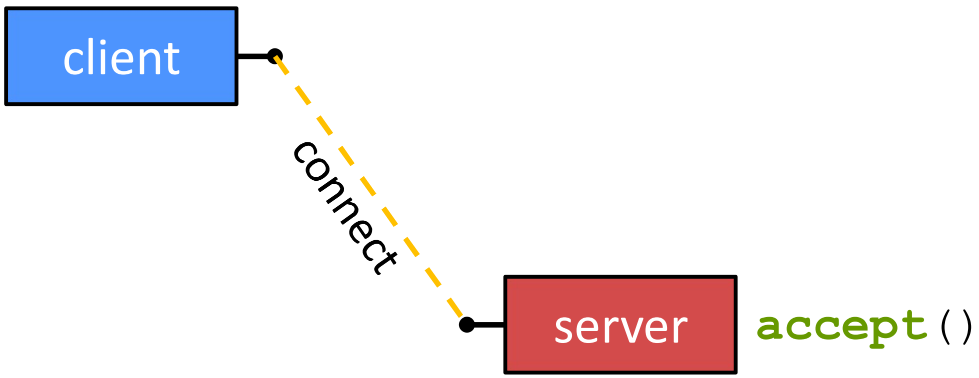

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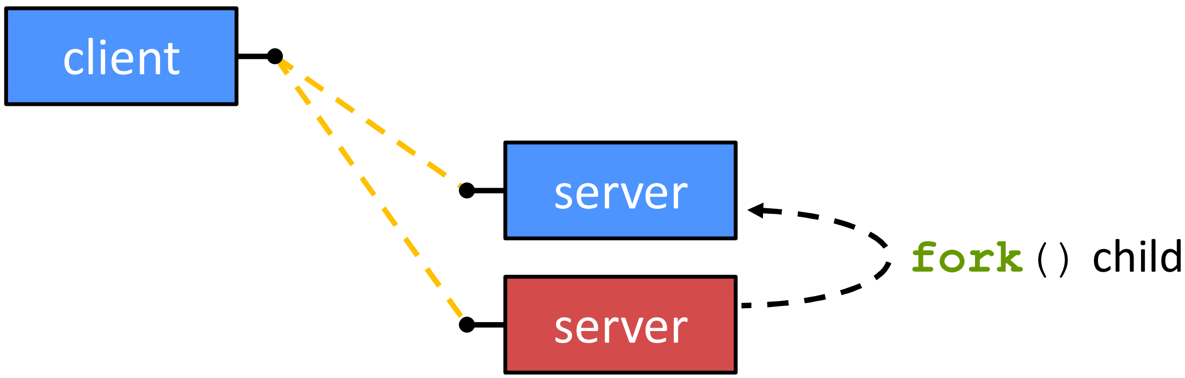

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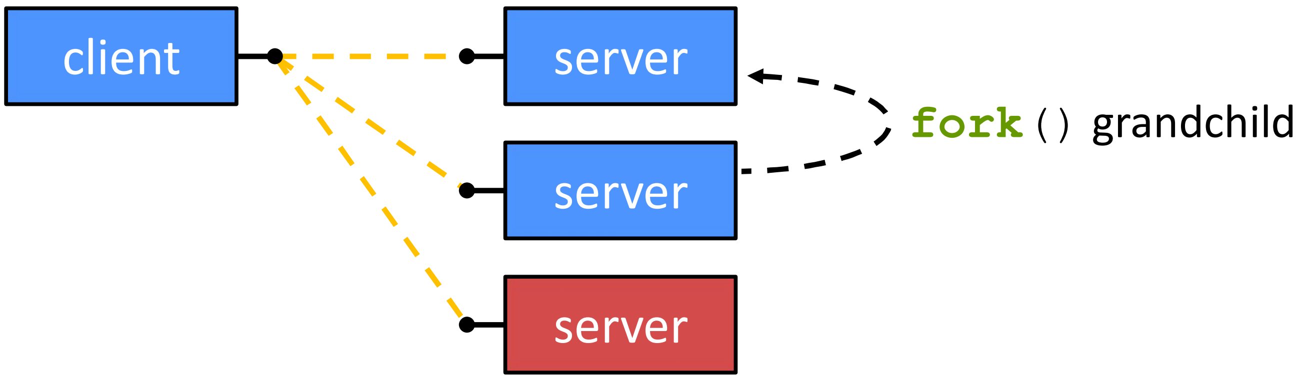

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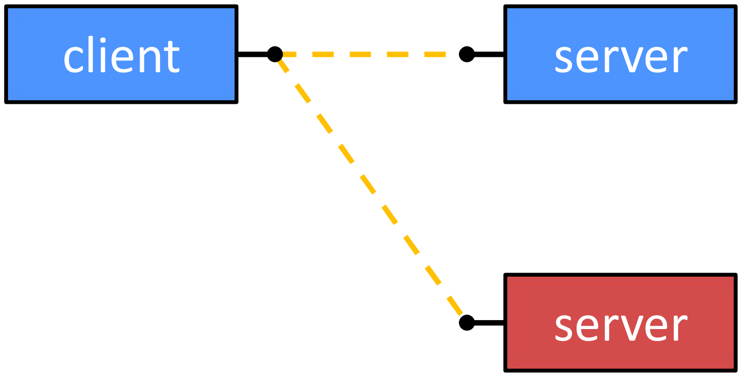
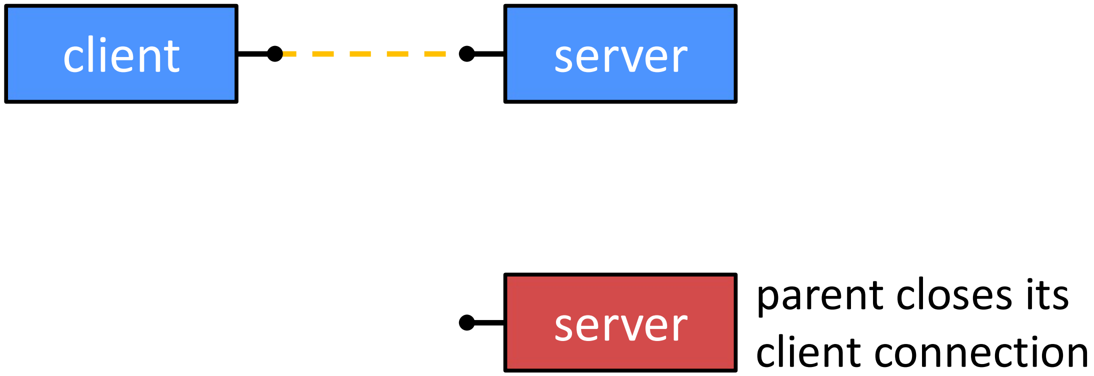


child `exit()`'s / parent `wait()`'s

Double-fork Trick



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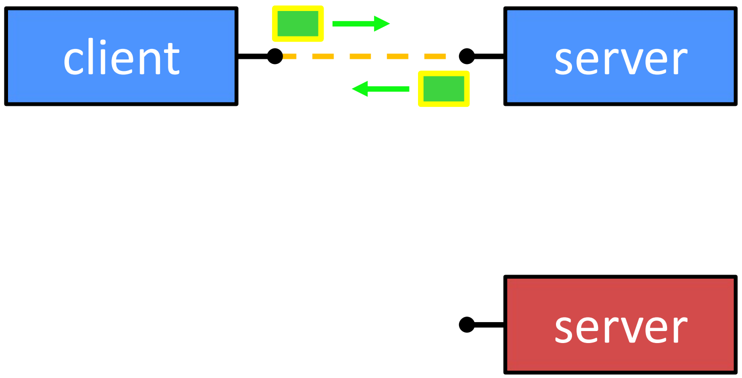

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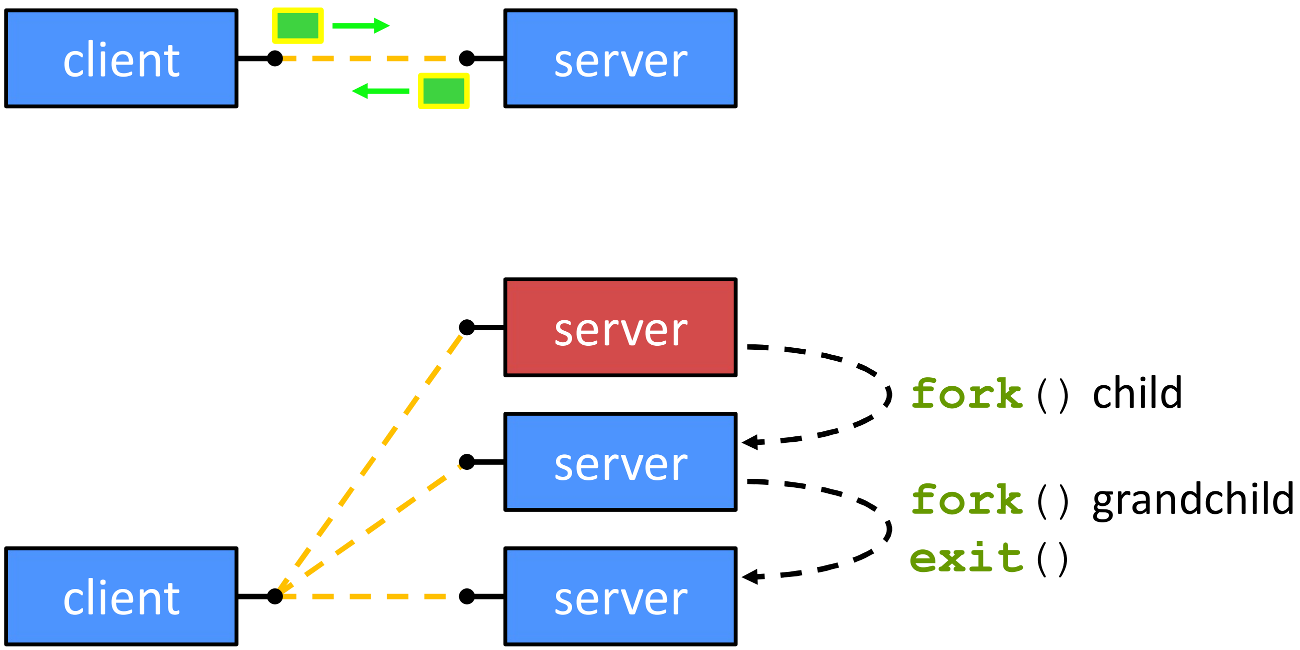

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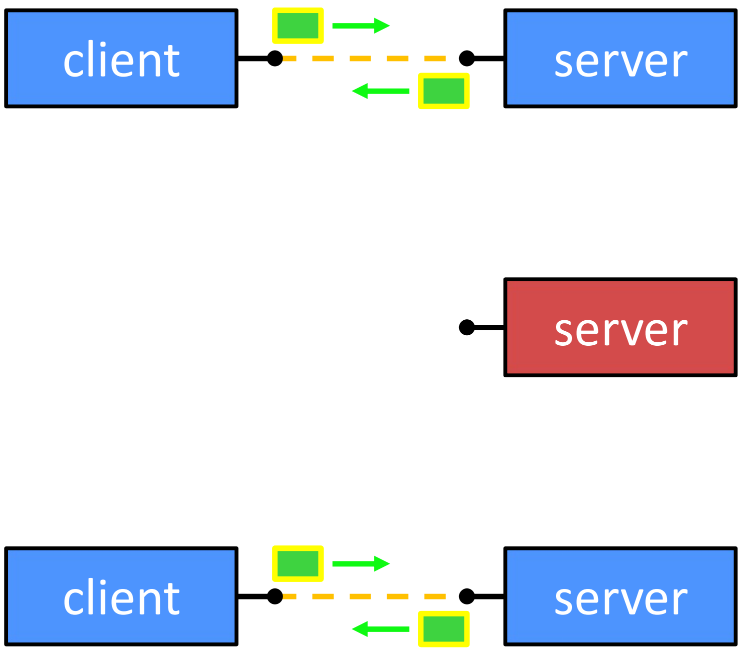

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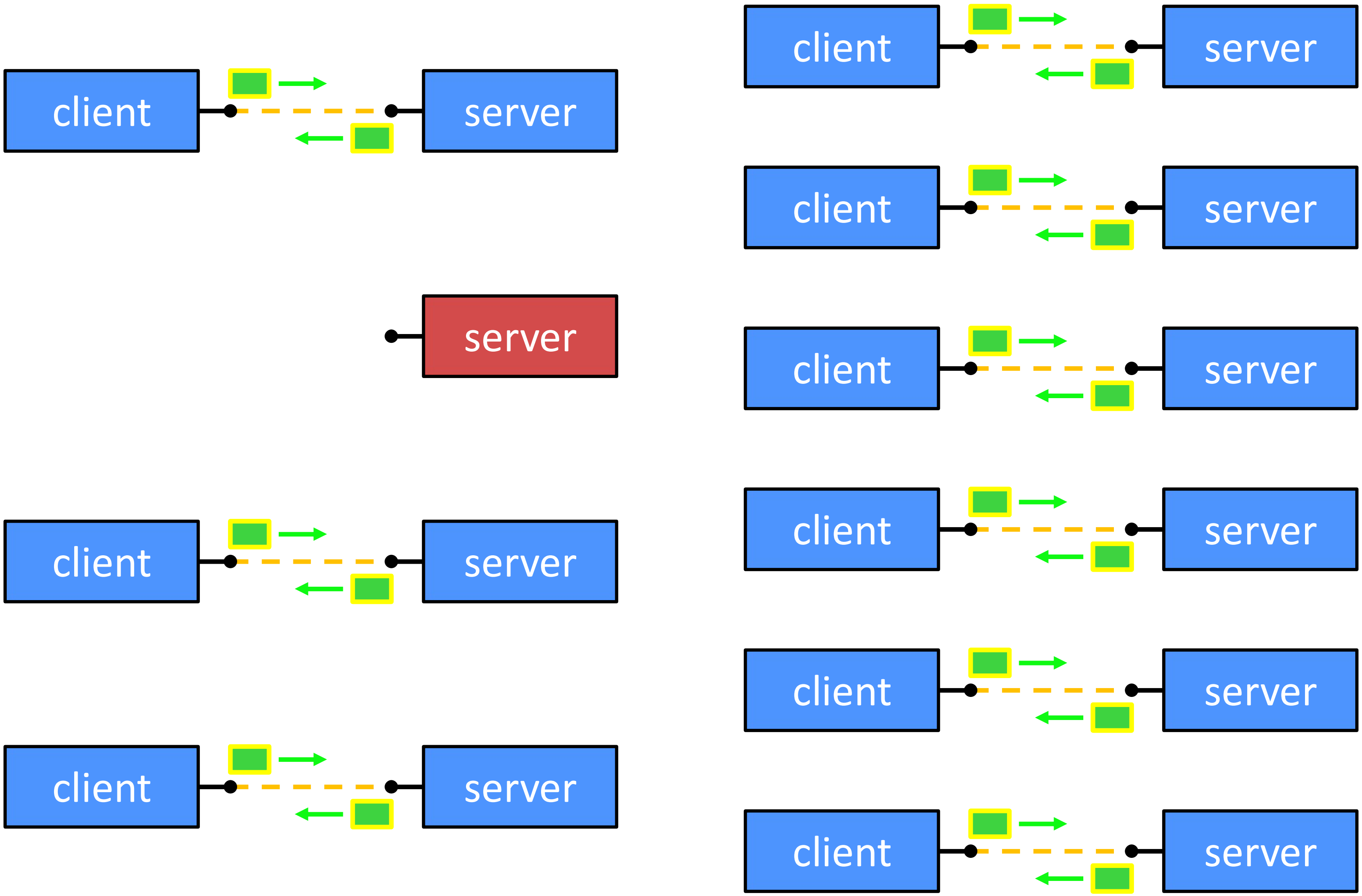

Review Question

- What will happen when one of the grandchildren processes finishes?
  - Vote at http://PollEv.com/justinh

A. **Zombie until grandparent exits**

B. **Zombie until grandparent reaps**

C. **Zombie until init reaps**

D. **ZOMBIE FOREVER!!!**

E. **We're lost…**

Concurrent with Processes Pseudocode

- See searchserver_processes/

```
... // Server set up
while (1) {
  sock_fd = accept();
  pid = fork();
  if (pid == 0) {
    // ??? process








  } else {
    // ??? process



  }
}
```

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while (1) {
  sock_fd = accept();
  pid = fork();
  if (pid == 0) {
    // Child process
    pid = fork();
    if (pid == 0) {
      // Grand-child process
      HandleClient(sock_fd, ...);
    }


  } else {
    // Parent process



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    // Clean up resources...
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      HandleClient(sock_fd, ...);
    }
    // Clean up resources...
    exit();
  } else {
    // Parent process
    // Wait for child to immediately die
    wait();
    close(sock_fd);
  }
}
```

Why 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`
- ~ **0.5 milliseconds** per fork*
  - ∴ maximum of (1000/0.5) = 2,000 connections/sec/core
  - ~175 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, …
- Tested on `attu` (3/2/2020)

How Fast is `pthread_create()`?

- See `threadlatency.cc`

- ~**0.05 milliseconds** per thread creation*
  - ~10x faster than `fork()`
  - ∴ maximum of (1000/0.05) = 20,000 connections/sec/core
  - ~2 billion connections/day/core

- Mush 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()
- Tested on `attu` (3/2/2020)

Aside: Thread Pools

- In real servers, we'd like to avoid overhead needed to create a new thread or process for every request
  - We wrote a Thread Pool implementation for you in HW4

- Idea: Thread Pools:
  - Create a fixed set of worker threads when the server starts
  - When a request arrives, add it to a queue of tasks (using locks)
  - Each thread tries to remove a task from the queue (using locks)
  - When a thread is finished with one task, it tries to get a new task from the queue (using locks)