CSE 333

Lecture 20 - intro to concurrency

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Administrivia (1)

HW4 due next Wednesday, 11 pm w/usual late days

- How's it going?

Reminder: watch your late days! (4 max per quarter)

- Check the "late days remaining" entry in the gradebook
- Pop quiz: What happens if you turn in something late and have no late days left?

This week in section: thread programming and pthreads

- One last exercise on threads out after section, due before class next Monday

Administrivia (2)

Course evals are (apparently) online now. Please fill out sometime between now and next week.

Second exam is a week from Friday (last day of class)

- Topic list and old exams on the web now
- Review in sections next week

Goals

Understand concurrency

- why it is useful
- why it is hard

Exposure to concurrent programming styles

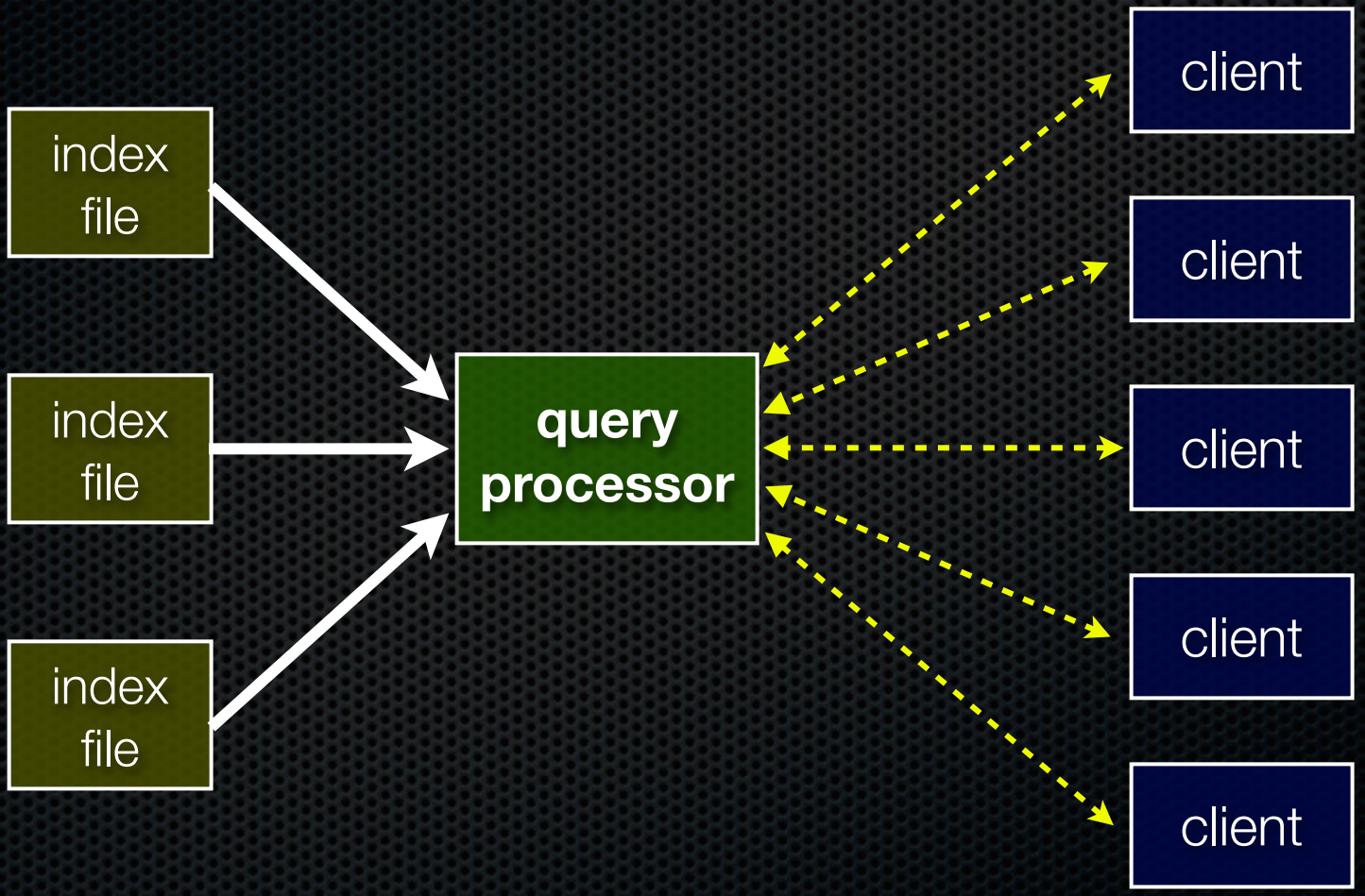
- using multiple threads or multiple processes
- using asynchronous or non-blocking I/O
  - "event-driven programming"

Let's imagine you want to...

...build a web search engine.

- you need a Web index
  - an inverted index (a map from "word" to "list of documents containing the word")
  - probably *sharded* over multiple files
- a query processor
  - accepts a query composed of multiple words
  - looks up each word in the index
  - merges the result from each word into an overall result set

Architecturally

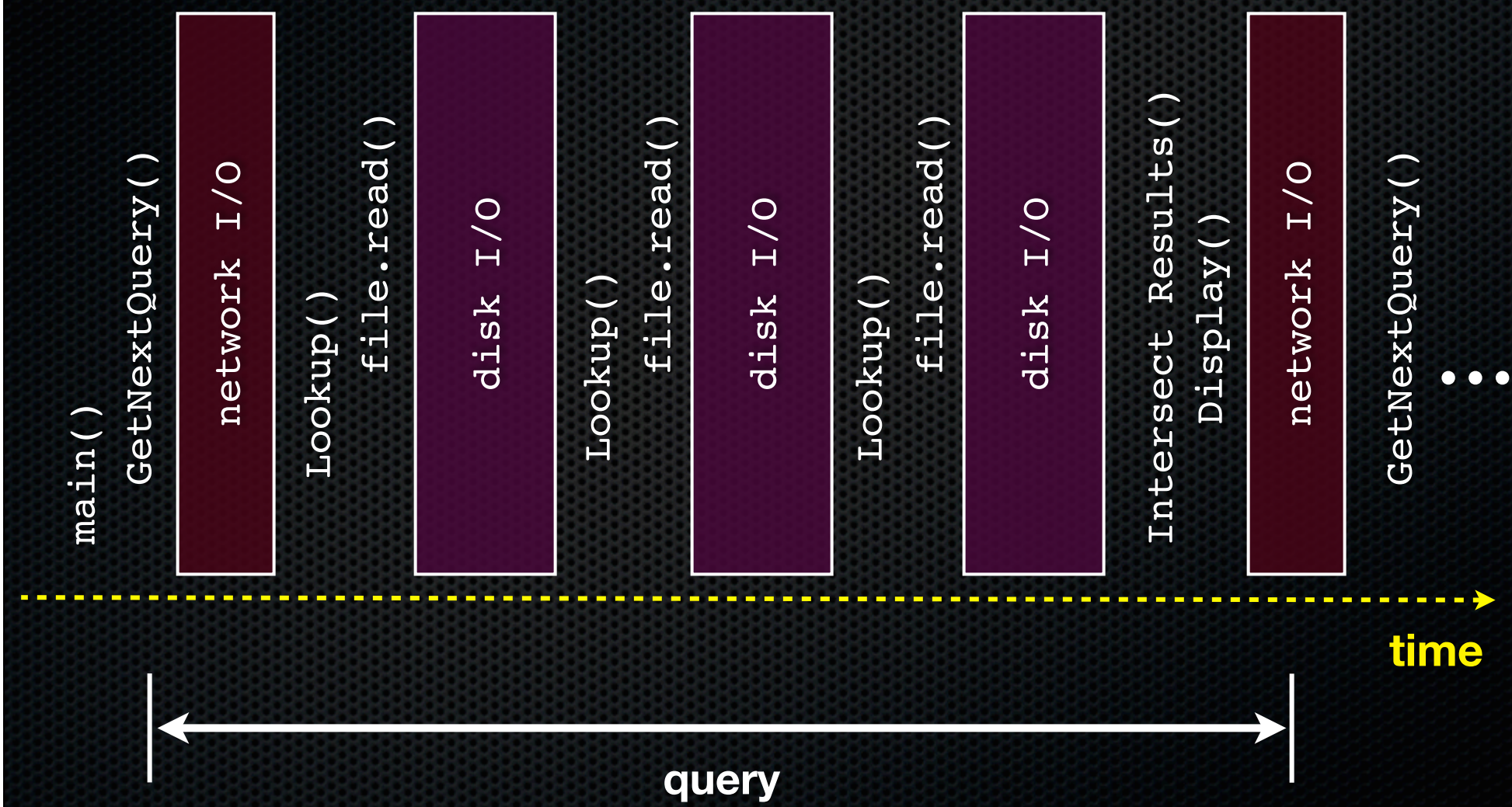


A sequential implementation

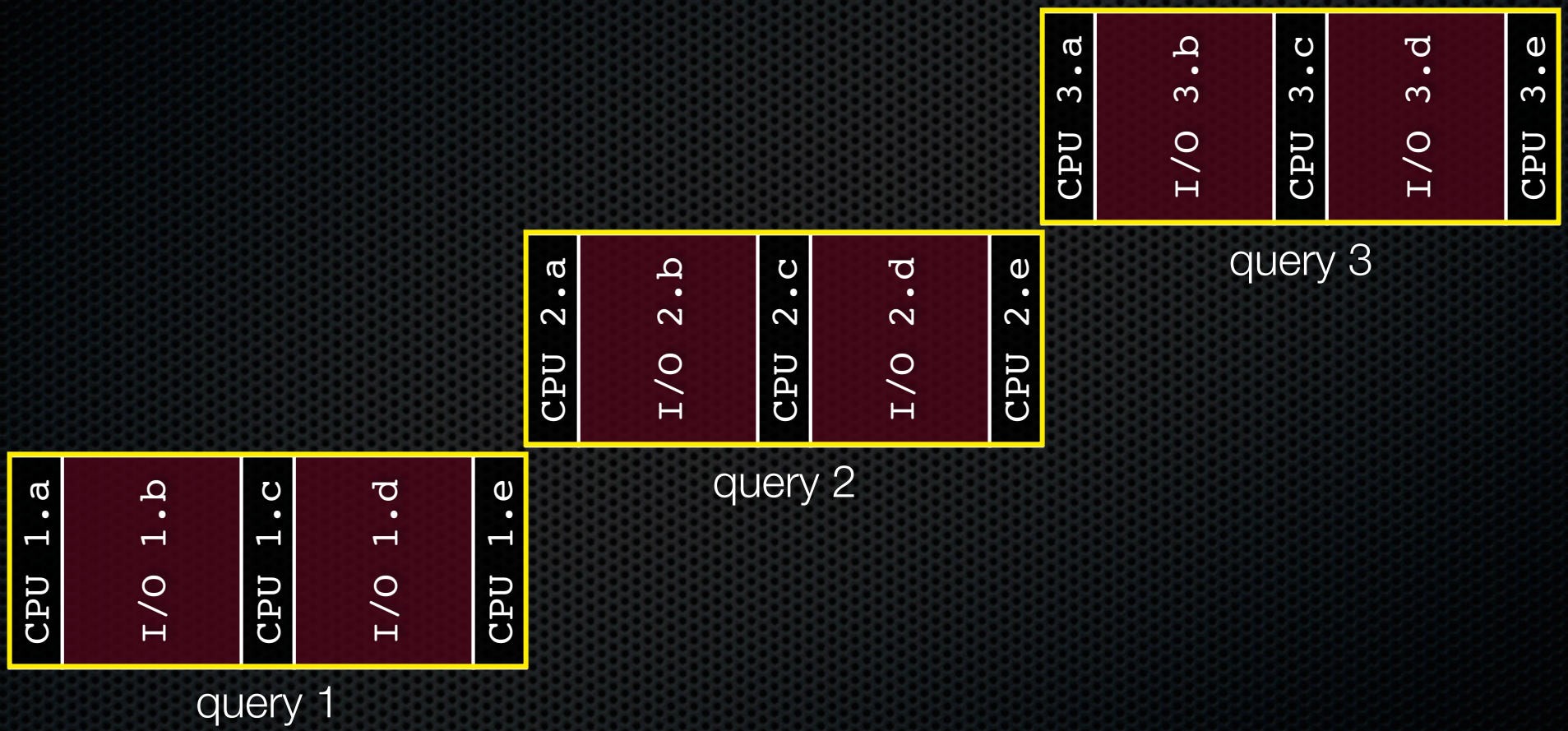
```
doclist Lookup(string word) {
  bucket = hash(word);
  hitlist = file.read(bucket);
  foreach hit in hitlist {
    doclist.append(file.read(hit));
  }
  return doclist;
}

main() {
  while (1) {
    string query_words[] = GetNextQuery();
    results = Lookup(query_words[0]);
    foreach word in query[1..n] {
      results = results.intersect(Lookup(word));
    }
    Display(results);
  }
}
```

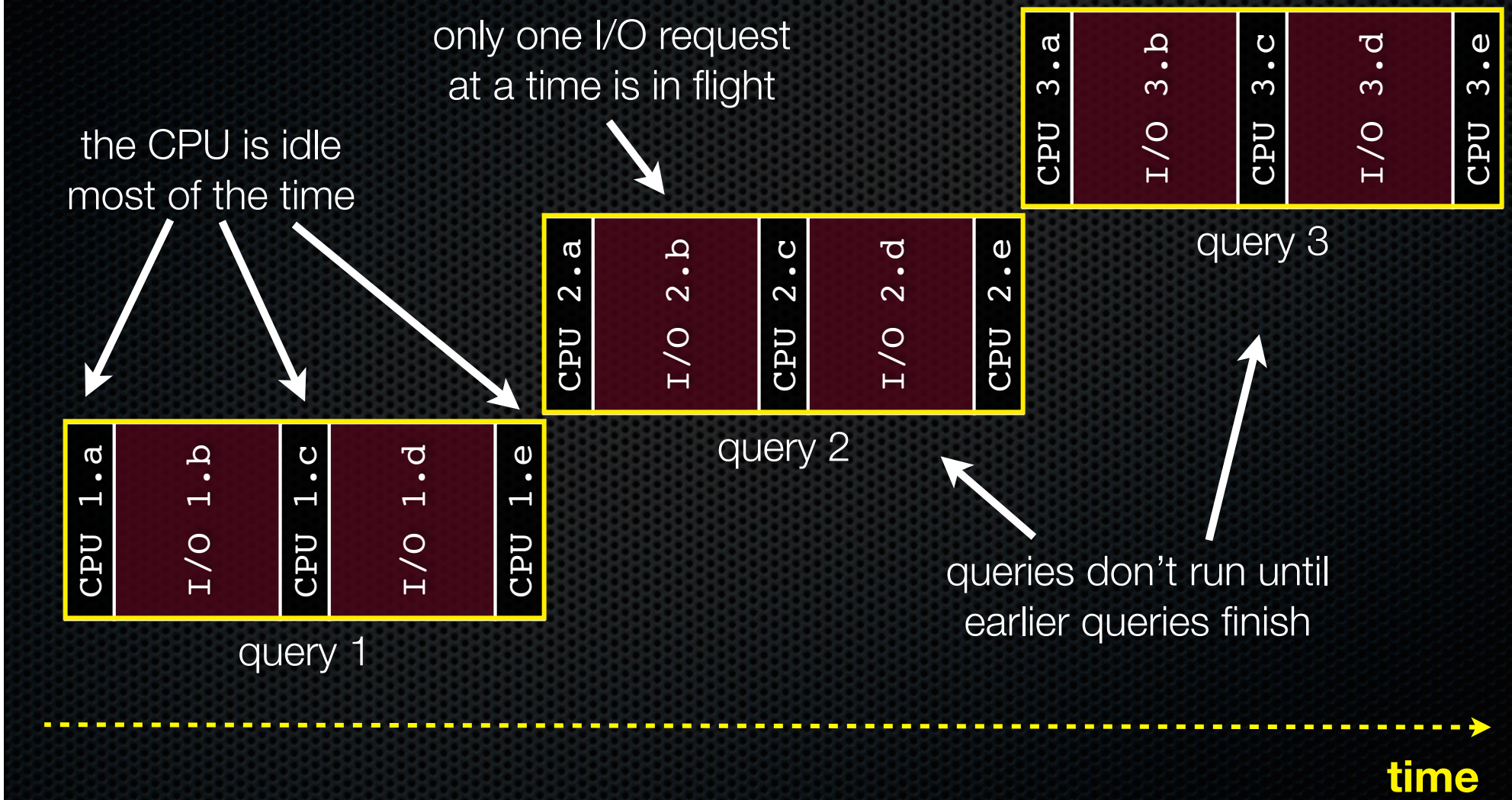
Visually


main()
GetNextQuery()
network I/O
Lookup()
file.read()
disk I/O
Lookup()
file.read()
disk I/O
Lookup()
file.read()
disk I/O
Intersect Results()
Display()
network I/O
GetNextQuery()
• • •
time
query

Simplifying



Simplifying



Sequentiality can be inefficient

Only one query is being processed at a time

- all other queries queue up behind the first one

The CPU is idle most of the time

- it is “blocked” waiting for I/O to complete
  - disk I/O can be very, very slow

At most one I/O operation is in flight at a time

- misses opportunities to speed I/O up
  - separate devices in parallel, better scheduling of single device, ...

What we want...concurrency

A version of the program that executes multiple **tasks** simultaneously

- it could execute multiple **queries** at the same time
  - while one is waiting for I/O, another can be executing on the CPU
- or, it could execute queries one at a time, but issue **IO requests** against different files/disks simultaneously
  - it could read from several different index files at once, processing the I/O results as they arrive

Concurrency != parallelism

- parallelism is when multiple CPUs work simultaneously

One way to do this

Use multiple **threads** or **processes**

- as a query arrives, **fork** a new thread (or process) to handle it
  - the thread reads the query from the console, issues read requests against files, assembles results and writes to the console
  - the thread uses blocking I/O; the thread alternates between consuming CPU cycles and blocking on I/O
- the OS context switches between threads / processes
  - while one is blocked on I/O, another can use the CPU
  - multiple threads' I/O requests can be issued at once

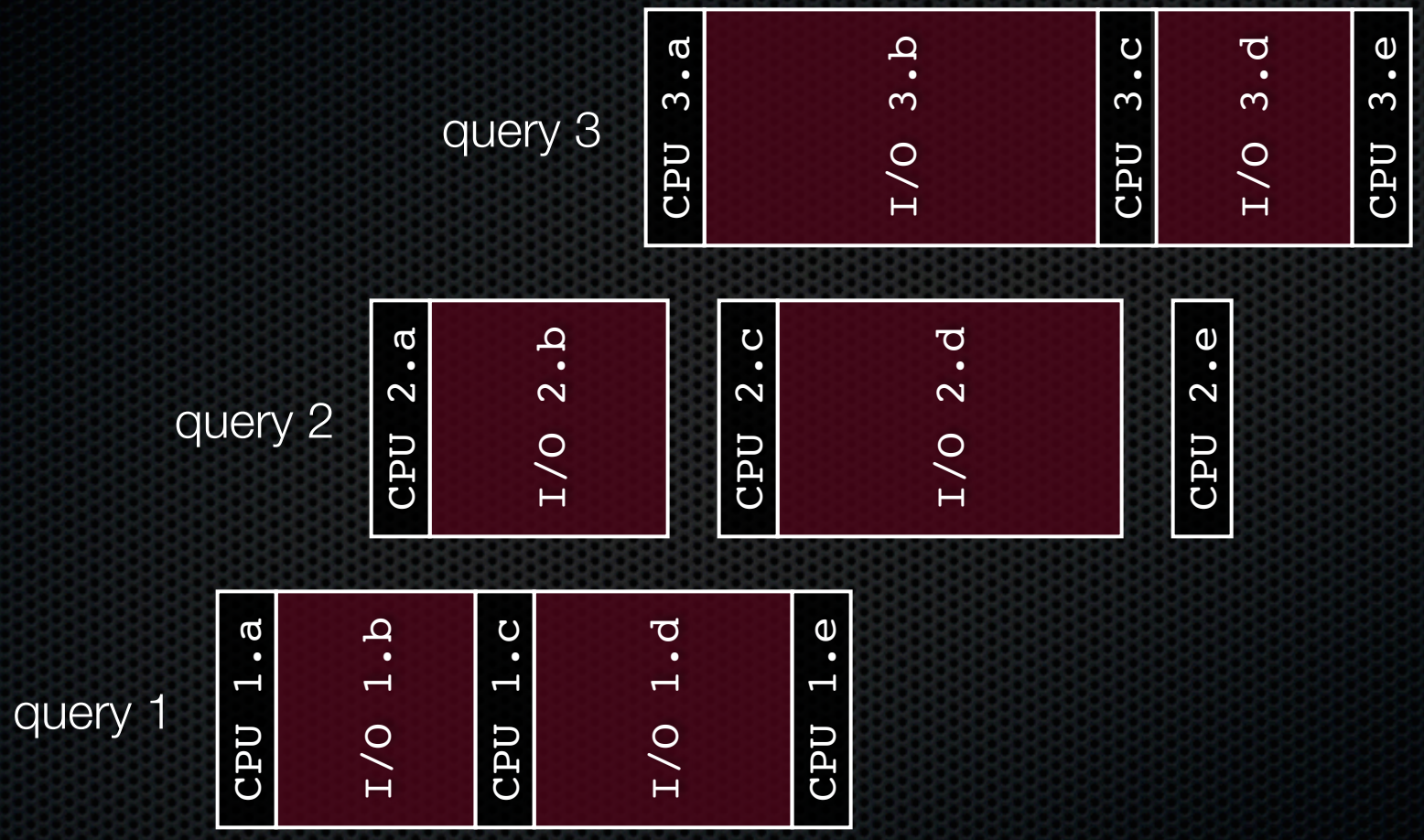
Multithreaded pseudocode

```
main() {
  while (1) {
    string query_words[] = GetNextQuery();
    ForkThread(ProcessQuery());
  }
}
```

```
doclist Lookup(string word) {
  bucket = hash(word);
  hitlist = file.read(bucket);
  foreach hit in hitlist
    doclist.append(file.read(hit));
  return doclist;
}

ProcessQuery() {
  results = Lookup(query_words[0]);
    foreach word in query[1..n] {
      results = results.intersect(Lookup(word));
    }
  Display(results);
}
```

Multithreaded, visually



Whither threads?

Advantages

- you (mostly) write sequential-looking code
- if you have multiple CPUs / cores, threads can run in **parallel**

Disadvantages

- if your threads share data, need locks or other **synchronization**
  - this is very bug-prone and difficult to debug
- threads can introduce overhead
  - lock contention, context switch overhead, and other issues
- need language support for threads

One alternative

Fork **processes** instead of threads

- advantages:
  - no shared memory between processes, so no need to worry about concurrent accesses to shared variables / data structures
  - no need for language support; OS provides “fork”
- disadvantages:
  - more overhead than threads to create, context switch
  - cannot easily share memory between processes, so typically share through the file system

Another alternative

Use **asynchronous** or **non-blocking** I/O

- your program begins processing a query
  - when your program needs to read data to make further progress, it registers interest in the data with the OS, then switches to a different query
  - the OS handles the details of issuing the read on the disk, or waiting for data from the console (or other devices, like the network)
  - when data becomes available, the OS lets your program know
- your program (almost never) blocks on I/O

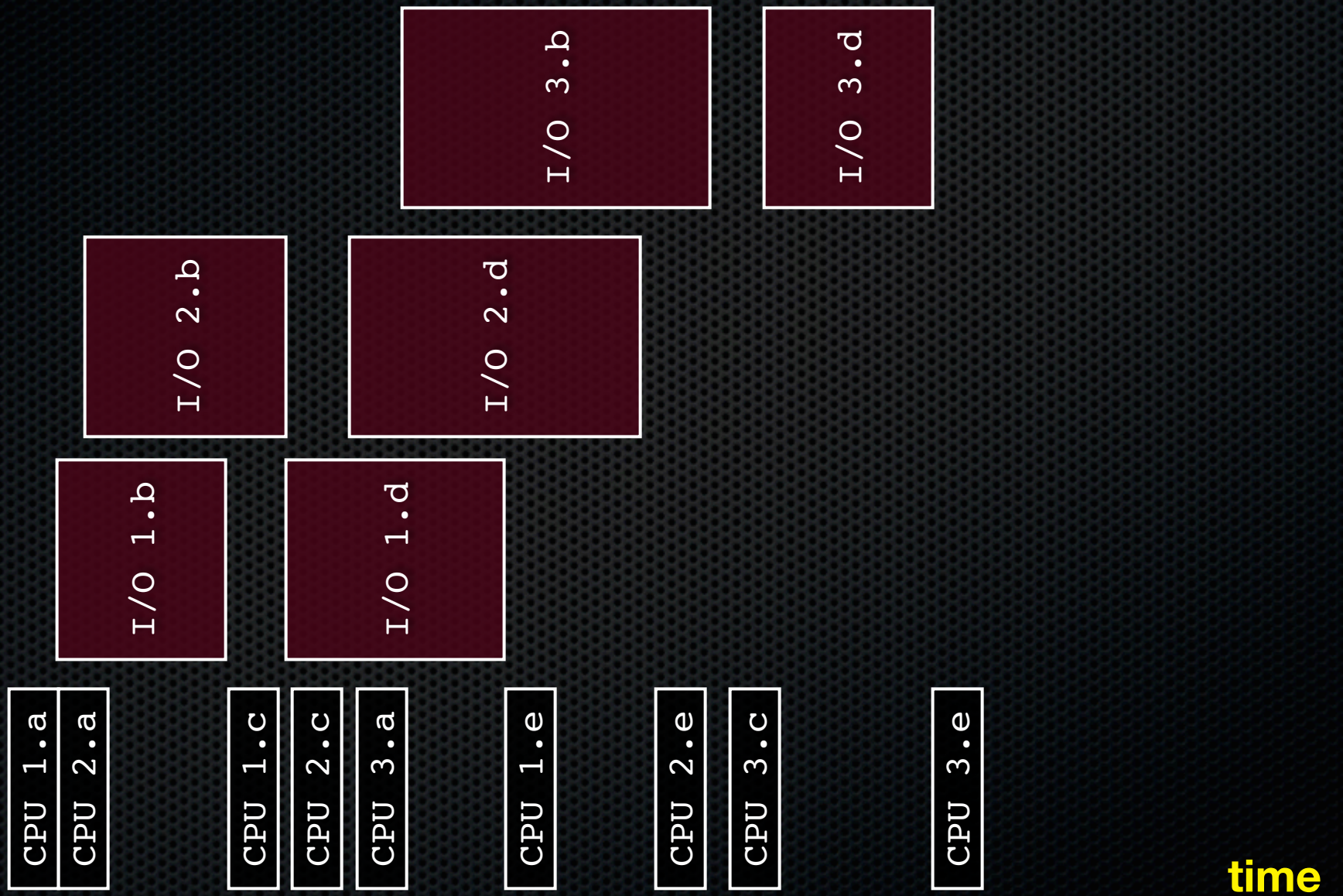
Event-driven programming

Your program is structured as an *event-loop*

```
void dispatch(task, event) {
  switch(task.state) {
    case READING_FROM_CONSOLE:
      query_words = event.data;
      async_read(index, query_words[0]);
      task.state = READING_FROM_INDEX;
      return;
    case READING_FROM_INDEX:
      ...etc.
  }
}

while(1) {
  event = OS.GetNextEvent( );
  task = lookup(event);
  dispatch(task, event);
}
```

Asynchronous, event-driven



Non-blocking vs. asynchronous

Non-blocking I/O (network, console)

- your program enables non-blocking I/O on its fd's
- your program issues read( ), write( ) system calls
  - if the read/write would **block**, the system call returns immediately
- program can ask the OS which fd's are readable/writeable
  - program can choose to block while no fds are ready

Asynchronous I/O (disk)

- program tells the OS to begin reading / writing
  - the "begin_read" or "begin_write" returns immediately
  - when the I/O completes, OS delivers an event to the program

Why the difference?

Non-blocking I/O is for networks

- according to Linux, the disk never **blocks** your program
  - it just delays it
- but, reading from the network can truly block your program
  - a remote computer may wait arbitrarily long before sending data

Asynchronous I/O is for files

- primarily used to hide disk latency
  - asynchronous I/O system calls are messy and complicated :(
  - instead, typically use a threadpool to emulate asynchronous I/O

Whither events?

Advantages

- don't have to worry about locks and "race conditions"
- for some kinds of programs, especially GUIs, leads to a very simple and intuitive program structure
  - one event handler for each UI event

Disadvantages

- can lead to very complex structure for programs that do lots of disk and network I/O
  - sequential code gets broken up into a jumble of small event handlers
  - you have to package up all task state between handlers

One way to think about it

Threaded code:

- each thread executes its task sequentially, and per-task state is naturally stored in the thread's stack
- OS and thread scheduler switch between threads for you

Event-driven code:

- *you* are the scheduler
- you have to bundle up task state into continuations; tasks do not have their own stacks

See you on Friday!