CS 33

Signals Part 3

Reaping: Zombie Elimination

- **Shell must call `waitpid` on each child**
  - **easy for a foreground child**
  - **what about background?**

```
pid_t waitpid(pid_t pid, int *status, int options);
```

  - ***pid* values:**

< −1	**any child process whose process group is |pid|**
−1	**any child process**
0	**any child process whose process group is that of caller**
> 0	**child process whose ID is equal to pid**

  - `wait(&status)` **is equivalent to** `waitpid(-1, &status, 0)`

(continued)

```
pid_t waitpid(pid_t pid, int *status, int options);
```

- ***options*** **are some combination of the following**
  - » **WNOHANG**
    - **return immediately if no child has exited (returns 0)**
  - » **WUNTRACED**
    - **also return if a child has been stopped (suspended)**
  - » **WCONTINUED**
    - **also return if a child has been continued (resumed)**

When to Call `waitpid`

- **Shell reports status only when it is about to display its prompt**
  - **thus sufficient to check on background jobs just before displaying prompt**

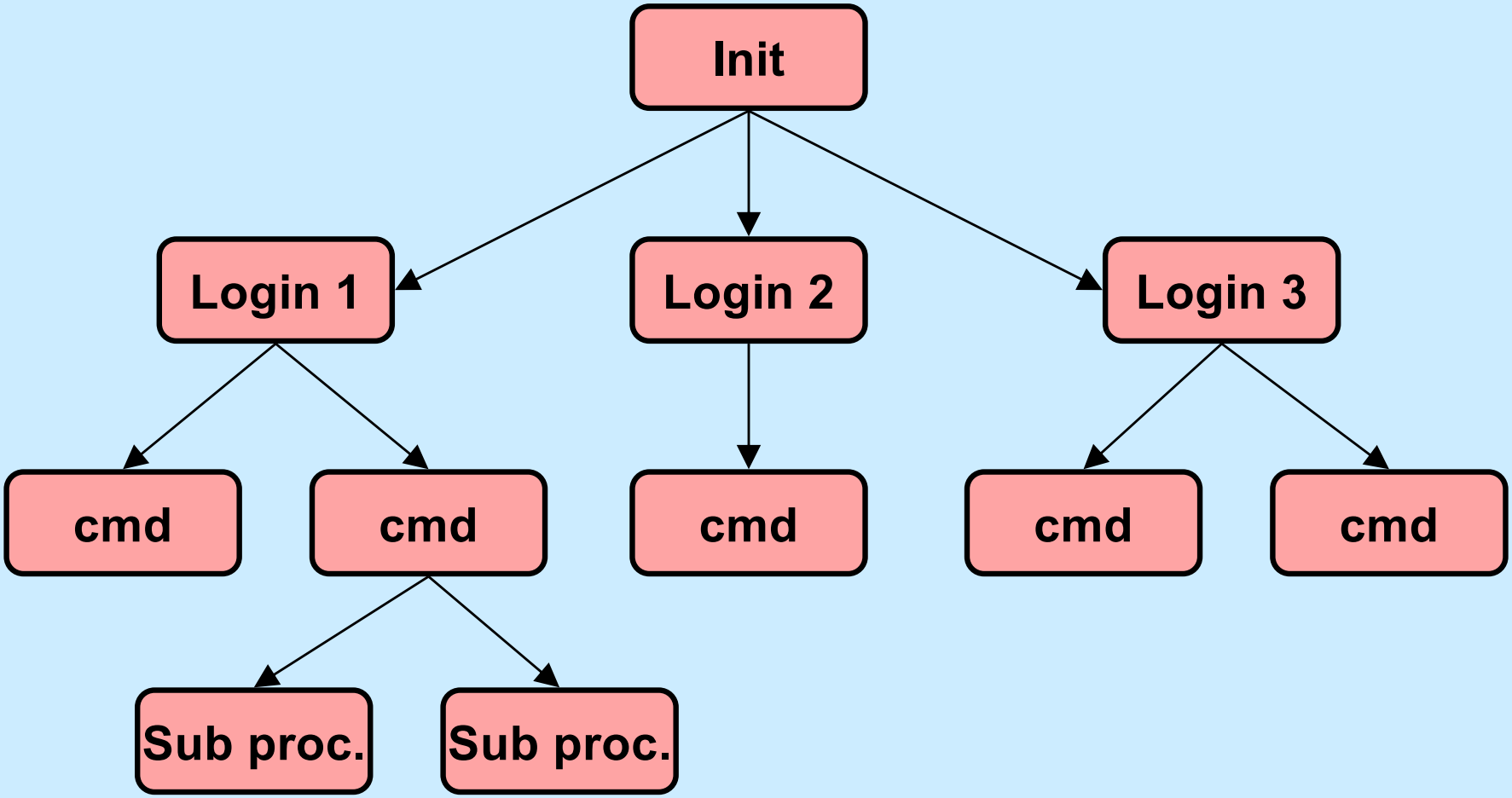
`waitpid` status

- WIFEXITED(*status): 1 if the process terminated normally and 0 otherwise
- WEXITSTATUS(*status): argument to exit
- WIFSIGNALED(*status): 1 if the process was terminated by a signal and 0 otherwise
- WTERMSIG(*status): the signal which terminated the process if it terminated by a signal
- WIFSTOPPED(*status): 1 if the process was stopped by a signal
- WSTOPSIG(*status): the signal which stopped the process if it was stopped by a signal
- WIFCONTINUED(*status): 1 if the process was resumed by SIGCONT and 0 otherwise

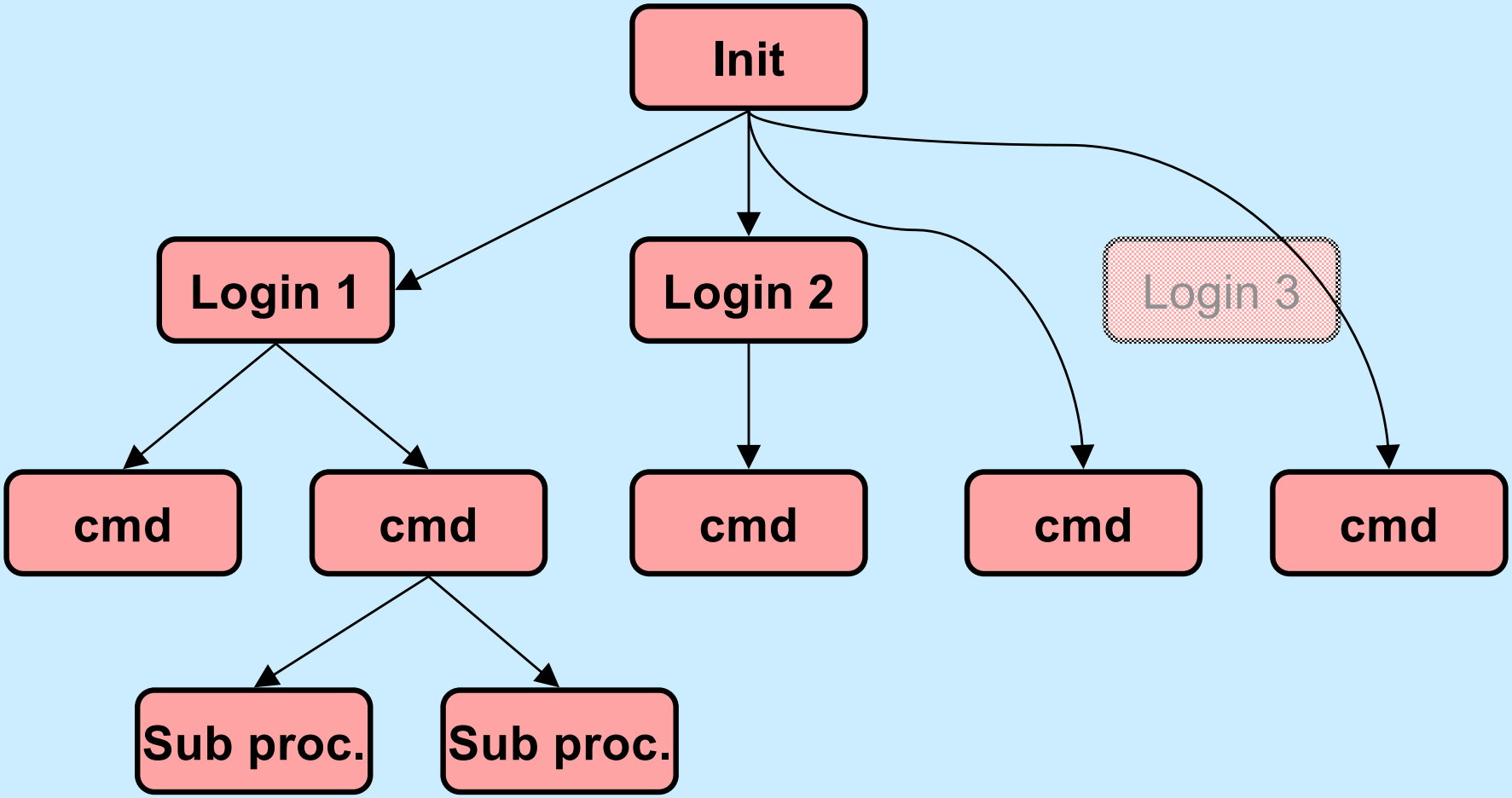
Example (in Shell)

```
int wret, wstatus;
while ((wret = waitpid(-1, &wstatus, WNOHANG|WUNTRACED)) > 0){
  // examine all children who've terminated or stopped
  if (WIFEXITED(wstatus)) {
    // terminated normally
    ...
  }
  if (WIFSIGNALED(wstatus)) {
    // terminated by a signal
    ...
  }
  if (WIFSTOPPED(wstatus)) {
    // stopped
    ...
  }
}
```

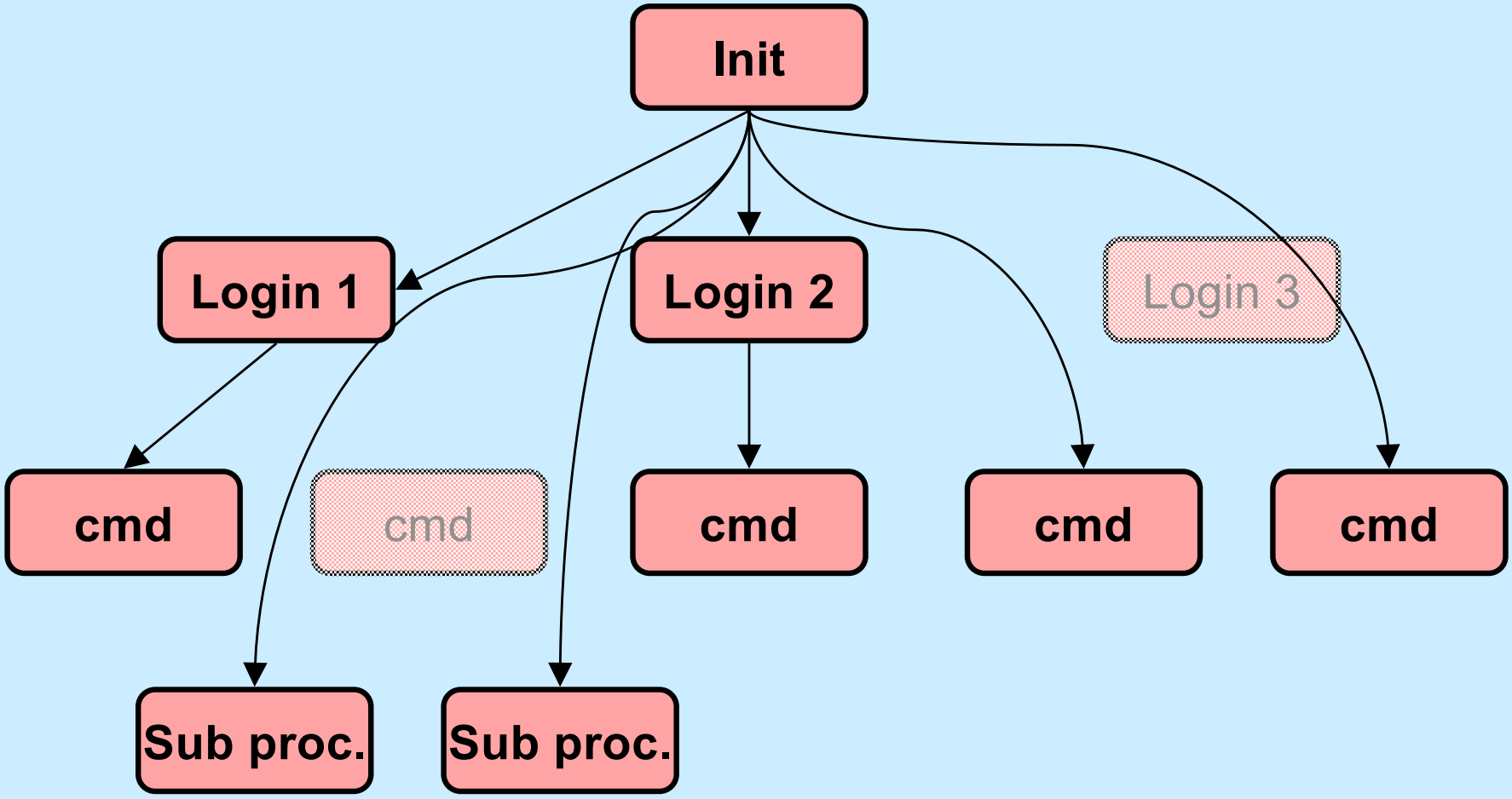
Process Relationships (1)



Process Relationships (2)



Process Relationships (3)



Signals, Fork, and Exec

```
// set up signal handlers ...
if (fork() == 0) {
    // what happens if child gets signal?
    ...
    signal(SIGINT, SIG_IGN);
    signal(SIGFPE, handler);
    signal(SIGQUIT, SIG_DFL);
    execv("new prog", argv, NULL);
    // what happens if SIGINT, SIGFPE,
    // or SIGQUIT occur?
}
```

Signals and System Calls

- What happens if a signal occurs while a process is doing a system call?
  - handler not invoked until just before system call returns to user
    - » system call might terminate early because of signal
  - system call completes
  - signal handler is invoked
  - user code resumed as if the system call has just returned

Signals and Lengthy System Calls

- Some system calls take a long time
  - large I/O transfer
    - » multi-gigabyte read or write request probably done as a sequence of smaller pieces
  - a long wait is required
    - » a read from the keyboard requires waiting for someone to type something
- If signal arrives in the midst of lengthy system call, handler invoked:
  - after current piece is completed
  - after cancelling wait

Interrupted System Calls

- What if a signal is handled before the system call completes?
  - invoke handler, then return from system call prematurely
    - if one or more pieces were completed, return total number of bytes transferred
    - otherwise return “interrupted” error

Summary: Signals Occurring During System Calls

- Either
  - wait for system call to finish, then invoke handler

  or
  - stop system call early, then invoke handler
    - » EINTR error if nothing had been done yet
    - » return partial results if it was underway

Interrupted System Calls: Lengthy Case

```
char buf[BSIZE];
fillbuf(buf);
long remaining = BSIZE;
char *bptr = buf;
while (1){
  long num_xfrd = write(fd,
       bptr, remaining);
  if (num_xfrd == -1) {
    if (errno == EINTR) {
      // interrupted early
      continue;
    }
    perror("big trouble");
    exit(1);
  }
  if (num_xfrd < remaining) {
    /* interrupted after the
       first step */
    remaining -= num_xfrd;
    bptr += num_xfrd;
    continue;
  }
  // success!
  break;
}
```

Asynchronous Signals (1)

```
main( ) {
   void handler(int);
   signal(SIGINT, handler);

   ...   /* long-running buggy code */

}

void handler(int sig) {
   ...   /* clean up */
   exit(1);
}
```

Asynchronous Signals (2)

```
computation_state_t  state;

main( ) {
  void handler(int);

  signal(SIGINT, handler);

  long_running_procedure( );
}
```

```
long_running_procedure( ) {
  while (a_long_time) {
    update_state(&state);
    compute_more( );
  }
}

void handler(int sig) {
  display(&state);
}
```

Asynchronous Signals (3)

```
main( ) {
  void handler(int);

  signal(SIGINT, handler);

  ...  /* complicated program */

  myputs("important message\n");

  ...  /* more program */

}
```

```
void handler(int sig) {

  ...  /* deal with signal */

  myputs("equally important "
      "message\n");
}
```

Asynchronous Signals (4)

```
char buf[BSIZE];
int pos;

void myputs(char *str) {
  int len = strlen(str);
  for (int i=0; i<len; i++, pos++) {
    buf[pos] = str[i];
    if ((buf[pos] == '\n') || (pos == BSIZE-1)) {
      write(1, buf, pos+1);
      pos = -1;
    }
  }
}
```

Async-Signal Safety

- **Which library functions are safe to use within signal handlers?**

- abort
- accept
- access
- aio_error
- aio_return
- aio_suspend
- alarm
- bind
- cfgetispeed
- cfgetospeed
- cfsetispeed
- cfsetospeed
- chdir
- chmod
- chown
- clock_gettime
- close
- connect
- creat
- dup
- dup2
- execle
- execve
- _exit
- fchmod
- fchown
- fcntl
- fdatasync
- fork
- fpathconf
- fstat
- fsync
- ftruncate
- getegid
- geteuid
- getgid
- getgroups
- getpeername
- getpgrp
- getpid
- getppid
- getsockname
- getsockopt
- getuid
- kill
- link
- listen
- lseek
- lstat
- mkdir
- mkfifo
- open
- pathconf
- pause
- pipe
- poll
- posix_trace_event
- pselect
- raise
- read
- readlink
- recv
- recvfrom
- recvmsg
- rename
- rmdir
- select
- sem_post
- send
- sendmsg
- sendto
- setgid
- setpgid
- setsid
- setsockopt
- setuid
- shutdown
- sigaction
- sigaddset
- sigdelset
- sigemptyset
- sigfillset
- sigismember
- signal
- sigpause
- sigpending
- sigprocmask
- sigqueue
- sigsuspend
- sleep
- sockatmark
- socket
- socketpair
- stat
- symlink
- sysconf
- tcdrain
- tcflow
- tcflush
- tcgetattr
- tcgetpgrp
- tcsendbreak
- tcsetattr
- tcsetpgrp
- time
- timer_getoverrun
- timer_gettime
- timer_settime
- times
- umask
- uname
- unlink
- utime
- wait
- waitpid
- write

Quiz 1

Printf is not listed as being async-signal safe. Can it be implemented so that it is?

a) yes, but it would be so complicated, it's not done
b) yes, it can be easily made async-signal safe
c) no, it's inherently not async-signal safe

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Memory Hierarchy II

What's Inside A Disk Drive?

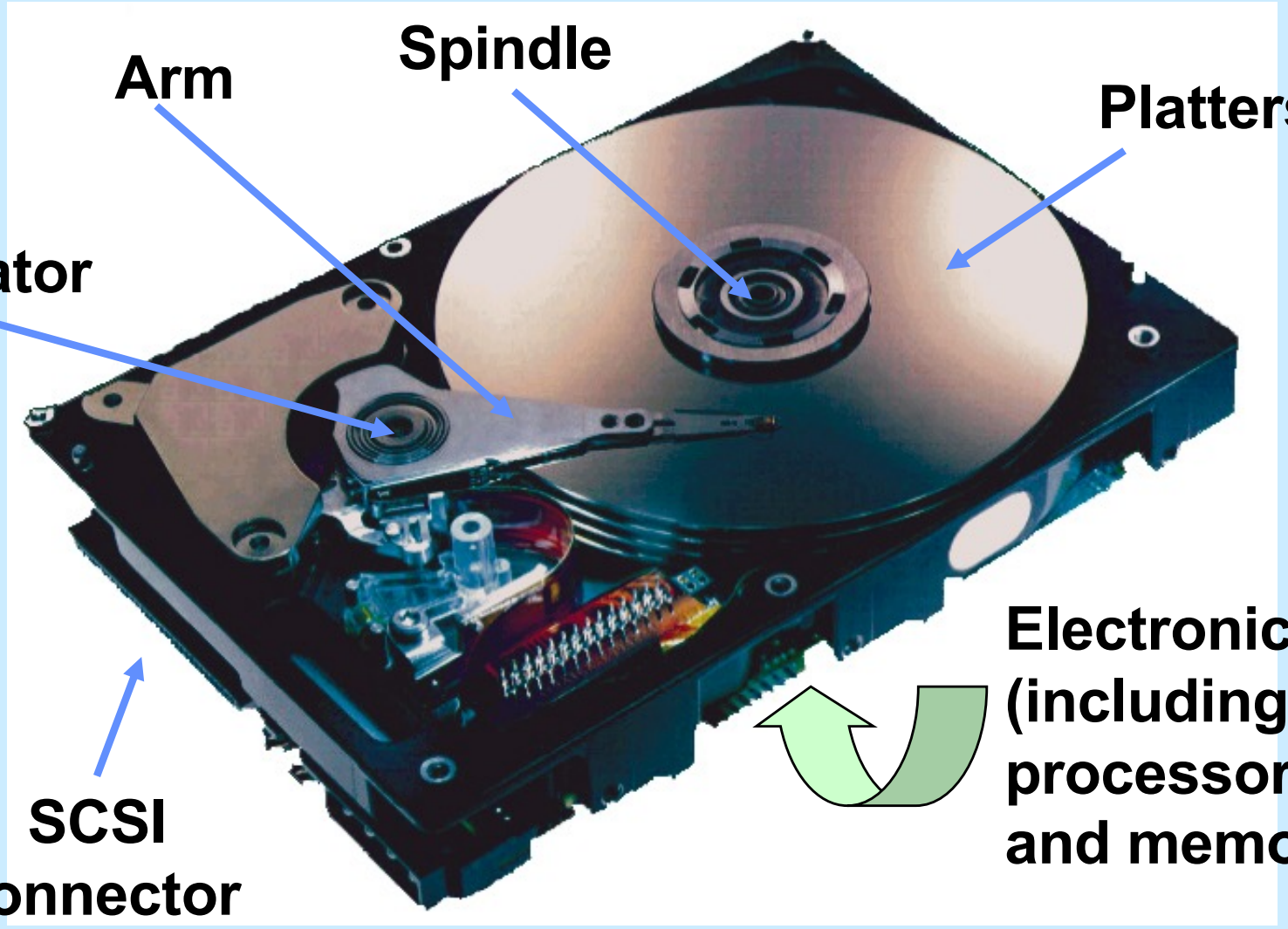
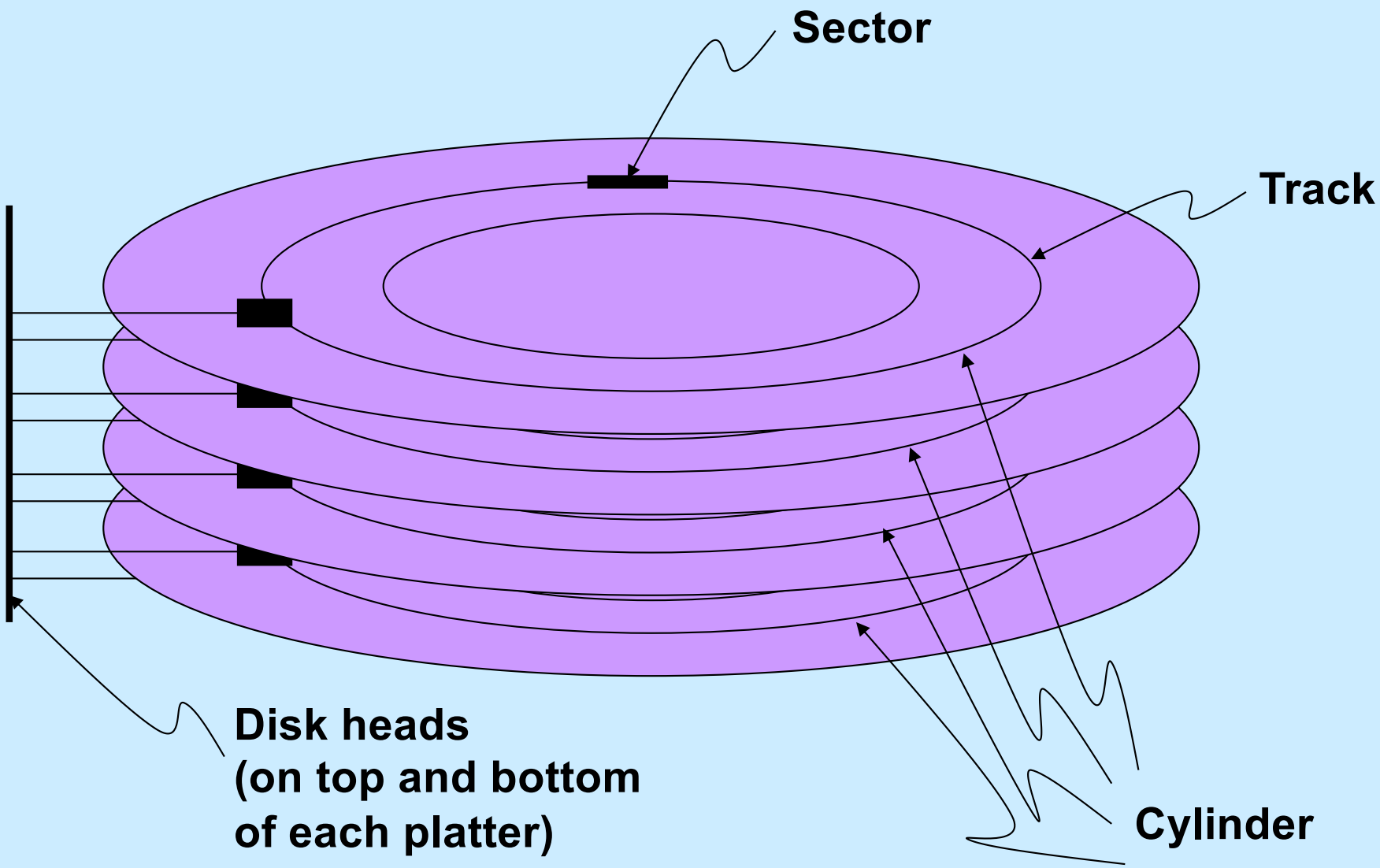


Image courtesy of Seagate Technology

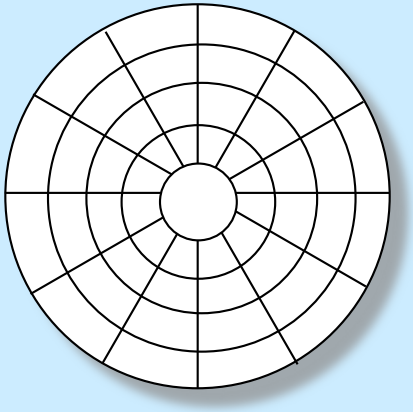
Disk Architecture



Example Disk Drive

Rotation speed	10,000 RPM
Number of surfaces	8
Sector size	512 bytes
Sectors/track	500-1000; 750 average
Tracks/surface	100,000
Storage capacity	307.2 billion bytes
Average seek time	4 milliseconds
One-track seek time	.2 milliseconds
Maximum seek time	10 milliseconds

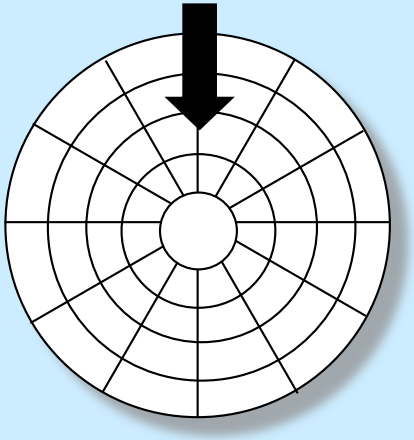
Disk Structure: Top View of Single Platter



Surface organized into tracks

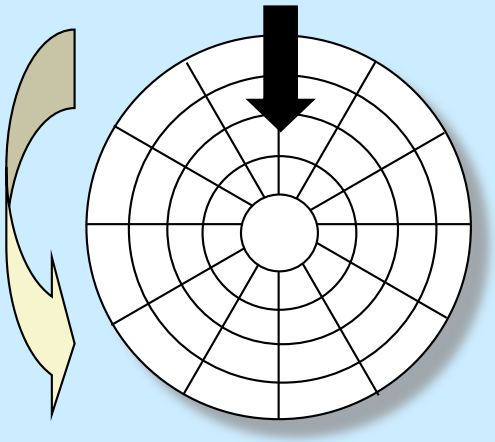
Tracks divided into sectors

Disk Access



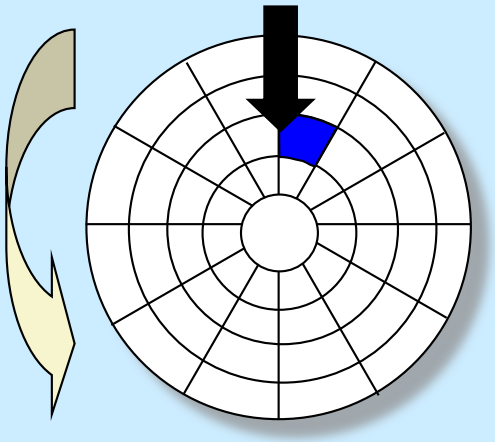
Head in position above a track

Disk Access



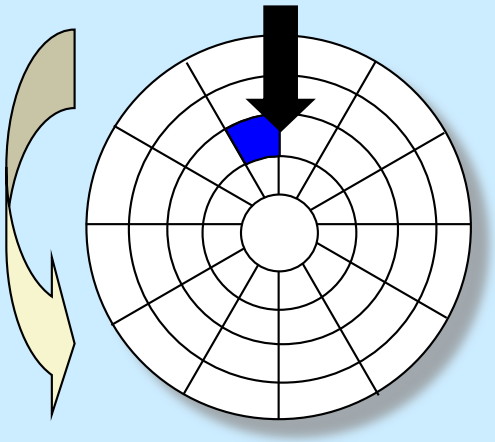
Rotation is counter-clockwise

Disk Access – Read



About to read blue sector

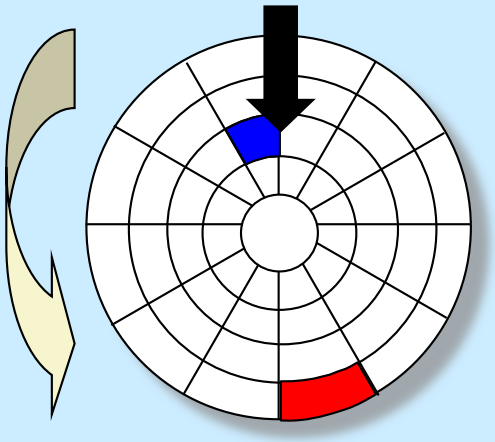
Disk Access – Read



After **BLUE** read

After reading blue sector

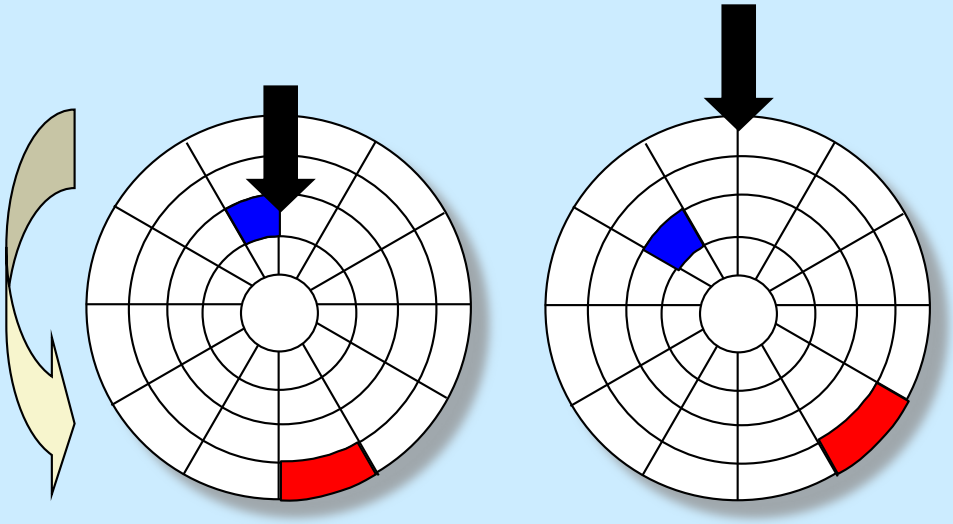
Disk Access – Read



After BLUE read

Red request scheduled next

Disk Access – Seek

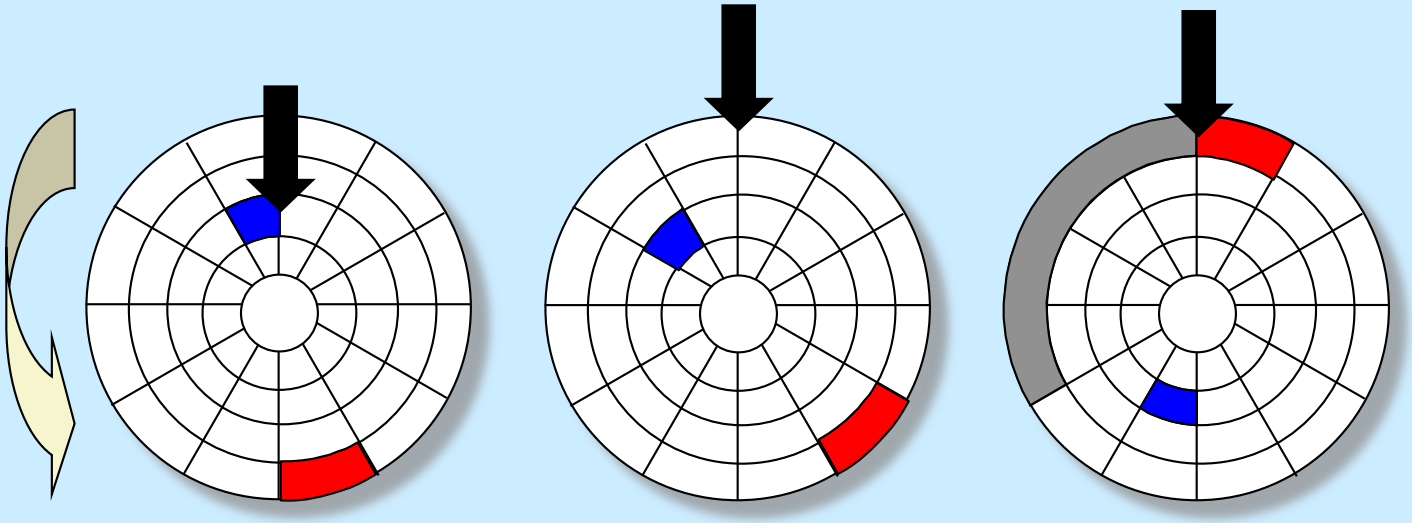


After BLUE read

Seek for RED

Seek to red's track

Disk Access – Rotational Latency



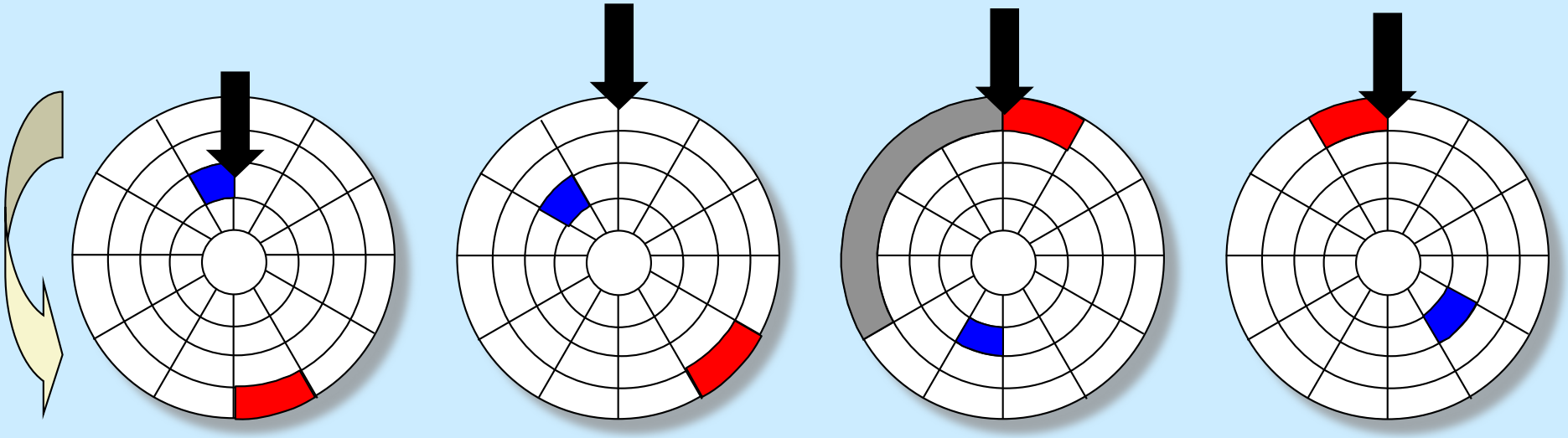
After BLUE read

Seek for RED

Rotational latency

Wait for red sector to rotate around

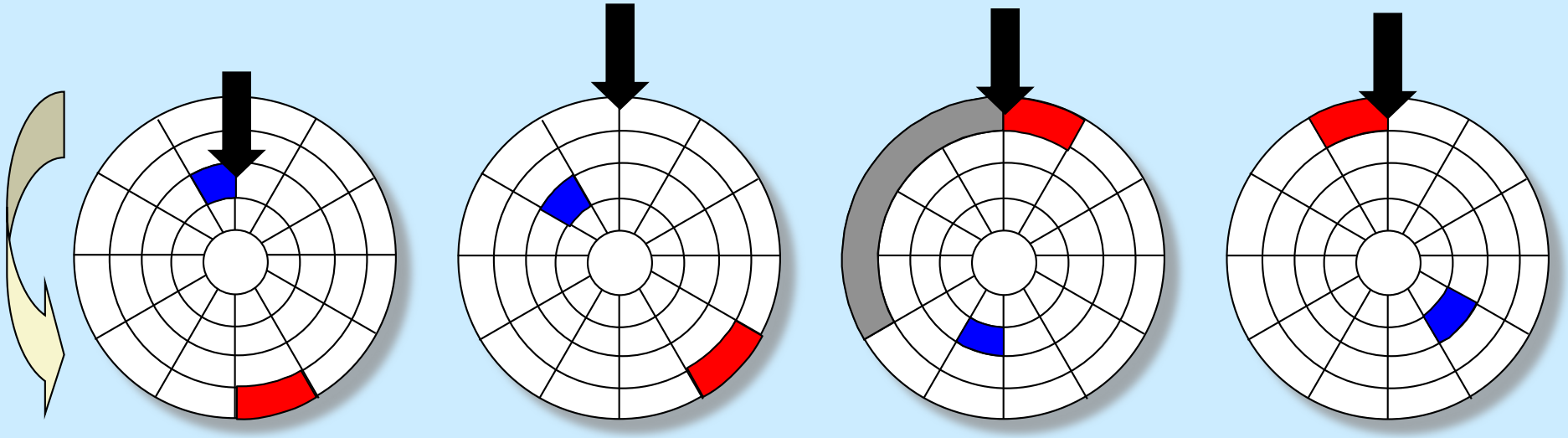
Disk Access – Read



After BLUE read | Seek for RED | Rotational latency | After RED read

Complete read of red

Disk Access – Service Time Components



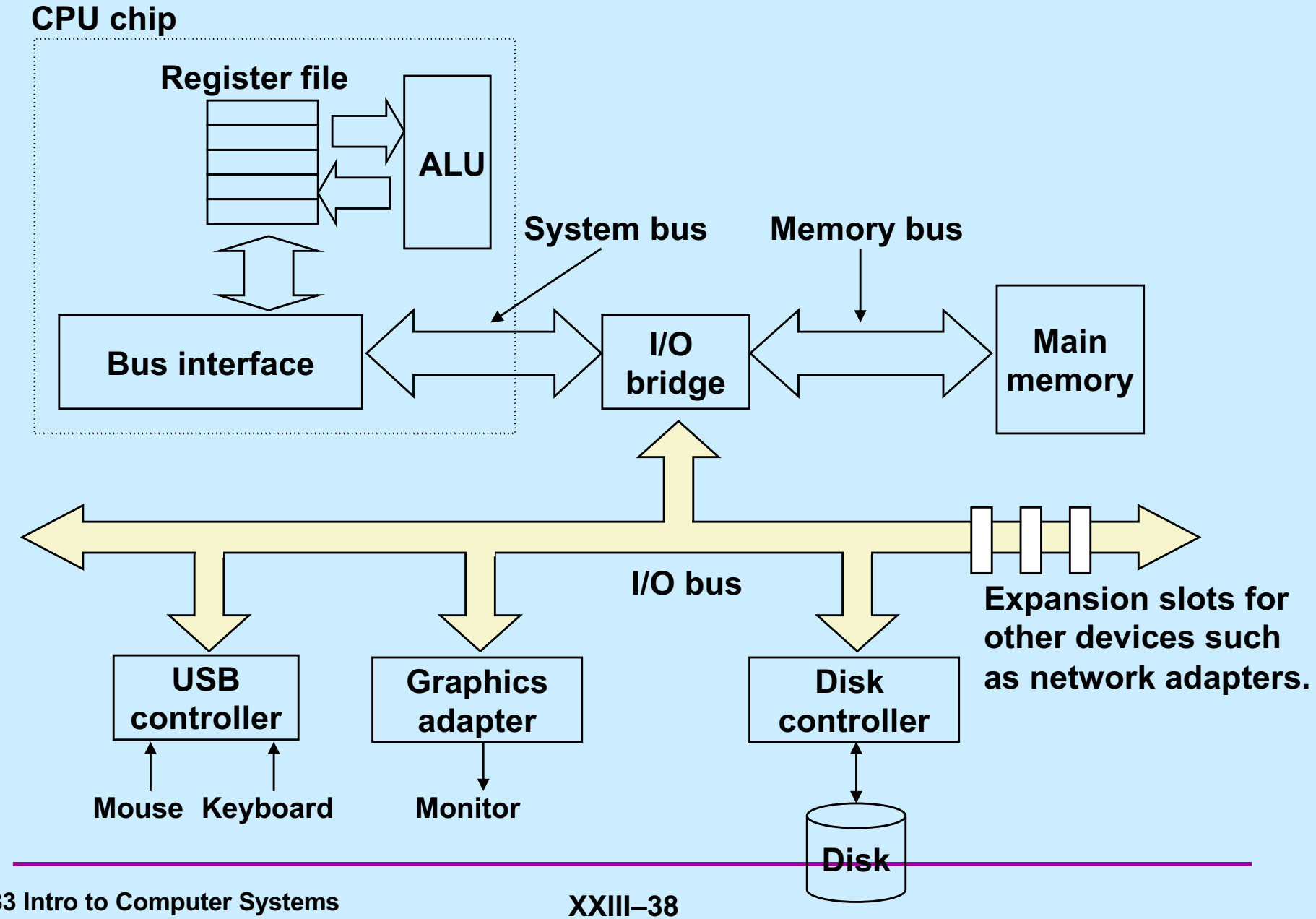
Disk Access Time

- Average time to access some target sector approximated by :
  - Taccess = Tavg seek + Tavg rotation + Tavg transfer
- Seek time (Tavg seek)
  - time to position heads over cylinder containing target sector
  - typical Tavg seek is 3–9 ms
- Rotational latency (Tavg rotation)
  - time waiting for first bit of target sector to pass under r/w head
  - typical rotation speed R = 7200 RPM
  - Tavg rotation = 1/2 x 1/R x 60 sec/1 min
- Transfer time (Tavg transfer)
  - time to read the bits in the target sector
  - Tavg transfer = 1/R x 1/(avg # sectors/track) x 60 secs/1 min

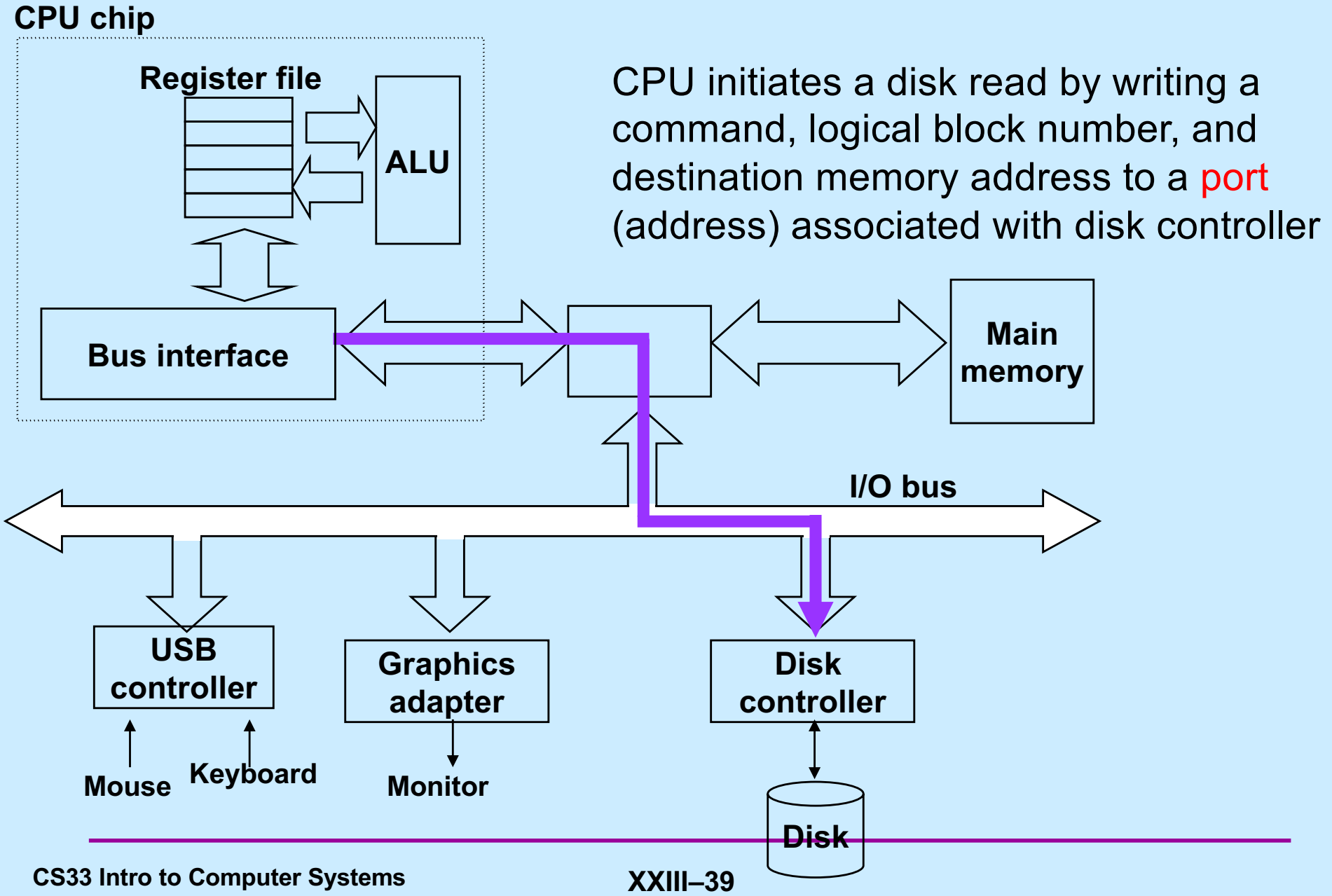
Disk Access Time Example

- Given:
  - rotational rate = 7,200 RPM
  - average seek time = 9 ms
  - avg # sectors/track = 600
- Derived:
  - Tavg rotation = 1/2 x (60 secs/7200 RPM) x 1000 ms/sec = 4 ms
  - Tavg transfer = 60/7200 RPM x 1/600 sects/track x 1000 ms/sec = 0.014 ms
  - Taccess = 9 ms + 4 ms + 0.014 ms
- Important points:
  - access time dominated by seek time and rotational latency
  - first bit in a sector is the most expensive, the rest are free
  - SRAM access time is about 4 ns/doubleword, DRAM about 60 ns
    - » disk is about 40,000 times slower than SRAM
    - » 2,500 times slower than DRAM

I/O Bus

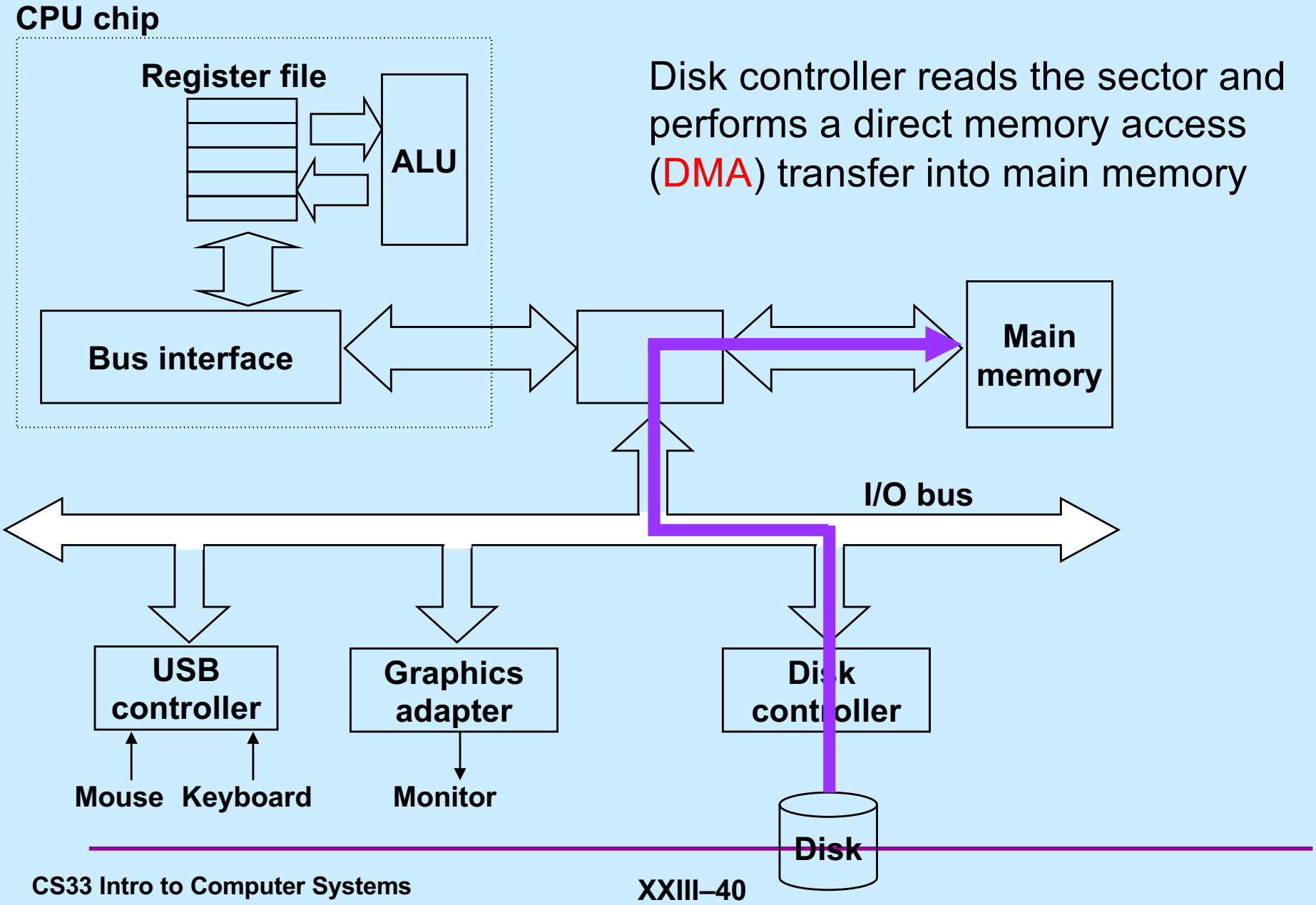

CPU chip
Register file
ALU
System bus
Memory bus
Bus interface
I/O bridge
Main memory
I/O bus
Expansion slots for other devices such as network adapters.
USB controller
Graphics adapter
Disk controller
Mouse
Keyboard
Monitor
Disk

Reading a Disk Sector (1)



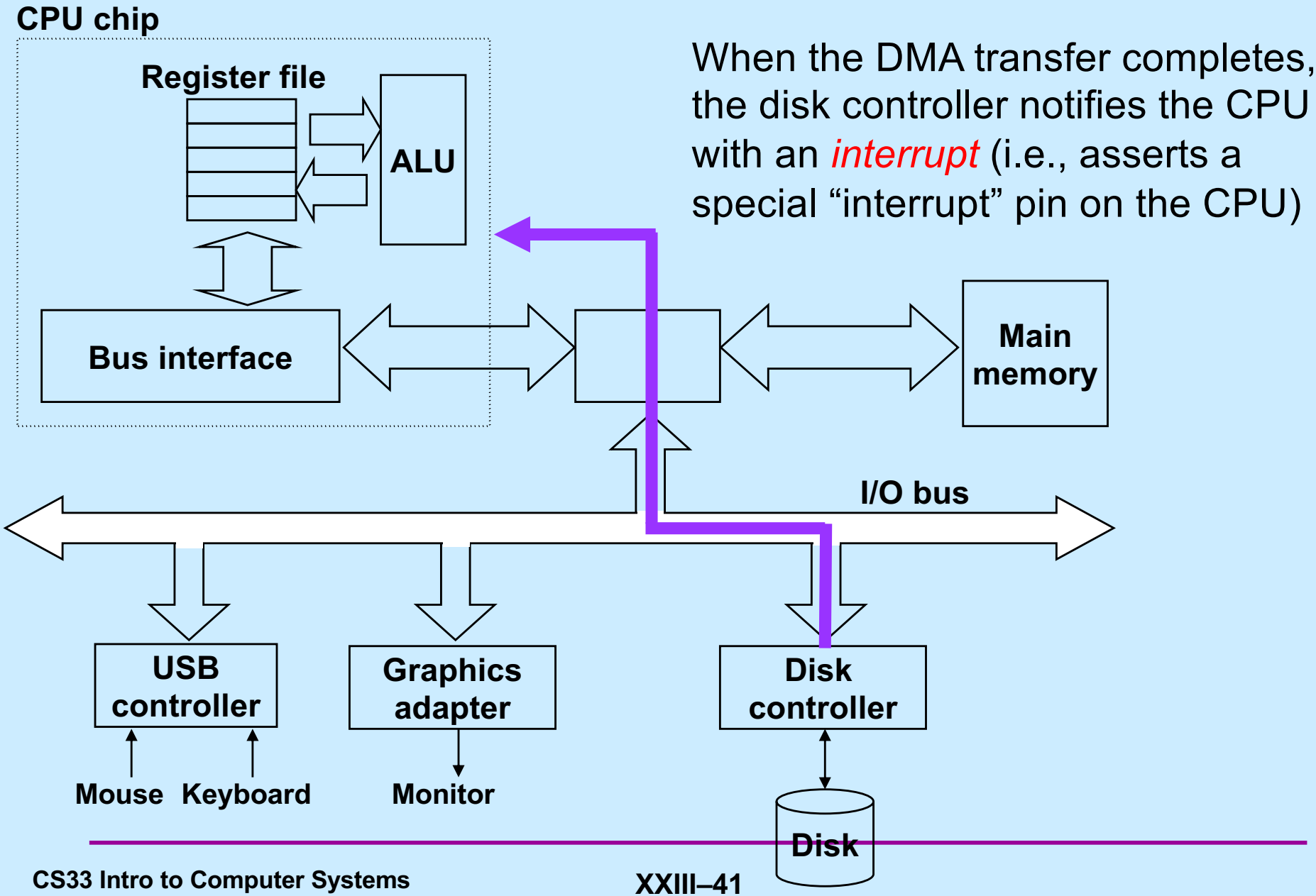
CPU initiates a disk read by writing a command, logical block number, and destination memory address to a port (address) associated with disk controller

Reading a Disk Sector (2)



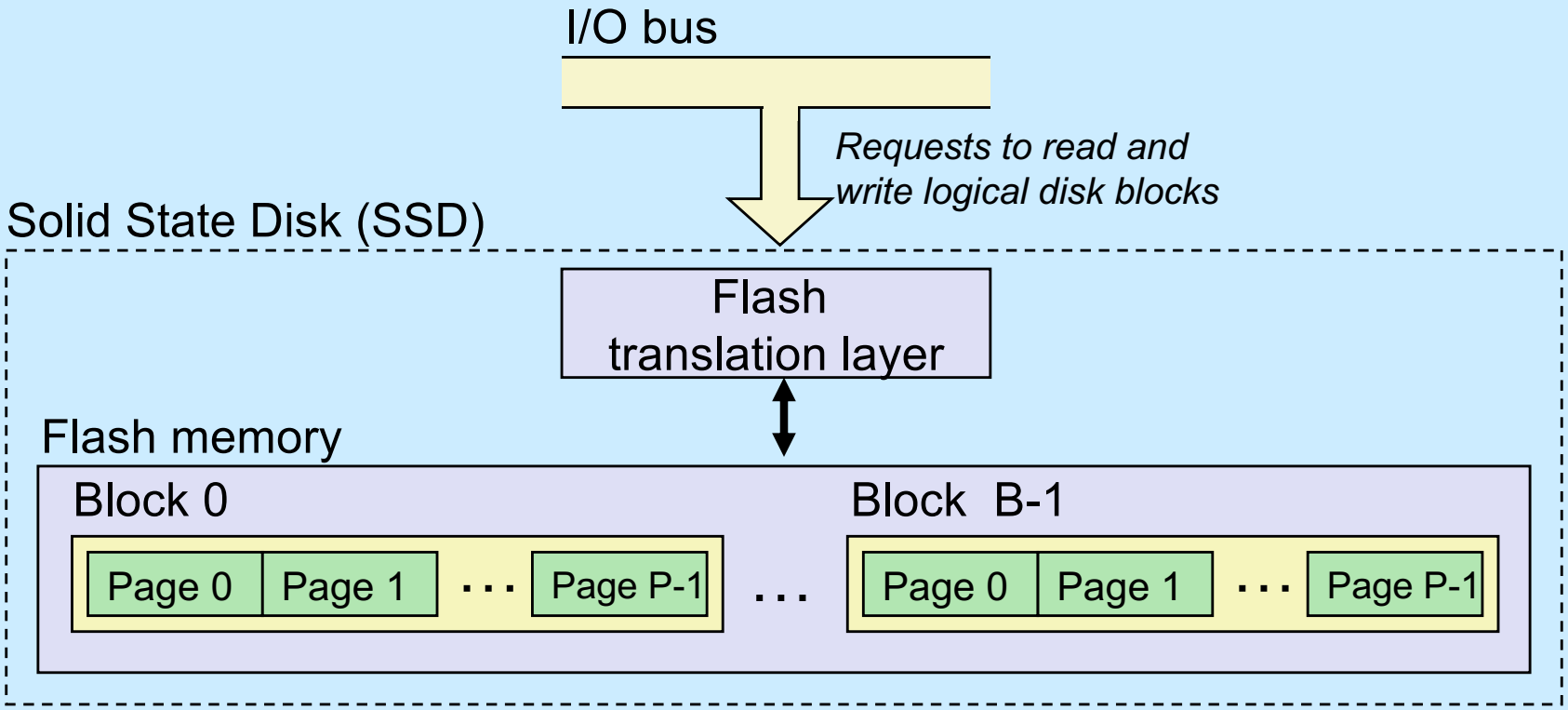
Disk controller reads the sector and performs a direct memory access (DMA) transfer into main memory

Reading a Disk Sector (3)



When the DMA transfer completes, the disk controller notifies the CPU with an *interrupt* (i.e., asserts a special "interrupt" pin on the CPU)

Solid-State Disks (SSDs)



- **Pages: 512KB to 4KB; blocks: 32 to 128 pages**
- **Data read/written in units of pages**
- **Page can be written only after its block has been erased**
- **A block wears out after 100,000 repeated writes**

SSD Performance Characteristics

Sequential read tput	250 MB/s	Sequential write tput	170 MB/s
Random read tput	140 MB/s	Random write tput	14 MB/s
Random read access	30 us	Random write access	300 us

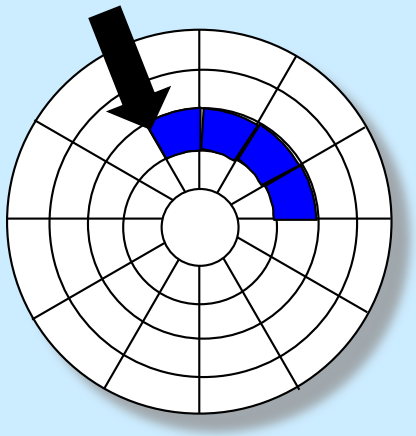
- Why are random writes so slow?
  - erasing a block is slow (around 1 ms)
  - modifying a page triggers a copy of all useful pages in the block
    - » find a used block (new block) and erase it
    - » write the page into the new block
    - » copy other pages from old block to the new block

SSD Tradeoffs vs Rotating Disks

- Advantages
  - no moving parts → faster, less power, more rugged
- Disadvantages
  - have the potential to wear out
    - » mitigated by "wear-leveling logic" in flash translation layer
    - » e.g. Intel X25 guarantees 1 petabyte (10^{15} bytes) of random writes before they wear out
  - in 2010, about 100 times more expensive per byte
  - in 2017, about 6 times more expensive per byte
  - in 2023, about 1-1.5 times more expensive per byte
- Applications
  - smart phones, laptops, desktops

Reading a File on a Rotating Disk

- Suppose the data of a file are stored on consecutive disk sectors on one track
  - this is the best possible scenario for reading data quickly
    - » single seek required
    - » single rotational delay
    - » all sectors read in a single scan



Quiz 2

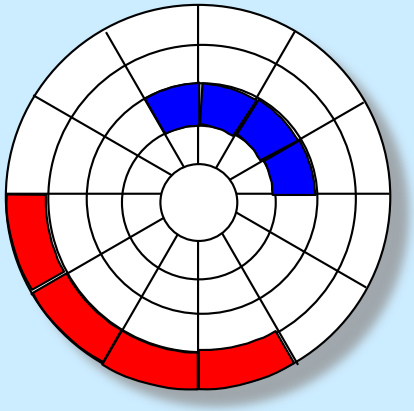
We have two files on the same (rotating) disk. The first file's data resides in consecutive sectors on one track, the second in consecutive sectors on another track. It takes a total of *t* seconds to read all of the first file then all of the second file.

Now suppose the files are read concurrently, perhaps a sector of the first, then a sector of the second, then the first, then the second, etc. Compared to reading them sequentially, this will take

a) less time

b) about the same amount of time (within a factor of 2)

c) much more time



Quiz 3

We have two files on the same solid-state disk. Each file's data resides in consecutive blocks. It takes a total of *t* seconds to read all of the first file then all of the second file.

Now suppose the files are read concurrently, perhaps a block of the first, then a block of the second, then the first, then the second, etc. Compared to reading them sequentially, this will take

a) **less time**

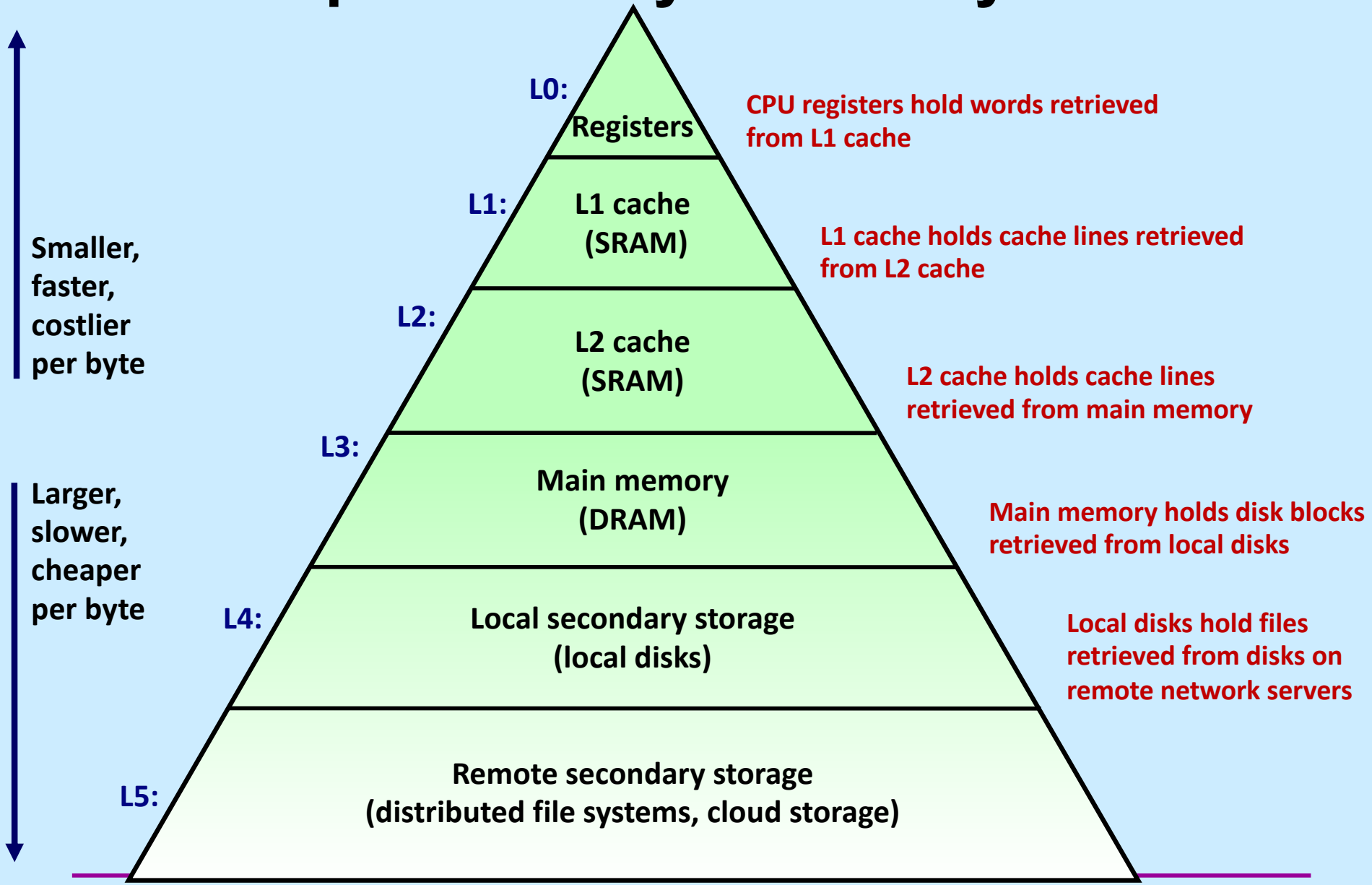
b) **about the same amount of time (within a factor of 2)**

c) **much more time**

Memory Hierarchies

- Some fundamental and enduring properties of hardware and software:
  - fast storage technologies cost more per byte, have less capacity, and require more power (heat!)
  - the gap between CPU and main memory speed is widening
  - well written programs tend to exhibit good locality
- These fundamental properties complement each other beautifully
- They suggest an approach for organizing memory and storage systems known as a memory hierarchy

An Example Memory Hierarchy



Putting Things Into Perspective ...

- Reading from:
  - ... the L1 cache is like grabbing a piece of paper from your desk (3 seconds)
  - ... the L2 cache is picking up a book from a nearby shelf (14 seconds)
  - ... main system memory (DRAM) is taking a 4-minute walk down the hall to talk to a friend
  - ... a hard drive is like leaving the building to roam the earth for one year and three months

Disks Are Still Important

- Cheap
  - cost/byte less than SSDs
- (fairly) Reliable
  - data written to a disk is likely to be there next year
- Sometimes fast
  - data in consecutive sectors on a track can be read quickly
- Sometimes slow
  - data in randomly scattered sectors takes a long time to read

Abstraction to the Rescue

- Programs don't deal with sectors, tracks, and cylinders
- Programs deal with *files*
  - maze.c rather than an ordered collection of sectors
  - OS provides the implementation

Implementation Problems

- Speed
  - use the hierarchy
    - » copy files into RAM, copy back when done
  - optimize layout
    - » put sectors of a file in consecutive locations
  - use parallelism
    - » spread file over multiple disks
    - » read multiple sectors at once

Implementation Problems

- Reliability
  - computer crashes
    - » what you thought was safely written to the file never made it to the disk — it's still in RAM, which is lost
    - » worse yet, some parts made it back to disk, some didn't
      - you don't know which is which
      - on-disk data structures might be totally trashed
  - disk crashes
    - » you had backed it up … yesterday
  - you screw up
    - » you accidentally delete the entire directory containing your shell 1 implementation

Implementation Problems

- Reliability solutions
  - computer crashes
    - » transaction-oriented file systems
    - » on-disk data structures always in well defined states
  - disk crashes
    - » files stored redundantly on multiple disks
  - you screw up
    - » file system automatically keeps "snapshots" of previous versions of files