CMSC 433 – Programming Language Technologies and Paradigms

Concurrency

What is Concurrency?

- Simple definition
  - *Sequential* programs have one thread of control
  - *Concurrent* programs have many

Concurrency vs. Parallelism

- Concurrency
  - Logically simultaneous processing
  - Does not imply multiple physical processing elements (PPEs)
- Parallelism
  - Physically simultaneous processing
  - Involves multiple PPEs and/or independent devices
- Will ignore this distinction from here on out

Benefits of Concurrency

- Exploiting multiple processors
  - Processor speeds are not increasing as fast as they used to
  - Multi-CPU machines becoming standard
  - Can’t take full advantage of multiple CPUs without concurrent software

Benefits of Concurrency (cont.)

- For some problems, concurrency provides a very natural programming model
- For example, problems involving many, largely independent actors or actions, e.g.,
  - Simulations
  - Compute servers

Benefits of Concurrency (cont.)

- Isolates and simplifies tasks
- For instance servers typically interact with multiple clients
  - High performance, non-concurrent implementations have to multiplex (switch between) clients
  - Concurrent servers can handle each client in a separate thread of control

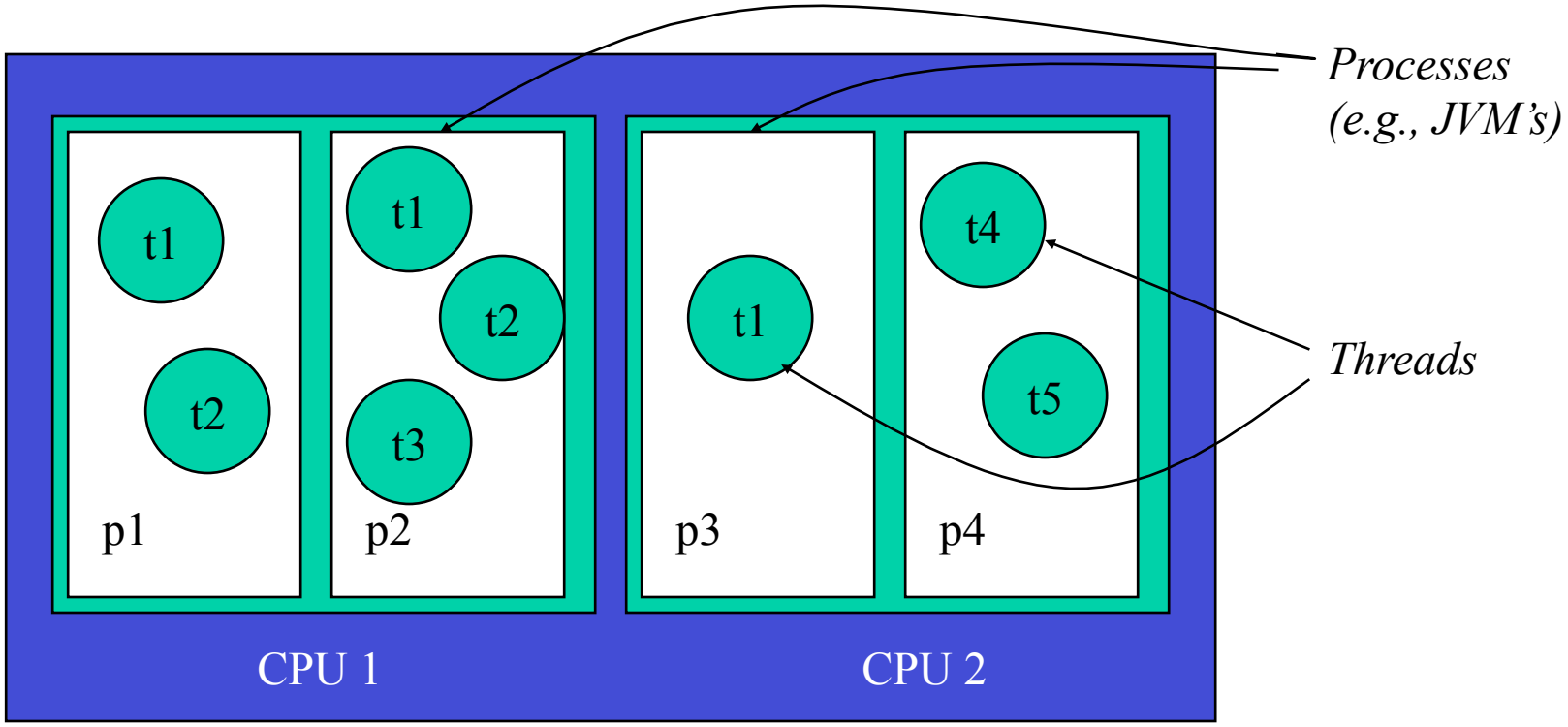
Concurrency Risks

- Concurrency is notoriously complex
  - Behaviors can depend on the relative timing of concurrent events
  - Bugs can be hard to reproduce
- Over the next few weeks we will discuss
  - What these difficulties are
  - How we can build correct concurrent systems

Implementing Concurrent Systems

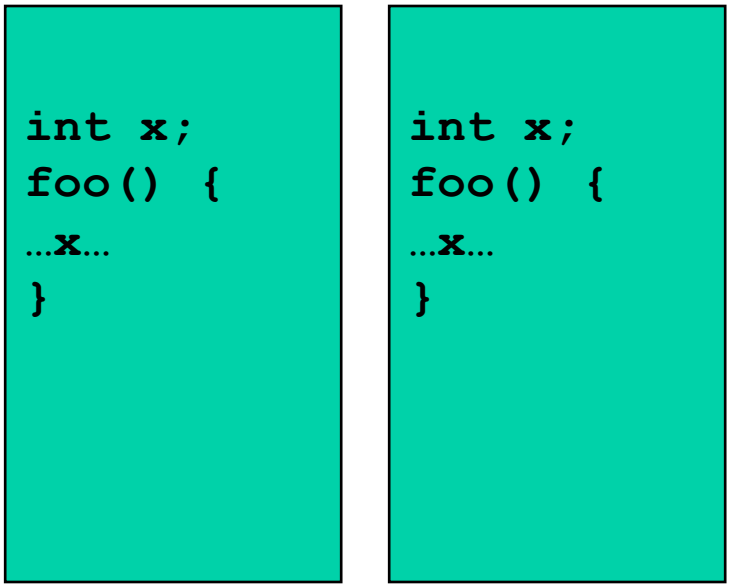
- Overview
- What are threads?
  - Conceptual view
  - Java implementation
- Thread concerns
  - *Safety* and *Liveness*
- Threading design patterns

Computation Abstractions

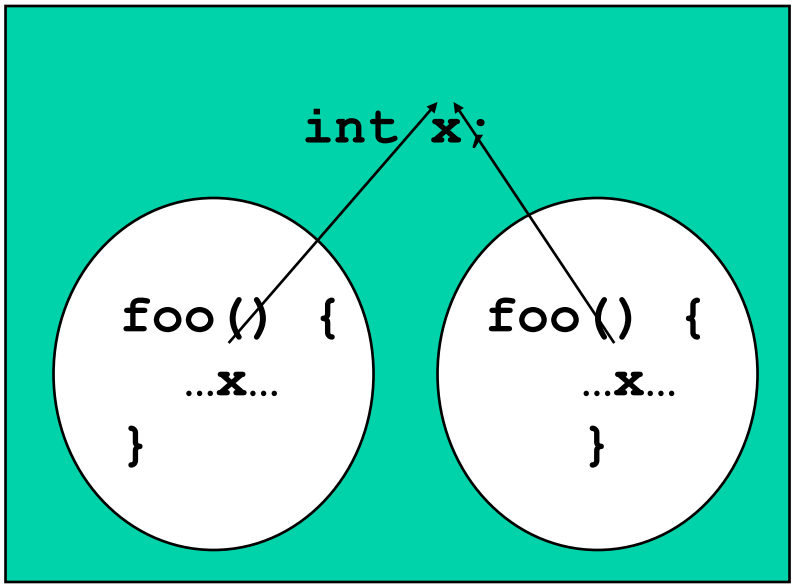


A computer

Processes vs. Threads



Processes do not share data



Threads within a process share data

So, What Is a Thread?

- **Conceptually**: It's a concurrent computation occurring within a process
- **Implementation view**: It's a program counter and a stack. The heap and static area are shared among all threads
- All programs have at least one thread
  - *aka* the main thread

Why Multiple Threads?

- Performance:
  - Parallelism on multiprocessors
  - Concurrency of computation and I/O
- Can easily express some programming paradigms
  - Event processing
  - Simulations
- Keep computations separate, as in an OS
  - But - why not use processes?

Why Not Multiple Threads?

- Complexity:
  - Dealing with safety, liveness, composition
  - The root of the problem is shared, mutable state
- Overhead
  - Higher resource usage
  - May limit performance compared to direct event processing
    - context switching, locking, etc.

Programming Threads

- Threads are available in many languages
  - C, C++, Objective Caml, Java, SmallTalk …
- Threads are part of the Java language specification
- In other languages (*e.g.*, C), threads are a platform specific add-on

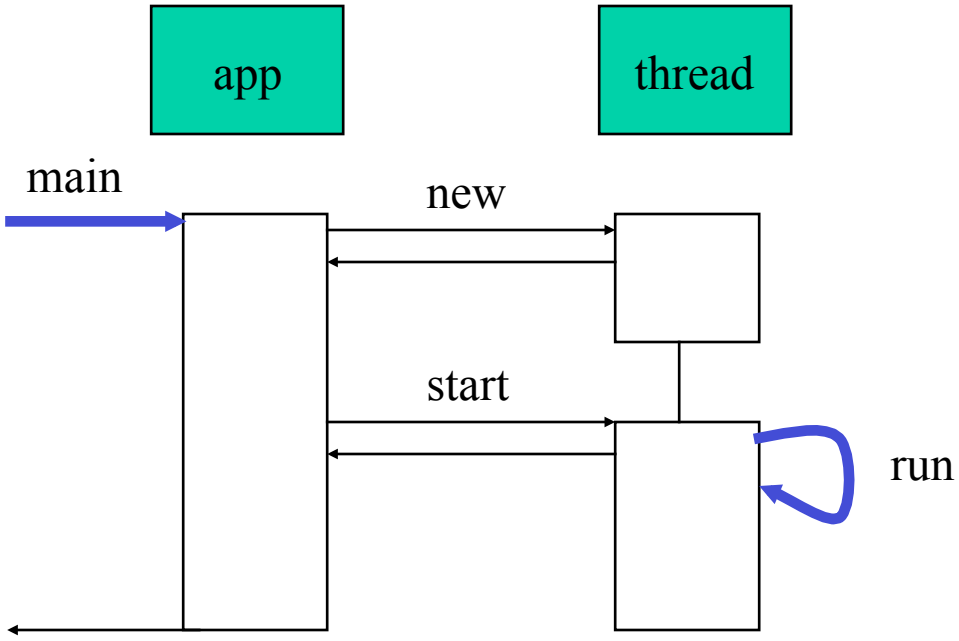
Java Threads

- Every application has at least one thread
  - The "main" thread, started by the JVM to run the application's **main()** method
- That code can create other threads
  - Explicitly, by using the **Thread** class
  - Implicitly, by calling libraries that create threads as a consequence
    - RMI, AWT/Swing, Applets, etc.

Java Threads: Creation

- To explicitly create a thread
  - Instantiate a **Thread** object
    - An object of class Thread *or* a subclass of Thread
  - Invoke the object's **start()** method
    - This will start executing the **Thread**'s **run()** method concurrently with the current thread
  - Thread terminates when its run() method returns

Java Threads: Creation



Running Example: Alarms

- Goal: set alarms that will be triggered in the future
  - Input: Time t (seconds) and message m
  - Result: We'll see m printed after t seconds

Example: Synchronous alarms

```
while (true) {
  System.out.print("Alarm> ");

  // read user input
  String line = b.readLine();
  parseInput(line); // sets timeout

  // wait (in msecs)
  try {
    Thread.sleep(timeout * 1000);
  } catch (InterruptedException e) { }

  // fire alarm
 System.out.println("(" + timeout + ") " + msg);
}
```


ThreadTestSync.java

Making It Threaded (1)

```
public class AlarmThread extends Thread {
  private String msg = null;
  private int timeout = 0;
  public AlarmThread(String msg, int time) {
    this.msg = msg; this.timeout = time;
  }
  public void run() {
    try { // wait
      Thread.sleep(timeout * 1000);
    } catch (InterruptedException e) { }

    // fire alarm
    System.out.println("(" + timeout + ") " + msg);
  }
}
```


ThreadTestThreaded.java

Making It Threaded (2)

```
while (true) {
  System.out.print("Alarm> ");

  // read user input
  String line = b.readLine();
  parseInput(line);
  if (msg != null) {
    // start alarm thread
    Thread t = new AlarmThread(msg, timeout);
    t.start();
  }
}
```


ThreadTestThreaded.java

Alternative: The **Runnable** Interface

- Extending **Thread** prohibits a different parent
- Instead implement **Runnable**
  - Declares that the class has a **void run()** method
- Construct a **Thread** from the **Runnable**
  - Constructor **Thread(Runnable** target)
  - Constructor **Thread(Runnable** target, **String** name)

Thread Example Revisited

```
public class AlarmRunnable implements Runnable {
  private String msg = null;
  private int timeout = 0;

  public AlarmRunnable(String msg, int time) {
    this.msg = msg;this.timeout = time;
  }

  public void run() {
    try {
      Thread.sleep(timeout * 1000);
    } catch (InterruptedException e) { }
    System.out.println("(" + timeout + ") " + msg);
  }
}
```


ThreadTestRunnable.java

Thread Example Revisited (2)

```
while (true) {
  System.out.print("Alarm> ");

  // read user input
  String line = b.readLine();
  parseInput(line);
  if (m != null) {
    // start alarm thread
    Thread t = new Thread(new AlarmRunnable(m,timeout));
    t.start();
  }
}
```


ThreadTestRunnable.java

Notes: Passing Parameters

- **run()** doesn't take parameters
- Can "pass parameters" to the new thread by storing them as private fields
  - In a Thread subclass or in a **Runnable** object
  - Example: the msg and timeout fields in the AlarmThread and AlarmRunnable classes

Thread Scheduling

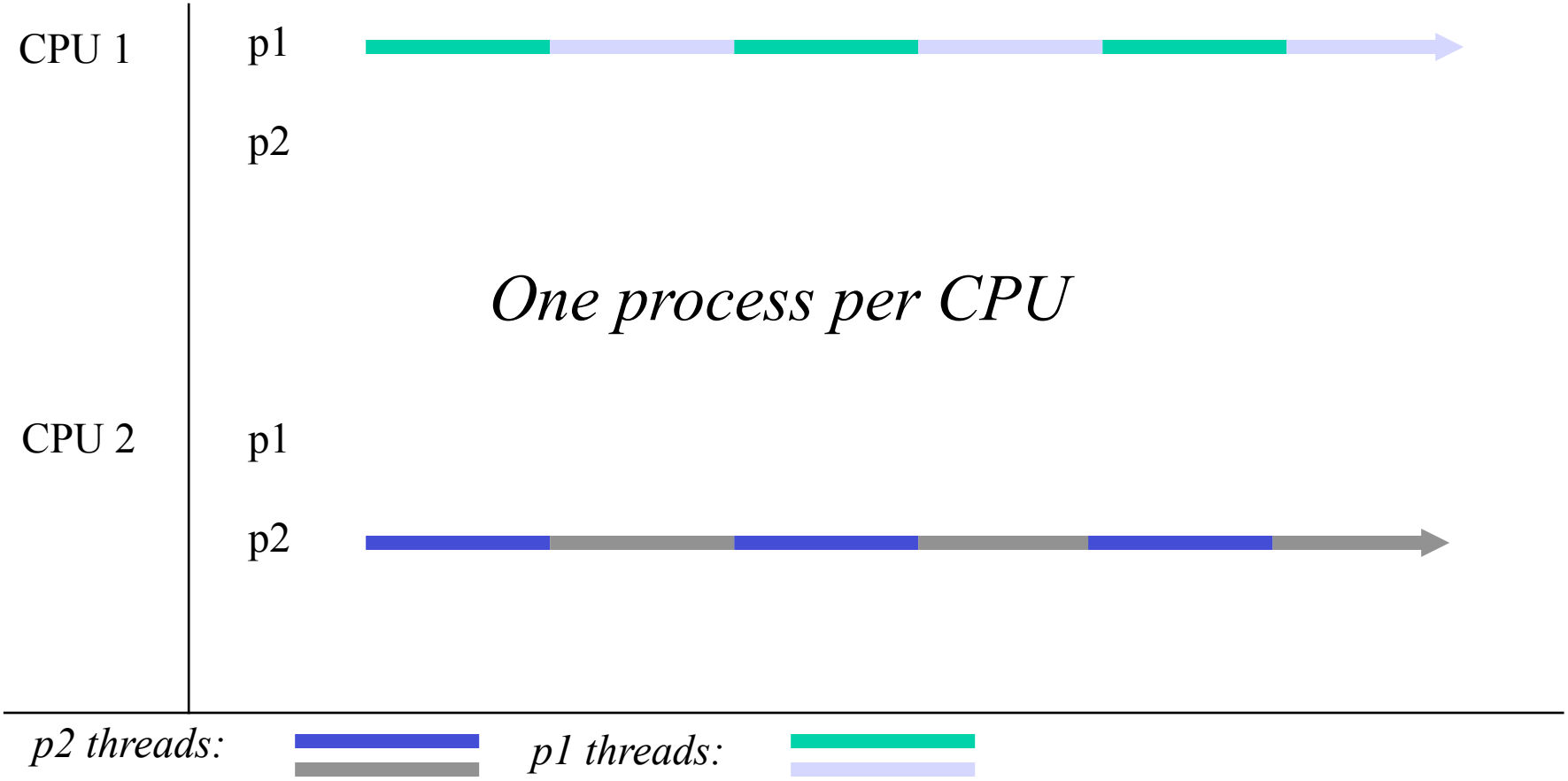
- Once a new thread is created, how does it interact with existing threads?

- This is a question of scheduling:
  - Given N processors and M threads, which thread(s) should be run at any given time?

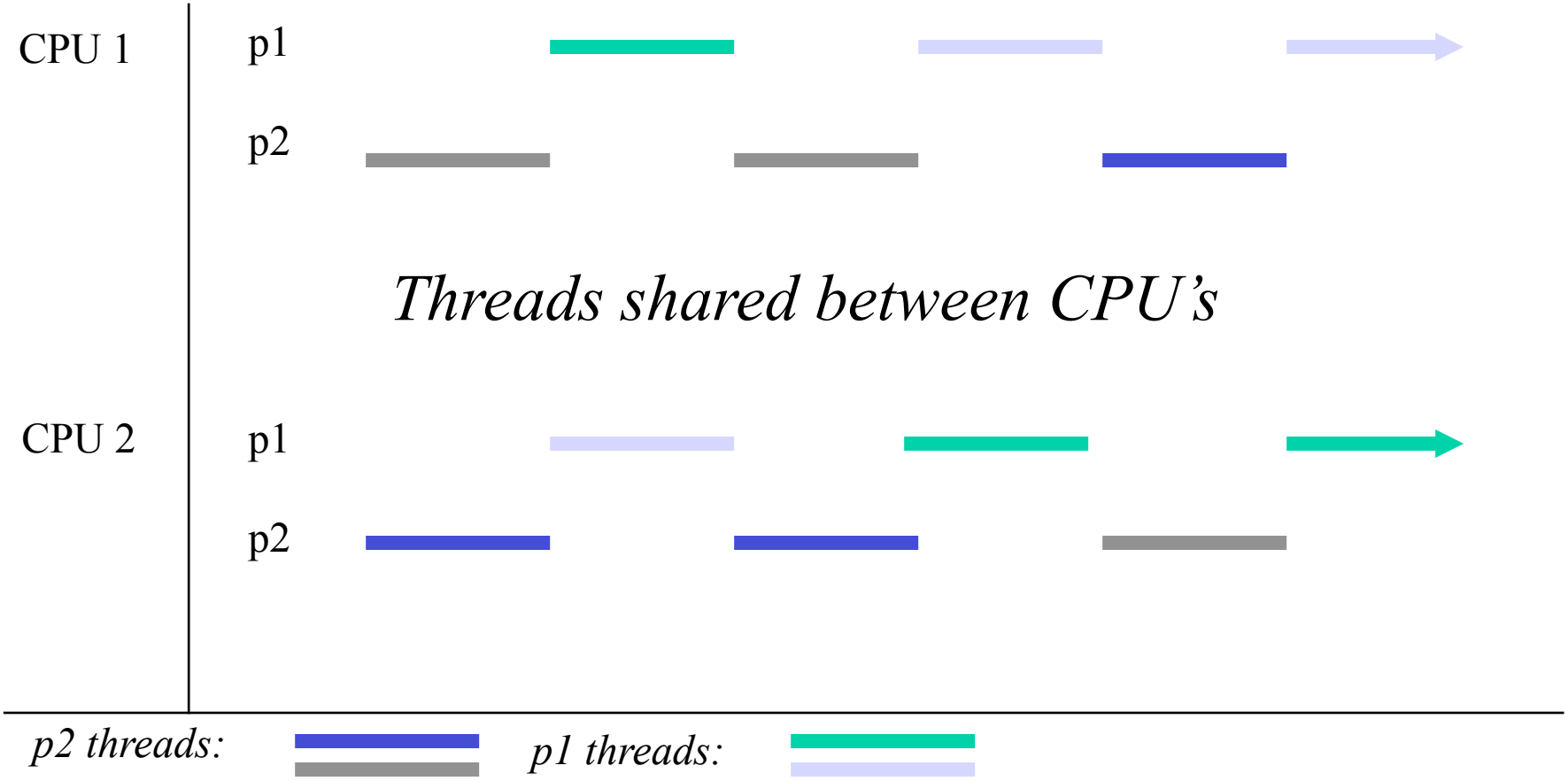
Thread Scheduling

- Multithreaded process scheduling:
  - More processors than threads
    - Can have each thread runs on its own processor
    - Splits a process across CPU's
    - Exploits hardware-level concurrency
  - More threads than processors
    - Need to share CPU in slices of time

Scheduling Example (1)



Scheduling Example (2)



Scheduling Consequences

- Parallelism
  - Different threads from the same application can be running *at the same time* on different processors
- Interleaving
  - Threads can be **pre-empted** *at any time* in order to schedule other threads

Thread Scheduling

- When multiple threads share a CPU, must decide:
  - When the current thread should stop running
  - What thread to run next
- A thread can voluntarily **yield()** the CPU
  - Call to yield() may be ignored; you can't depend on it
- *Preemptive schedulers* can de-schedule the current thread at any time
- Threads are de-scheduled whenever they block (e.g., on a lock or on I/O) or go to sleep

Thread Lifecycle

- While a thread executes, it goes through a number of different phases
  - **New**: created but not yet started
  - **Runnable**: is running, or can run on a free CPU
  - **Blocked**: waiting for I/O or for a lock
  - **Sleeping**: paused for a user-specified interval
  - **Terminated**: completed

Which Thread to Run Next?

- The scheduler looks at all of the runnable threads, including threads that were unblocked because
  - A lock was released
  - I/O became available
  - They finished sleeping, etc.
- Of these threads, it considers the thread's priority. This can be set with **setPriority().** Higher priority threads typically get preference.
  - Oftentimes, threads waiting for I/O are also preferred

Simple Thread Methods

- void start()
- boolean isAlive()
- void setPriority(int newPriority)
  - Scheduler might/might not respect priority
- void join() throws InterruptedException
  - Waits for a thread to die/finish

Example: Threaded, Sync Alarm

```
while (true) {
  System.out.print("Alarm> ");

  // read user input
  String line = b.readLine();
  parseInput(line);

  // wait (in secs) asynchronously
  if (m != null) {
    // start alarm thread
    Thread t = new AlarmThread(m,tm);
    t.start();
    // wait for the thread to complete
    t.join();
  }
}
```

Simple Static Thread Methods

- void yield()
  - Hint to give up the CPU
- void sleep(long milliseconds)
  throws InterruptedException
  - Sleep for the given period
- Thread currentThread()
  - Thread object for currently executing thread
- All apply to thread invoking the method

Daemon Threads

- void setDaemon(boolean on)
  - Marks thread as a daemon thread
  - Must be set before thread started
- By default, thread acquires status of thread that spawned it
- Program execution terminates when no threads running except daemons

SingleThreaded Logging Server

- Assuming the ClientSimulator is fixed
  - What factors account for the program's running time?
  - What possibilities might exist to speed things up?

A MultiThreaded Logging Server

- Logging server
  - Accepts records from client
  - Creates a thread that writes the record to client-specific file
- Organization
  - Utils
    - DataRecord.java
    - MsgHandler.java
  - Client
    - ClientSimulator.java
  - Server
    - LoggingServerCore.java
    - MultiThreadedServer.java

Let's Look at the Code

- Repo
  - https://bitbucket.org/aporter/cmsc433
- Project
  - MultiThreadedLoggingServer

Ungraded Assignment

- Download the code
- Read and understand how it works
- Run this code and observe its performance
  - How does this code perform relative to the singleThreadedServer?
  - What might account for any performance differences?
  - Are there any problems/concerns with the MultiThreadedServer's behavior?