CMSC 330: Organization of Programming Languages

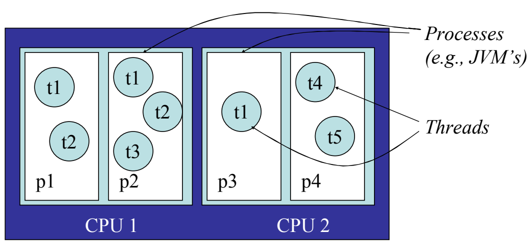
Threads

Reminders

- Homework 2 due on Oct. 30
- Project 3 due Oct. 31
- Midterm 2 on Nov. 1

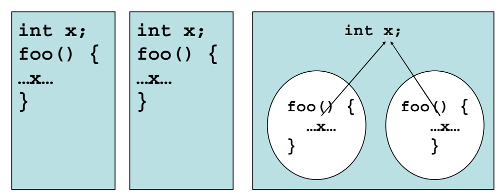
- Done with OCaml… now onto Threads…

Computation Abstractions



A computer

Processes vs. Threads



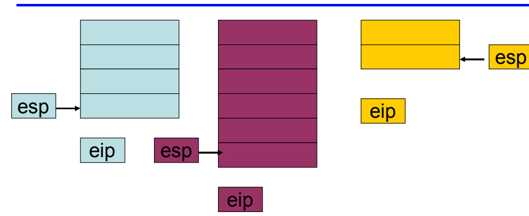
Processes do not share data

Threads share data within a process

So, What Is a Thread?

- **Conceptually**: it is a parallel 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 (main)

Implementation View



- Per-thread stack and instruction pointer
  - Saved in memory when thread suspended
  - Put in hardware esp/eip when thread resumes

Tradeoffs

- Threads can increase performance
  - Parallelism on multiprocessors
  - Concurrency of computation and I/O
- Natural fit for some programming patterns
  - Event processing
  - Simulations
- But increased complexity
  - Need to worry about safety, liveness, composition
- And higher resource usage

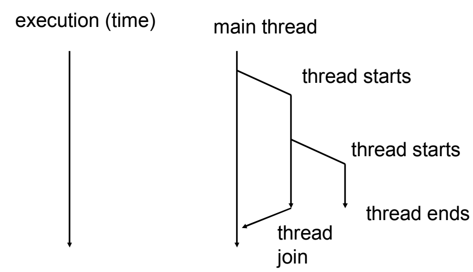
Programming Threads

- Threads are available in many languages
  - C, C++, Objective Caml, Java, SmallTalk …
- In many languages (e.g., C and C++), threads are a platform specific add-on
  - Not part of the language specification
- They're part of the Java language specification

Java Threads

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

Thread Creation



Thread Creation in Java

- 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

Running Example: Alarms

- Goal: let's set alarms which 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 secs)
  try {
    Thread.sleep(timeout * 1000);
  } catch (InterruptedException e) { }
  System.out.println("("+timeout+") "+msg);
}
```

like phone calls

thrown when another thread calls interrupt

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


Making It Threaded (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 AlarmThread(m,tm);
    t.start();
  }
}
```


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);
  }
}
```


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,tm));
    t.start();
  }
}
```

Notes: Passing Parameters

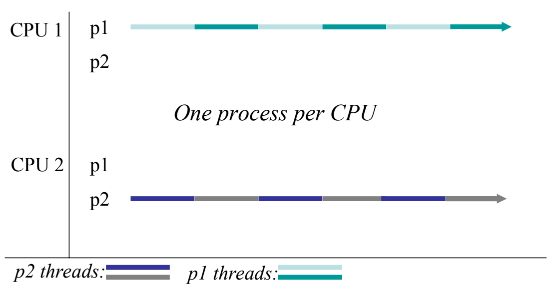
- run() doesn't take parameters

- We "pass parameters" to the new thread by storing them as private fields
  - In the extended class
  - Or the Runnable object
  - Example: the time to wait and the message to print in the AlarmThread class

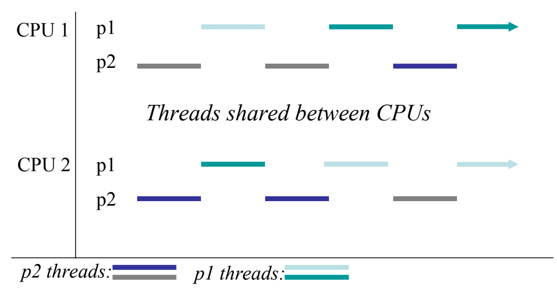
Concurrency

- A *concurrent* program is one that has multiple threads that may be active at the same time
  - Might run on one CPU
    - The CPU alternates between running different threads
    - The *scheduler* takes care of the details
      - Switching between threads might happen *at any time*
  - Might run *in parallel* on a *multiprocessor* machine
    - One with more than one CPU
    - May have multiple threads per CPU
- Multiprocessor machines are becoming more common
  - Multi-CPU machines aren't that expensive any more
  - Dual-core CPUs are available now

Scheduling Example (1)



Scheduling Example (2)



Concurrency and Shared Data

- Concurrency is easy if threads don't interact
  - Each thread does its own thing, ignoring other threads
  - Typically, however, threads need to communicate with each other

- Communication is done by *sharing* data
  - In Java, different threads may access the heap simultaneously
  - But the scheduler might interleave threads arbitrarily
  - Problems can occur if we're not careful.

Data Race Example

```
public class Example extends Thread {
  private static int cnt = 0;  // shared state
  public void run() {
    int y = cnt;
    cnt = y + 1;
  }
  public static void main(String args[]) {
    Thread t1 = new Example();
    Thread t2 = new Example();
    t1.start();
    t2.start();
  }
}
```

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state cnt = 0

Start: both threads ready to run. Each will increment the global cnt.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state cnt = 0

y = 0

T1 executes, grabbing the global counter value into its own y.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state **cnt = 1**

y = 0

T1 executes again, storing its value of y + 1 into the counter.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state cnt = 1

y = 0

y = 1

T1 finishes. T2 executes, grabbing the global counter value into its own y.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state **cnt = 2**

y = 0

y = 1

T2 executes, storing its incremented cnt value into the global counter.

But When it's Run Again?

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state cnt = 0

Start: both threads ready to run. Each will increment the global count.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state cnt = 0

y = 0

T1 executes, grabbing the global counter value into its own y.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state cnt = 0

y = 0

y = 0

T1 is preempted. T2 executes, grabbing the global counter value into its own y.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state **cnt = 1**

y = 0

y = 0

T2 executes, storing the incremented cnt value.

Data Race Example

```
static int cnt = 0;
t1.run() {
  int y = cnt;
  cnt = y + 1;
}
t2.run() {
  int y = cnt;
  cnt = y + 1;
}
```

Shared state **cnt = 1**

y = 0

y = 0

T2 completes. T1 executes again, storing the incremented original counter value (1) rather than what the incremented updated value would have been (2)!

What Happened?

- Different schedules led to different outcomes
  - This is a *data race* or *race condition*
- A thread was preempted in the middle of an operation
  - Reading and writing cnt was supposed to be *atomic*- to happen with no interference from other threads
  - But the schedule (interleaving of threads) which was chosen allowed atomicity to be violated
  - These bugs can be extremely hard to reproduce, and so hard to debug
    - Depends on what scheduler chose to do, which is hard to predict

Question

- If instead of

```
int y = cnt;
cnt = y+1;
```

- We had written
  - `cnt++;`
- Would the result be any different?
- Answer: NO!
  - Don't depend on your intuition about atomicity

Question

- If you run a program with a race condition, will you always get an unexpected result?
  - No! It depends on the scheduler, i.e., which JVM you're running, and on the other threads/processes/etc, that are running on the same CPU
- Race conditions are hard to find

What's Wrong with the Following?

```
static int cnt = 0;
static int x = 0;
```

```
Thread 1
  while (x != 0);
  x = 1;
  cnt++;
  x = 0;
```

```
Thread 2
  while (x != 0);
  x = 1;
  cnt++;
  x = 0;
```

- Threads may be interrupted after the while but before the assignment x = 1
  - Both may think they "hold" the lock!
- This is *busy waiting*
  - Consumes lots of processor cycles