CS 351
Design of Large Programs
Threads and Concurrency

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Concurrency in Java

- Java has basic concurrency support built into the language.
- Also has high-level APIs available in `java.util.concurrent` package

Processes vs Threads

- Processes
  - Self-contained execution environment
  - Each process has own memory space
  - Communicate with other processes through interprocess communication (pipes, sockets, files, etc.)
- Threads
  - Creating new thread requires fewer resources than an new process.
  - Threads within same process share process's resources.
  - Threads have shared heap, but separate stacks.

Thread objects

- Each thread is associated with an instance of `Thread`
- Two ways to create a new thread:
  - Subclass `Thread`
  - Implement `Runnable` interface and pass `Runnable` object to `Thread` constructor.
- In both cases, you'll implement `run` method to contain the code to be executed on the thread.
- Implementing `Runnable` is the more flexible approach.

Thread.sleep method

- The sleep method causes the current thread to suspend execution for a specified number of milliseconds.
- Sleep time is not guaranteed to be precise. (Limits of OS)
- Sleep period may be terminated by an interrupt.

Thread methods

If I have initialized a `Thread` named `myThread`

- `myThread.start()` – starts running `myThread`
- `myThread.join()` – Pauses current thread until `myThread` terminates

Synchronized Methods

```
public class SynchronizedCounter {
  private int c = 0;
  public synchronized void increment() { c++; }
  public synchronized int value() { return c; }
}
```

- It is not possible for two invocations of synchronized methods on the same object to interleave.
- When one thread is executing a synchronized method for an object, all other threads that invoke synchronized methods for the same object block until the first thread is done with the object.

Synchronized Blocks

```
public void copyP(Point destination){
  synchronized(p) {
    destination.x = p.x;
    destination.y = p.y;
  }
}

public void addP()(int n) {
  synchronized(p) {
    p.x += n;
    p.y += n;
  }
}
```

Both synchronized blocks obtain lock on member variable `p`

Synchronized Methods vs Blocks

- Making a method synchronized is equivalent to wrapping method body in a `synchronized(this)` block.
- Synchronized blocks are more complicated, but offer finer grained synchronization than synchronized methods.

Liveness Problems

- Deadlock – Threads are blocked forever waiting for each other.
- Starvation – Thread cannot gain access to shared resources held by other "greedy" threads.
- Livelock – Threads too busy responding to each other to actually make progress.

FibThreads: Worker (1/1)

```
public static class Worker extends Thread {
  private final String name;
  private long step = 0;
  private int x = 0;
  private int y = 1;
  private int z;
  private boolean keepGoing = true;

  public Worker(String name) {
    this.name = name;
    z = x + y;
  }

  private synchronized void update() {
    step++;
    if (z < 0) {
      // restart after overflow
      x = 0;
      y = 1;
    } else {
      x = y;
      y = z;
    }
    z = x + y;
  }
```

FibThreads: Worker (2/2)

```
    public void quit() {
      keepGoing = false;
    }

    @Override
    public void run() {
      while(keepGoing) {
        update();
      }
      System.out.println(name +
          " stopping at step " + step);
    }

    @Override
    public synchronized String toString() {
      return name + " step " + step +
        ", x = " + x + ", y = " + y + ", z = " + z;
    }
  }
```

FibThreads: main

```
public static void main(String[] args) throws InterruptedException {

  Worker[] workers = new Worker[]{ new Worker("A"), new Worker("B") };

  for(Worker worker : workers) { worker.start(); }

  for(int i = 0; i < 10; ++i) {

    System.out.println("i = " + i);
    for(Worker worker : workers) {
      System.out.println(worker);
    }
    Thread.sleep(1000); // Take a short nap
  }

  for(Worker worker : workers) { worker.quit(); }

  for(Worker worker : workers) {
    // wait until this thread has finished.
    worker.join();
  }

  System.out.println("All workers are done. Goodbye.");
}
```

FibThreads: Why synchronized?

- update and toString methods are synchronized
- What might happen if we didn't?

Producer/Consumer Pattern

- Producers and consumers run concurrently.
- Producer produces values and places them in a shared queue.
- Consumer removes values from queue and processes them.
- May be multiple producers, consumers, queues.

Producer/Consumer with BlockingQueue

- Could implement with any queue type and careful use of synchronized blocks, but there is an easier way.
- The `java.util.concurrent.BlockingQueue` interface extends `java.util.Queue` with methods that make current thread wait if necessary.
  - put – add item to queue (wait if no room)
  - take – remove next item from queue (wait if empty)

ProducerConsumer: Producer

```
public static class Producer implements Runnable {
  private final String name;
  private final BlockingQueue<Integer> queue;

  public Producer(String name, BlockingQueue<Integer> queue) {
    this.name = name;
    this.queue = queue;
  }

  @Override
  public void run() {
    System.out.println("Start " + name);
    try {
      for(int i = 0; i < 20; i++) {
        System.out.println(name + " produces " + i);
        queue.put(i);
      }
      System.out.println(name + " is done producing");
    } catch (InterruptedException e) {
      System.out.println(name + " was interrupted");
    }
  }
}
```

ProducerConsumer: Consumer

```
public static class Consumer implements Runnable {
  private final String name;
  private final BlockingQueue<Integer> queue;

  public Consumer(String name, BlockingQueue<Integer> queue) {
    this.name = name;
    this.queue = queue;
  }

  @Override
  public void run() {
    System.out.println("Start " + name);
    try {
      while(true) {
        int value = queue.take();
        System.out.println(name + " consumes " + value);
      }
    } catch (InterruptedException e) {
      System.out.print(name + " was interrupted");
    }
  }
}
```

ProducerConsumer: main

```
public static void main(String[] args)
                throws InterruptedException {

  BlockingQueue<Integer> sharedQueue =
        new LinkedBlockingQueue<>();

  Thread prodThread =
        new Thread(new Producer("P", sharedQueue));
  Thread consThread =
        new Thread(new Consumer("C", sharedQueue));

  prodThread.start();
  consThread.start();
}
```