CSx55: Distributed Systems [Threads]

Threads block when they can't get that lock

Wanna have your threads stall?
Go ahead, synchronize it all

The antidote to this liveness pitfall?
Keeping the lock scope small

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Frequently asked questions from the previous class survey

- Typical cache hit rates?
- What if a thread does not fully utilize its allocated local mini heap? Is that not inefficient?
- A thread T_1 can execute instructions that belong to some other Thread object T_2?
- Is liveness stall same as a deadlock?
- Threads create threads? Is that the only way?
- How does blocking occur with a blocking call?

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Topics covered in this lecture

- Threads
  - Thread Lifecycle
- Data synchronization
- Synchronized blocks
- Lock scope

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Two approaches to stopping a thread

- Setting a flag
- Interrupting a thread

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Stopping a Thread: Setting a flag

- **Set some internal flag** to signal that the thread should stop
- Thread periodically **queries the flag** to determine if it should exit

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Stopping a Thread: Setting a flag

```
public class RandomGen extends Thread {
   private volatile boolean done = false;

   public void run() {
      while (!done) {
         ...
      }
   }

   public void setDone() {
      done = true;
   }
}
```

`run()` method investigates the state of the `done` variable on every loop.
Returns when the `done` flag has been set.

Interrupting a thread

- In the previous slide, there may be a *delay* in the `setDone()` being invoked & thread terminating
  - Some statements are executed after `setDone()` and before the value of `done` is checked
  - In the worst case, `setDone()` is called right after the the `done` variable was checked
- **Delays** while waiting for a thread to terminate are *inevitable*
  - But it would be good if they could be minimized

Interrupting a thread

- When we arrange for thread to terminate, we:
  - Want it to *complete its blocking method* immediately
  - Don't wish to wait for the data (or ...) because the thread will exit
- Use `interrupt()` method of the `Thread` class to **interrupt** any *blocking method*

Effects of the interrupt method

- Causes blocked method to **throw** an **`InterruptedException`**
  - `sleep()`, `wait()`, `join()`, and methods to read I/O
- Sets a **flag** inside the thread object to indicate that the thread has been interrupted
  - Queried using `isInterrupted()`
    - Returns `true` if it was interrupted, even though it was not blocked

Stopping a thread: Using interrupts

```
public class RandomGen extends Thread {

   public void run() {
     while (!isInterrupted()) {
         ...
      }
   }

}
```

```
radomGeneratorThread.interrupt()
```


The Runnable interface

- Allows **separation** of the *implementation* of the task *from the thread* used to run task

```
public interface Runnable {

   public void run();

}
```

Creation of a thread using the `Runnable` interface

- Construct the thread
  - Pass runnable object to the thread's constructor
- Start the thread
  - Instead of starting the runnable object

Creation of a thread using the `Runnable` interface

```
public class RandomGenerator implements Runnable {

   public void run() { ... }

}

...
     generator = new RandomGenerator();
     Thread createdThread = new Thread(generator);
     createdThread.start();
```

When to use `Runnable` and `Thread`

- If you would like your class to inherit behavior from the `Thread` class
  - **Extend** `Thread`
- If your class needs to inherit from other classes
  - **Implement** `Runnable`

If you extend the `Thread` class?

- You **inherit** *behavior* and *methods* of the Thread class
  - The `interrupt()` method is part of the `Thread` class
  - You can `interrupt()` *if you extend*

Advantages of using the `Runnable` interface

- Java provides several classes that handle threading *for* you
  - Implement pooling, scheduling, or timing
  - These require the **`Runnable`** interface

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But what if I still can't decide?

- Do a UML (Unified Modeling Language) model of your application
- The object hierarchy tells you what you need:
  - If your task needs to subclass another class?
    - Use `Runnable`
  - If you need to use methods of `Thread` within your class?
    - Use `Thread`

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Threads and Objects

- Instance of the `Thread` class is just an **object**
  - Can be passed to other methods
  - If a thread has a reference to another thread
    - It can invoke *any method* of that thread's object
- The `Thread` object is not the thread itself
  - It is the set of methods and data that *encapsulate* information about the thread

But what does this mean?

- You cannot look at the object source and know *which thread is*:
  - Executing its methods or examining its data
- You may wonder about which thread is running the code, but …
  - There may be many possibilities

Determining the current thread

- Code within a thread object might want to see that code is being executed either:
  - By thread represented by the object or
  - By a completely different thread
- Retrieve reference to current thread
  - `Thread.currentThread()`
  - Static method

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Checking which thread is executing the code

```
public class MyThread extends Thread {

   public void run() {
      if (Thread.currentThread() != this) {
         throw new IllegalStateException
            ("Run method called by incorrect thread …);
      } /* end if */

      ... Main logic
   }

}
```


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Allowing a `Runnable` object to see if it has been interrupted

```
public class MyRunnable implements Runnable {

   public void run() {
      if (!Thread.currentThread().isInterrupted() ) {
            ... Main logic
      }
   }

}
```


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Heisenbugs

- Term coined by ACM Turing Award winner Jim Gray
  - Pun on the name of Werner Heisenberg
  - Act of observing a system, alters its state!
- Describes a particular class of bugs
  - Those that disappear or change behavior when you try to examine them
- Multithreaded programs are a common source of Heisenbugs

What about regular bugs?

- Sometimes referred to as Bohr bugs
  - Deterministic
  - Generally, much easier to diagnose

Two friends plan to meet at Starbucks
But there are two Starbucks on College Avenue

	@ the First Starbucks Store	**@ the Second Starbucks Store**
12:10	**A** is looking for friend **B**	**B** is looking for friend **A**
12:15	**A** leaves for the second store	**B** leaves for the first store
12:20	**B** arrives at store	**A** arrives at store
12:30	**B** is Looking for friend **A**	**A** is looking for friend **B**
12:40	**B** leaves for the second store	**A** leaves for the first store

Both friends are now frustrated and undercaffeinated!

DATA SYNCHRONIZATION

Why sharing data between threads is problematic

- **Race conditions**
  - Correct outcome depends on lucky timing of uncontrollable events
- Threads attempt to access data more or less *simultaneously*
  - A thread may change the value of data that some other thread is operating on

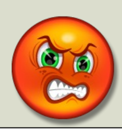
Example code with race condition

```
public class MyThread extends Thread {
   private byte[] values;
   private int position;

   public void
      modifyData(byte[] newValues, int newPosition) {
      ... Modify values and position
   }

   public void utilizeDataAndPerformFunction() {
      ... Use values and position
   }

   public void run() {
     ... Main logic
   }
}
```



In the previous snippet a race condition exists because …

- The thread that calls `modifyData()` is **accessing the same data** as the thread that calls `utilizeDataAndPerformFunction()`
- `utilizeDataAndPerformFunction()` and `modifyData()` **are not atomic**
  - It is possible that `values` and `position` are changed *while they are being used*

What is atomic?

- The code cannot be interrupted during its execution
  - Accomplished in hardware or *simulated* in software
- Code that cannot be found in an *intermediate state*

Eliminating the race condition using the `synchronized` keyword

- If we declared both `modifyData()` and `utilizeDataAndPerformFunction()` as **synchronized**?
  - Only one thread gets to call *either* method at a time
    - Only one thread accesses data at a time
  - When one thread calls one of these methods, while another is executing one of them?
    - The second thread must *wait*

Example code with no race conditions by using the synchronized keyword

```
public class MyThread extends Thread {
   private byte[] values;
   private int position;

   public void synchronized
      modifyData(byte[] newValues, int newPosition) {
      ... Modify values and position
   }

   public void synchronized
      utilizeDataAndPerformFunction() {
      ... Use values and position
   }

   public void run() {
     ... Main logic
   }
}
```

Revisiting the mutex lock

- **Mut**ually **ex**clusive lock
- If two threads try to grab a mutex?
  - Only one succeeds
- In Java, every object has an associated **lock**

When a method is declared `synchronized` ...

- The thread that wants to execute the method must **acquire** a lock
- Once the thread has acquired the lock?
  - It executes method and **releases** the lock
- When a method returns, the lock is released
  - Even if the return is because of an exception

Locks and objects

- There is only **one lock per object**
- If two threads call synchronized methods of the same object?
  - Only one can execute immediately
    - The other has to wait until the lock is released

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Afraid of what the truth might bring
He locks his doors and never leaves
Desperately searching for signs
To terrify, to find a thing
He battens all the hatches down
And wonders why he hears no sound
Frantically searching his dreams
He wonders what it's all about

Telescope, Cage the Elephant

SYNCHRONIZATION PITFALLS

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Another code snippet to look at …

```
public class MyThread extends Thread {
   private boolean done = false;

   public void run() {
     while (!done) {
        ... Main logic
     }
   }

   public void setDone(boolean isDone) {
     done = isDone;
   }
}
```

Can't we just synchronize the two methods as we did previously?

- If we synchronized both `run()` and `setDone()` ?
  - `setDone()` would never execute!
- The `run()` method does not exit until the `done` flag is set
  - But the `done` flag cannot be set because `setDone()` cannot execute till `run()` completes
- Uh oh …

The problem stems from the scope of the lock

- **Scope of a lock**
  - Period between grabbing and releasing a lock
- Scope of the `run()` method is too large!
  - Lock is grabbed and never released
- We will look at techniques to *shrink the scope* of the lock
- But let's look at another solution for now

Let's look at operations performed on the data item (`done`)

- The `setDone()` method stores a value into the flag
- The `run()` method reads the value

- In our previous example:
  - Threads were accessing *multiple* pieces of data
  - No way to update multiple data items *atomically* without the `synchronized` keyword

But Java specifies that the loading and storing of variables is atomic

- Except for `long` and `double` variables
- The `setDone()` should be atomic
  - The `run()` method has only one read operation of the data item
- The race condition should not exist
  - But why is it there?

Threads are allowed to hold values of variables in registers

- When one thread changes the value of the variable?
  - Another thread *may not see* the changed variable
- This is particularly true in loops controlled by a variable
  - Looping thread **loads value of variable in register** and *does not notice* when value is changed by another thread

Two approaches to solving this

- Providing setter and getter methods for variable and using the `synchronized` keyword
  - *When lock is acquired*, temporary values stored in registers are *flushed* to main memory
- The **`volatile`** keyword
  - Much cleaner solution

If a variable is marked as `volatile`

- Every time it is used?
  - Must be read from main memory
- Every time it is written?
  - Must be written to main memory
- Load and store operations are **atomic**
  - Even for `long` and `double` variables

Some more about volatile variables

- Prior to JDK 1.2 variables were always read from main memory
  - Using volatile variables was moot
- Subsequent versions introduced memory models and optimizations

Synchronization and the volatile keyword

- Can be used *only* when operations use a **single load and store**
  - Operations like `++`, `--`?
    - Load-change-store …
- The `volatile` keyword forces the JVM to not make temporary copies of a variable
- Declaring an array `volatile`?
  - The reference becomes volatile
  - The individual elements are not volatile

The contents of this slide-set are based on the following references

- *Java Threads. Scott Oaks and Henry Wong. . 3rd Edition. O'Reilly Press. ISBN: 0-596-00782-5/978-0-596-00782-9.* [Chapters 3, 4]