CS 455: INTRODUCTION TO DISTRIBUTED SYSTEMS

[THREADS]

The House of Heap and Stacks
Stacks clean up after themselves
But over deep recursions they fret
The cheerful heap has nary a care
Harboring memory leaks, hurtling to a crash

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Frequently asked questions from the previous class survey

- Extension headers in TCP Segments? No, these are in IPv6
- Calling System.exit(): Does this cause the process or thread to exit?
- What determines when garbage collection happens?
- Can a stack frame grow or is it fixed in size when it is allocated the first time?
- Registers, CPU, and the compiler? Physical or software?
- What is hyperthreading?
Topics covered in this lecture

- Creation and Management
- Thread lifecycle
  - Creating and starting threads
- Stopping and interrupting threads
- Approaches to writing threads
  - Subclassing Threads vs Implementing Runnable

Thread Abstraction

- A thread is a single execution sequence that represents a separately schedulable task
  - Single execution sequence
    - Each thread executes sequence of instructions – assignments, conditionals, loops, procedures, etc. – just as the sequential programming model
  - Separately schedulable task
    - The OS can run, suspend, or resume a thread at any time
Threads and heaps

- For performance reasons, heaps may **internally subdivide** their space into per-thread regions
  - Threads can allocate objects at the same time *without interfering* with each other
  - By allocating objects used by the same thread from the same memory region?
    - Cache hit rates may improve
- Each subdivision of the heap has **thread-local variables**
  - Track parts of thread-local heap in use, those that are free, etc.
- New memory allocations (`malloc()` and `new()`) can take memory from **shared heap**, only if local heap is used up
How big a stack? [1/2]

- The size of the stack must be large enough to accommodate the **deepest nesting level** needed during the thread’s **lifetime**

- Kernel threads
  - Kernel stacks are allocated in physical memory
  - The nesting depth for kernel threads tends to be small
  - E.g. 8KB default in Linux on an Intel x86
  - Buffers and data structures are allocated on the heap and never as procedure local variables

How big a stack? [2/2]

- User-level stacks are allocated in virtual memory

- To catch program errors
  - Most OS will trigger **error** if the program stack grows **too large too quickly**
    - Indication of an unbounded recursion
  - Google’s GO will automatically grow the stack as needed ... this is very uncommon
  - POSIX for e.g. allows default stack size to be library dependent (e.g. larger on a desktop, smaller on a phone)
    - “Exceeding default stack limit is very easy to do, with the usual results”
    - Program termination
Thread creation

- Using the **Thread** class
- Using the **Runnable** interface
The Thread class

```java
package java.lang;

public class Thread implements Runnable {
    public Thread();
    public Thread(Runnable target);
    public Thread(ThreadGroup group, Runnable target);
    public Thread(String name);
    public Thread(ThreadGroup group, String name);
    public Thread(Runnable target, String name);
    public Thread(ThreadGroup group, Runnable target, String name);
    public Thread(ThreadGroup group, Runnable target, String name, long stackSize);

    public void start();
    public void run();
}
```

Threads require 4 pieces of information

- **Thread name**
  - Default is Thread-N; N is a unique number

- **Runnable target**
  - List of instructions that the thread executes
  - Default: run() method of the thread itself

- **Thread group**
  - A thread is assigned to the thread group of the thread that calls the constructor

- **Stack size**
  - Store temporary variables during method execution
  - Platform-dependent: range of legal values, optimal value, etc.
A simple thread

```java
public class RandomGen extends Thread {
    private Random random;
    private int nextNumber;
    public RandomGen() {random = new Random();}

    public void run() {
        for (;;) {
            nextNumber = random.nextInt();
            try {
            } catch (InterruptedException ie) {
                ... return;
            }
        }
    }
}
```

About the code snippet

- Extends the Thread class
- Actual instructions we want to execute is in the `run()` method
  - Standard method of the Thread class
    - Place where Thread begins execution
Contrasting the run() and main() methods

- **main() method**
  - This is where the *first thread starts executing*
  - The **main thread**

- **The run() method**
  - *Subsequent threads* start executing with this method

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**THREAD LIFECYCLE**
Lifecycle of a thread

- Creation
- Starting
- Terminating
- Pausing, suspending, and resuming

Thread: Methods that impact the thread’s lifecycle

```java
public class Thread implements Runnable {
    public void start();
    public void run();
    public void stop();
    public void resume();
    public void suspend();
    public static void sleep(long millis);
    public boolean isAlive();
    public void interrupt();
    public boolean isInterrupted();
    public static boolean interrupted();
    public void join();
}
```

Deprecated, do not use
Thread creation

- Threads are represented by instances of the Thread class
- When you extend the Thread class?
  - Your instances are also Threads
- We looked at the 4 constructor arguments in the Thread class

Starting a thread [1/2]

- Thread exists once it's been constructed
  - But it is not executing … it's in a waiting state
- In the waiting state, other threads can interact with the existing thread object
  - Object state may be changed by other threads
    - Via method invocations
### Starting a thread [2/2]

- When we’re ready for a thread to begin executing code
  - Call the `start()` method
  - `start()` performs internal house-keeping and then calls the `run()` method

- When the `start()` method returns?
  - **Two threads** are executing in parallel
    1. The original thread which just returned from calling `start()`
    2. The newly started thread that is executing its `run()` method

### After a thread’s `start()` method is called

- The new thread is said to be **alive**
- The `isAlive()` method tells you about the state
  - `true`: Thread has been started and *is executing* its `run()` method
  - `false`: Thread may *not be started* yet or may be *terminated*
Terminating a thread

- Once started, a thread executes only one method: `run()`
- This `run()` may be complicated
  - May execute forever
  - Call several other methods
- Once the `run()` finishes executing, the thread has **completed** its execution

Like all Java methods, `run()` finishes when it …

1. Executes a `return` statement
2. Executes the last statement in its method body
3. When it throws an exception
   - Or fails to catch an exception thrown to it
The only way to terminate a thread?

- Arrange for its `run()` method to **complete**
- But the documentation for the `Thread` class lists a `stop()` method?
  - This has a *race condition* (unsafe), and has been deprecated

Some more about the `run()` method

- Cannot throw a **checked** exception
- But it can throw an **unchecked** exception
  - Exception that extends the `RuntimeException`
- A thread can be **stopped** by:
  1. *Throwing* an unchecked exception in `run()`
  2. *Failing to catch* an unchecked exception thrown by something that `run()` has called
Pausing, suspending and resuming threads

- Some thread models support the concept of **thread suspension**
  - Thread is told to *pause* execution and then told to *resume* its execution

- Thread contains `suspend()` and `resume()`
  - Suffers from vulnerability to *race conditions*: deprecated

- Thread can *suspend its own execution* for a specified period
  - By calling the `sleep()` method

But sleeping is not the same thing as thread suspension

- With true thread suspension
  - One thread can suspend (and later resume) *another thread*

- `sleep()` affects only the thread that executes it
  - Not possible to tell another thread to go to sleep
But you can achieve the functionality of suspension and resumption

- Use wait and notify mechanisms
- Threads **must be coded** to use this technique
  - This is **not a generic** suspend/resume that is imposed by another thread

Thread cleanup

- As long as some other active object holds a reference to the terminated thread object
  - Other threads can execute methods on the terminated thread … retrieve information
- If the object representing the terminated thread goes **out of scope**?
  - The thread object is **garbage collected**
Holding onto a thread reference allows us to determine if work was completed

- Done using the `join()` method
- The `join()` method
  - Blocks until the thread has completed
  - Returns immediately if
    - The thread has already completed its `run()` method
    - You can call `join()` any number of times
- Don’t use `join()` to poll if the thread is still running
  - Use `isAlive()`

STOPPING A THREAD
Two approaches to stopping a thread

- Setting a flag
- Interrupting a thread

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
Stopping a Thread: Setting a flag

```java
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

```java
public class RandomGen extends Thread {
    public void run() {
        while (!isInterrupted()) {
            ...
        }
    }
}
```

randomGeneratorThread.interrupt()

The Runnable interface

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

```java
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

```java
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

But what if I still can’t decide?

- Do a UML 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**
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

Checking which thread is executing the code

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

```java
public class MyRunnable implements Runnable {
    public void run() {
        if (!Thread.currentThread().isInterrupted()) {
            ... Main logic
        }
    }
}
```

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