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, hurting to a crash

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Frequently asked questions from the previous class survey
- Why is there an MTU for different transport technologies?
- How is the Advertised Window first established?
- Difference: Parallel vs Concurrent execution
- Is it possible for a Thread use up memory space of the process?

Topics covered in this lecture
- Creation and Management
- Thread lifecycle
- Creating and starting threads
- Stopping and interrupts 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

THREADS AND ...
HEAPS AND STACKS

CS 455: INTRODUCTION TO DISTRIBUTED SYSTEMS
[THREADS]

CS455: Introduction to Distributed Systems [Spring 2019]
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SLIDES CREATED BY: SHRIDEEP PALICKARA
How big a stack?

- 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 kernels 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.

User-level stacks are allocated in virtual memory.

- To catch program errors
  - Most OS will trigger an error if the program stack grows too large too quickly.
  - Indication of an unbounded recursion.
  - E.g., Google’s GO will automatically grow the stack as needed ...
  - Program termination.

Exceeding default stack limit is very easy to do, with the usual results.

_THREAD CREATION_

**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(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: `null` 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;
            }
        }
    }
}
```

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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
- `run()` method
  - Subsequent threads start executing with this method

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
- 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 (1/2)
- When we’re ready for a thread to begin executing code
  - Call the start() method
    - start() performs internal housekeeping 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

Starting a thread (2/2)

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 ...
- Executes a return statement
- Executes the last statement in its method body
- 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 ...
  - 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 `join()` any number of times
- Don't use `join()` to poll if the thread is still running
  - Use `isAlive()`

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**STOPPING A THREAD**

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

```java
public class RandomGen extends Thread {
    private volatile boolean done = false;
    public void run() {
        while (!done)
            ...
    }
    public void setDone() {
        done = true;
    }
}
```

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

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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`
  - For methods like `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()) {
            ...
        }
    }
}
radderGeneratorThread.interrupt();
```

The Runnable interface

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

Creation of a thread using the Runnable interface

```java
public class RandomGenerator implements Runnable {
    public void run() { ... }
    public class RandomGenerator extends Thread {
        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 …");
        }
    }
}
```

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