CMSC 132: Object-Oriented Programming II

Threads in Java

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Problem

- Multiple tasks for computer
  - Draw & display images on screen
  - Check keyboard & mouse input
  - Send & receive data on network
  - Read & write files to disk
  - Perform useful computation (editor, browser, game)

- How does computer do everything at once?
  - Multitasking
  - Multiprocessing
Multitasking (Time-Sharing)

Approach

- Computer does some work on a task
- Computer then quickly switch to next task
- Tasks managed by operating system (scheduler)

Computer *seems* to work on tasks concurrently

Can improve performance by reducing waiting
Multitasking Can Aid Performance

Single task

Total Execution Time = 7 seconds

Busy → Busy → Busy → Busy

Total Time Executing Code: 4 seconds
Total Time Waiting: 3 seconds
Time Executing Code: 57%  Time Waiting: 43%

Two tasks

P1: Busy → Busy → Busy → Busy

P2: Busy → Busy → Busy → Busy

Total Time Executing Code: 8 seconds
Total Time Waiting: 0 seconds
Time Executing Code: 100%  Time Waiting: 0%
Multiprocessing (Multithreading)

Approach

- Multiple processing units (multiprocessor)
- Computer works on several tasks in parallel
- Performance can be improved

- Dual-core AMD Athlon X2
- 32 processor Pentium Xeon
- 4096 processor Cray X1
- Beowulf computer cluster (Borg, 52-node cluster used by McGill University Image/Info from Wikipedia)
Perform Multiple Tasks Using...

1. Process
   - Definition – executable program loaded in memory
   - Has own address space
     - Variables & data structures (in memory)
   - Each process may execute a different program
   - Communicate via operating system, files, network
   - May contain multiple threads
2. Thread

- Definition – sequentially executed stream of instructions
- Shares address space with other threads
- Has own execution context
- Program counter, call stack (local variables)
- Communicate via shared access to data
- Multiple threads in process execute same program
- Also known as “lightweight process”
- Let’s see how memory is organized for a threaded environment
Motivation for Multithreading

1. Captures logical structure of problem
   - May have concurrent interacting components
   - Can handle each component using separate thread
   - Simplifies programming for problem

Example

Web Server uses threads to handle ...

Multiple simultaneous web browser requests
Motivation for Multithreading

2. Better utilize hardware resources
   - When a thread is delayed, compute other threads
   - Given extra hardware, compute threads in parallel
   - Reduce overall execution time

Example

Multiple simultaneous web browser requests…

Handled faster by multiple web servers
Multithreading Overview

- Motivation & background
- Threads
  - Creating Java threads
  - Thread states
  - Scheduling
- Synchronization
  - Data races
  - Locks
  - Deadlock
Programming with Threads

Concurrent programming
- Writing programs divided into independent tasks
- Tasks may be executed in parallel on multiprocessors

Multithreading
- Executing program with multiple threads in parallel
- Special form of multiprocessing
Creating Threads in Java

Need to specify work performed by thread

Two approaches

1. **Runnable interface (Preferred Approach)**
   ```java
   public interface Runnable {
       public void run();  // work => thread
   }
   ```

2. **Extending Thread class**
   ```java
   public class Thread extends Object {  ...  }
   ```
Thread Class

class Thread extends Object implements Runnable {

    public Thread();
    public Thread(String name); // Thread name
    public Thread(Runnable R); // Thread ⇒ R.run()
    public Thread(Runnable R, String name);

    public void run(); // if no R, work for thread
    public void start(); // begin thread execution

    ...
}

Creating Threads in Java

Runnable Approach

1. Define class implementing Runnable interface
   
   ```java
   public interface Runnable {
       public void run();
   }
   ```

2. Put work to be performed in run() method

3. Create instance of the “worker” class

4. Create thread to run it
   - Create Thread object
     - Pass worker object to Thread constructor
     - Or hand the worker instance to an executor
   - Alternative methods for running threads
Creating Threads in Java

Example

```java
public class MyT implements Runnable {
    public void run() {
        ...
        // work for thread
    }
}

Thread t = new Thread(new MyT());  // create thread
t.start();  // begin running thread
...
// thread executing in parallel
```

See Message example in code distribution
Alternative Thread Creation Approach

- **Thread Class Approach**
  - Extend Thread class and override run method
  - Not recommended

- **Example**
  ```java
  public class MyT extends Thread {
      public void run() {
          ...
          // work for thread
      }
  }
  ```
  
  ```java
  MyT t = new MyT();  // create thread
  t.start();          // begin running thread
  ...
  // thread executing in parallel
  ```

- See Message example in code distribution
Why Not Recommended?

- Not a big problem for getting started
  - But a bad habit for industrial strength development

- Methods of worker and Thread class intermixed

- Hard to migrate to more efficient approaches
  - Thread Pools
public class Thread extends Object {

    ...

    public static Thread currentThread()
    public String getName()
    public void interrupt()
    public boolean isAlive()
    public void join()
    public void setDaemon()
    public void setName()
    public void setPriority()
    public static void sleep()
    public static void yield()

}
Creating Threads in Java

**Note**

- Thread eventually starts executing **only if** start() is called

Runnable is interface
- So it can be implemented by any class
- Required for multithreading in applets
- Do not call the run method directly
Threads – Thread States

- Java thread can be in one of these states
  - New – thread allocated & waiting for start()
  - Runnable – thread can begin execution
  - Running – thread currently executing
  - Blocked – thread waiting for event (I/O, etc.)
  - Dead – thread finished

- Transitions between states caused by
  - Invoking methods in class Thread
    - new(), start(), yield(), sleep(), wait(), notify()…
  - Other (external) events
    - Scheduler, I/O, returning from run()…

- In Java states defined by Thread.State
Threads – Thread States

State diagram

- new
- runnable
- running
- blocked
- dead
- notify, notifyAll, IO complete, sleep expired, join complete
- yield, timeslice
- IO, sleep, wait, join
- terminate
- scheduler

Running is a logical state → indicates runnable thread is actually running
Daemon Threads

Java threads types

- **User**
- **Daemon**
  - Provide general services
  - Typically never terminate
  - Call `setDaemon()` before `start()`

Program termination

1. All user threads finish
2. Daemon threads are terminated by JVM
Threads – Scheduling

Scheduler
- Determines which runnable threads to run
- Can be based on thread priority
- Part of OS or Java Virtual Machine (JVM)

Scheduling policy
- Nonpreemptive (cooperative) scheduling
- Preemptive scheduling
Threads – Non-preemptive Scheduling

Threads continue execution until

- Thread terminates
- Executes instruction causing wait (e.g., IO)
- Thread volunteering to stop (invoking yield or sleep)
Threads – Preemptive Scheduling

- Threads continue execution until
  - Same reasons as non-preemptive scheduling
  - Preempted by scheduler
Java Thread Example

public class ThreadNoJoin extends Thread {
    public void run() {
        for (int i = 0; i < 3; i++) {
            try {
                sleep((int)(Math.random() * 5000)); // 5 secs
            } catch (InterruptedException e) { e.printStackTrace(); }
            System.out.println(i);
        }
    }

    public static void main(String[] args) {
        Thread t1 = new ThreadNoJoin();
        Thread t2 = new ThreadNoJoin();
        t1.start();
        t2.start();
        System.out.println("Done");
    }
}
Java Thread Example – Output

Possible outputs

- 0,1,2,0,1,2,Done  // thread 1, thread 2, main()
- 0,1,2,Done,0,1,2  // thread 1, main(), thread 2
- Done,0,1,2,0,1,2  // main(), thread 1, thread 2
- 0,0,1,1,2,Done,2  // main() & threads interleaved

main (): thread 1, thread 2, println Done

thread 1: println 0, println 1, println 2

thread 2: println 0, println 1, println 2
Thread Class – `join()` Method

- Can wait for thread to terminate with `join()`

Method prototype

- `public final void join()`
  - Returns when thread is done
  - Throws `InterruptedException` if interrupted
Java Thread Example (Join)

```java
public class ThreadJoin extends Thread {
    public void run() {
        for (int i = 0; i < 3; i++) {
            try {
                sleep((int)(Math.random() * 5000)); // 5 secs
            } catch (InterruptedException e) { e.printStackTrace(); }
            System.out.println(i);
        }
    }

    public static void main(String[] args) {
        Thread t1 = new ThreadJoin();
        Thread t2 = new ThreadJoin();
        t1.start();
        t2.start();
        try {
            t1.join();
            t2.join();
        } catch (InterruptedException e) { e.printStackTrace(); }
        System.out.println("Done");
    }
}
```
About Join

**Important:** You will limit the concurrency level if you do not start/join correctly.

Suppose you want to run many threads concurrently. **Start them all and then execute the join for each one.** Do not start one thread, then join on that thread, start the second one, join on that thread, etc.

Feel free to use arrays, sets, etc. to keep track of your threads.
Thread Scheduling Observations

- Order thread is selected is indeterminate
  - Depends on scheduler

- Scheduling may not be fair
  - Some threads may execute more often

- Thread can block indefinitely (starvation)
  - If other threads always execute first
About Threads

- **Common mistake** → calling the run() method. If you want to run a thread you must execute start() and not call the run() method; the run() method is called for you.

- **Thread.sleep** → Suppose you have a thread object reference (t1) and invoke t1.sleep(2000). Which thread will be sleeping for 2 seconds? It will not be t1.
Thread Example

- Swing uses a single-threaded model
- Long computations in the EDT freezes the GUI
- Example: Progress Bar Example