Lecture 15
Task Execution
Tasks and Concurrent Applications

• So far: mechanics of concurrency in Java
  – Threads
  – Locking
  – Concurrency control
  – Visibility
  – Etc.

• Tasks have more to do with *concurrent-application design*
  – Tasks are units of work to be done
  – Task-oriented applications work by executing tasks as they are available
  – Example: web server
    • Tasks correspond to requests to the server
    • Server handles requests as they arrive
Design Considerations for Tasks

• Independence
  – Tasks should not interact with one another, if possible
  – This facilitates concurrency
• Size
  – “Smaller is better”
  – Gives more flexibility to scheduling, etc.
• The above considerations are sometimes referred to as determining task boundaries
• Task boundaries + execution policy for tasks helps determine application
  – Throughput: how many tasks are being completed per unit time?
  – Responsiveness: how long for individual tasks to complete?
  – Graceful degradation: how does system behave as it becomes overloaded?
Implementing Tasks

- Tasks: design-level artifacts
- Threads: run-time (implementation) artifacts
- Question: how you map tasks to threads?
  - One idea: sequentially
    - One thread used to execute all the tasks, one right after the other
    - Simple, but ...
      - A big task can delay completion of other tasks
      - A crashing task can bring down the whole system!
  - Another idea: one thread / task
    - Solves problems with sequential implementation
    - But it introduces others
      - Task-handling code must be thread-safe
      - There is overhead associated with task creation
      - There are limits on how many threads can be created
**SingleThreadWebServer (JCIP p. 114)**

```java
public class SingleThreadWebServer {
    public static void main(String[] args)
        throws IOException {
        ServerSocket socket = new ServerSocket(80);
        while (true) {
            Socket connection = socket.accept();
            handleRequest(connection);
        }
    }
}
```

- An instance of sequential task processing
  - Each task (connection) is handled by main thread
  - `handleRequest()` implemented elsewhere
- If `handleRequest()` crashes, so does webserver!
ThreadPerTaskWebServer (JCIP p. 115)

```java
public class ThreadPerTaskWebServer {
    public static void main(String[] args)
        throws IOException {
        ServerSocket socket = new ServerSocket(80);
        while (true) {
            final Socket connection = socket.accept();
            Runnable task = new Runnable() {
                public void run() {
                    handleRequest(connection);
                }
            };
            new Thread(task).start();
        }
    }
}
```

- Each task given a separate thread
- Under light-to-moderate load, this improves throughput, responsiveness
- Heavy load: too many threads!
Executors

• A middle ground between sequential task processing and thread-per-task processing
  – Executors contain a thread pool of worker threads
  – When a task comes in, and a thread is available, executor gives task to an idle thread
  – If no thread is available, executor queues the result for future execution
• Based on producer / consumer pattern
  – Producers: generators of tasks
  – Consumers: threads that execute tasks
• Decouples task submission from task execution
• Interface
  public interface Executor {
    void execute(Runnable command);
  }
public class TaskExecutionWebServer {
    private static final int NTHREADS = 100; // Fixed number of threads
    private static final Executor exec = Executors.newFixedThreadPool(NTHREADS);
    public static void main(String[] args) throws IOException {
        ServerSocket socket = new ServerSocket(80);
        while (true) {
            final Socket connection = socket.accept();
            Runnable task = new Runnable() {
                public void run() {
                    handleRequest(connection);
                }
            };
            exec.execute(task);
        }
    }
    private static void handleRequest(Socket connection) {
        // request-handling logic here
    }
}
Execution Policies

• Executor implementation enables different execution policies to be defined
• An execution policy specifies how tasks get executed
  – Which thread?
  – What order (FIFO, LIFO, priority order)?
  – How many concurrent tasks?
  – How many tasks may be queued pending execution?
  – Overload policy? (Which task to kill, and how)
  – Pre- / post-task actions to perform, if any?
• Execution policies are a resource-management tool Permit management of concurrency vis a vis number of processors, other resources
Thread Pools

• Contains collection of homogeneous *worker threads*
• Is tightly bound to a work queue holding tasks to be executed
• Worker threads:
  – Request next task from work queue
  – Execute it
  – Return to waiting for next task
• Advantages (vs. creating new thread)
  – No need to wait for creation of new task
  – No overhead associated with task creation, elimination
• **Executors** class contains factory methods for creating thread pools, e.g.
  – `static ExecutorService newFixedThreadPool(int nThreads)`
    Creates a thread pool that reuses a fixed number of threads operating off a shared unbounded queue.
  – `static ExecutorService newCachedThreadPool()`
    Creates a thread pool that creates new threads as needed, but will reuse previously constructed threads when they are available.
  – `static ExecutorService newSingleThreadExecutor()`
    Creates an Executor that uses a single worker thread operating off an unbounded queue.
  – `static ScheduledExecutorService newScheduledThreadPool(int corePoolSize)`
    Creates a thread pool that can schedule commands to run after a given delay, or to execute periodically.
ExecutorService?

- The factory methods in Executors return objects in `ExecutorService`
- `ExecutorService`
  - Is an interface extending `Executor`
  - The new methods include mechanisms for shutting down an executor
    - JVM cannot terminate until all non-daemon threads shut down
    - Worker threads are non-daemon threads
    - Shutting down an executor requires shutting down these threads and dealing with any queued tasks
Executor Life Cycle

• An executor can be in one of three states
  – *Running*: executor is executing tasks, accepting new tasks
  – *Shutdown*: executor has stopped accepting new tasks, may or may not be finishing already accepted tasks
  – *Terminated*: executor has terminated all worker threads and is done
• ExecutorService interface includes methods corresponding to these states
  – void shutdown()
    Initiates an orderly shutdown in which previously submitted tasks are executed, but no new tasks will be accepted.
  – List<Runnable> shutdownNow()
    Attempts to stop all actively executing tasks, halts the processing of waiting tasks, and returns a list of the tasks that were awaiting execution.
  – boolean isShutdown()
    Returns true if this executor has been shut down.
  – boolean isTerminated()
    Returns true if all tasks have completed following shut down.
  – boolean awaitTermination(long timeout, TimeUnit unit)
    Blocks until all tasks have completed execution after a shutdown request, or the timeout occurs, or the current thread is interrupted, whichever happens first.
What About Tasks Submitted After Shutdown?

They are handled by the *rejected execution handler*

- Could just swallow the tasks
- Could throw `RejectedExecutionException`
- Depends on implementation!

• More details in later part of book
public class LifecycleWebServer {
    private final ExecutorService exec = Executors.newCachedThreadPool();

    public void start() throws IOException {
        ServerSocket socket = new ServerSocket(80);
        while (!exec.isShutdown()) {
            try {
                final Socket conn = socket.accept();
                exec.execute(new Runnable() {
                    public void run() {
                        handleRequest(conn);
                    }
                });
            } catch (RejectedExecutionException e) {
                if (!exec.isShutdown()) log("task submission rejected", e);
            }
        }
    }

    public void stop() { exec.shutdown(); }

    void handleRequest(Socket connection) {
        Request req = readRequest(connection);
        if (isShutdownRequest(req)) stop();
        else dispatchRequest(req);
    }
}