CS 351
Design of Large Programs
Java Threads

October 21, 2021

Processes and Threads

Process

- has a private, self-contained execution environment
  - OS allocated memory space, processor resources

Thread

- has a private, self-contained execution environment
  - a subset of the parent process' resources
- constituent of a process
  - every process consists of at least one thread
  - a "lightweight process"

Threads

A *thread* is a programming abstraction that allows concurrency to be implemented

- runs a single, sequential set of operations
- possesses its own call stack
- has access to shared state (among threads)

Every process begins as a single thread of execution
Additional threads are created to handle concurrent operations

Threads

Threads may:

- perform different tasks in parallel
- perform different instances of the same task in parallel

Common designs

- Threads are created by the main program to handle tasks
  - thread management is handled directly by the main application
- Tasks are passed to an *executor*
  - Executor creates threads and assigns them to received tasks
  - thread management is abstracted from the rest of the application

Case Study: Auto-Save

Consider a word processing application which retains "undo" capabilities throughout the lifetime of a document:

- documents grow very large over time
- saving large documents to disk can take several seconds

The user wants to enable *auto-save* which will automatically save changes to the document while she works.

Auto-Save: Sequential Design

File writes and user interface (UI) rendering occur in the same thread

- same thread, same sequence of execution

What will this look like?

Sequential Design: Pitfall

Since saves are time-consuming for large files, UI updates will stop each time the document is auto-saved.

What this looks like: a "laggy" user interface

Auto-Save: Concurrent Design

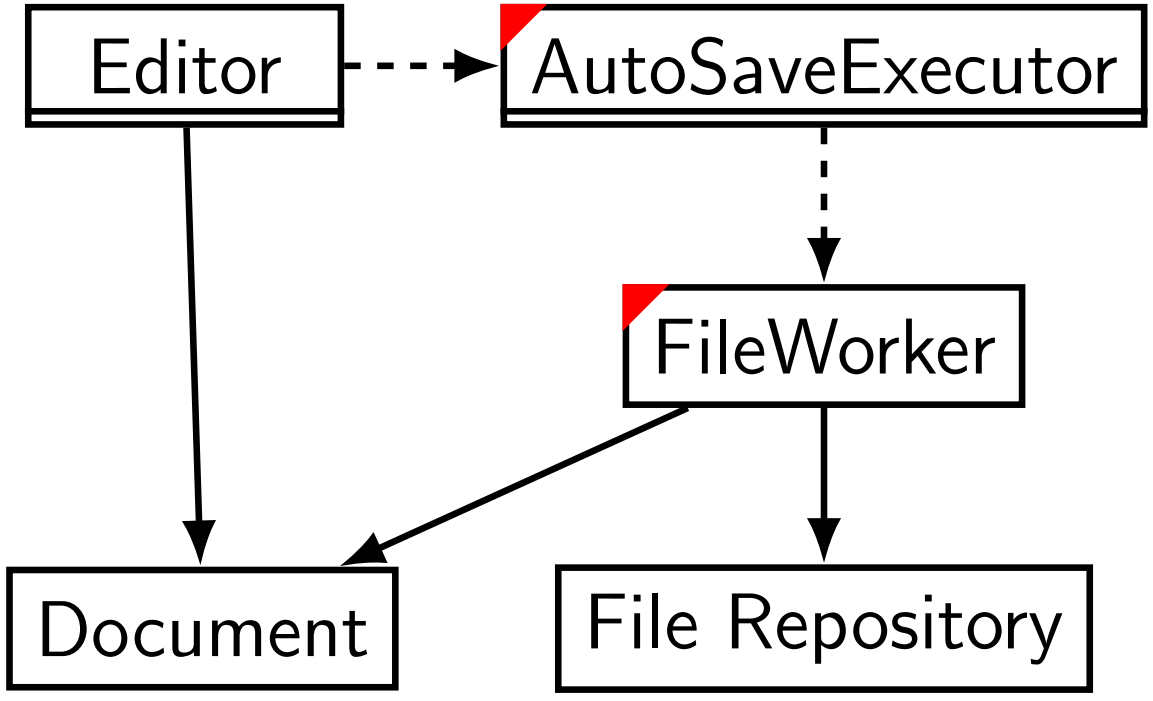
Auto-saves should be processed in a separate (worker) thread.

- In general: long jobs/tasks should occur in *different threads* than tasks which demand responsiveness (i.e. rendering a user interface)

Even with threads at our disposal, in practice we should utilize an efficient data structure to store the document

- in this case: a data structure which minimizes time complexity of document saves
- food for thought: how might this data structure be designed?

Auto-Save: Concurrent Design Overview



Auto-Save: Concurrent Design Overview

- Editor – the UI and main thread
  - renders and updates the user interface
  - has its own thread
- Document – the shared state we want to save
- AutoSaveExecutor – an *executor*
  - manages the creation of FileWorker threads assigned to save operations
- FileWorker
  - writes the current snapshot of the Document into the File Repository in a separate thread

Threads: Extending Thread

```
class FileWorker extends Thread {
  @Override
  public void run() {
    // save the file
  }
}
// other methods, etc.

public static void main(String[] args) {
  FileWorker worker = new FileWorker();
  worker.start();
}
```

We can invoke start only once during the Thread's lifecycle. Our code in run will be executed; the Thread terminates upon return

Threads: Implementing Runnable

```
class FileWorker implements Runnable {
  @Override
  public void run() {
    // save the file
  }
}
// other methods, etc.

public static void main(String[] args) {
  FileWorker worker = new FileWorker();
  Thread workerThread = new Thread(worker);
  workerThread.start();
}
```

Again, start can only be invoked once during the Thread's lifecycle. We cannot reuse Thread instances after they have returned from run.

Which is preferable?

Implementing Runnable is preferable in most cases:

- extending Thread inherits all of the overhead of the Thread superclass
- a class which implements Runnable can be further extended, while a class which extends Thread cannot
    - single inheritance, which sacrifices modularity

An Aside: Inter-thread Communication

- Threads in Java can call one another's methods (assuming they have references to one another)
- This allows:
  - inter-thread communication
  - *polling*: one thread periodically checks the state of another

Inter-thread Communication: Dominos

```
public class Domino extends Thread {
  private static int count = 0;
  private Domino next;
  private boolean standing = true;

  public Domino(Domino next) {
    setName("" + count++); // get/setName inherited from Thread
    this.next = next;
  }

  @Override
  public void run() {
    while(standing) {
      // remain standing
    }
    if (next != null) { next.topple(); }
  }

  public void topple() {
    standing = false;
    System.out.println(Thread.currentThread().getName()
                       + " toppled " + getName());
  }
}
```

Inter-thread Communication: Dominos

```
public static void main(String[] args) {
  Domino d5 = new Domino(null);
  Domino d4 = new Domino(d5);
  Domino d3 = new Domino(d4);
  Domino d2 = new Domino(d3);
  Domino d1 = new Domino(d2);

  d1.start();
  d2.start();
  d3.start();
  d4.start();
  d5.start();

  d1.topple(); // topple the first domino
}
```

Does this code always work??

Auto-Save: Implementation Overview

Beginning with basic functionality, we will incrementally implement auto-save:

1. Class and method stubs
2. Thread.sleep: Implementing a timed auto-save interval
3. Spawning FileWorker threads to perform the save operation
4. Thread.join: Pausing execution until save completion
5. Thread.interrupt: Terminating threads
6. Thread.setPriority: Providing optimizing hints to the JVM thread scheduler

AutoSaveExecutor

```
public class AutoSaveExecutor implements Runnable {
  private int saveInterval;
  private Document document;

  public AutoSaveExecutor(int saveInterval,
                          Document document) {
    this.saveInterval = saveInterval;
    this.document = document;
  }

  @Override
  public void run() {
    // spawn a new FileWorker every saveInterval...
  }
}
```

Editor

```
public class Editor {
  private Document curDoc = new Document();
  private Thread autoSaveThread;

  public Editor(boolean autoSaveEnabled) {
    // Instantiation of Document state...

    if(autoSaveEnabled) {
      AutoSaveExecutor autoSaveExec =
            new AutoSaveExecutor(60000, curDoc);
      autoSaveThread = new Thread(autoSaveExec);
      autoSaveThread.start();
    }
  }
  // GUI rendering, associated methods...
}
```

Document

```
public class Document {
  private Path path;

  public Path getPath() {
    return path;
  }

  @Override
  public String toString() {
    // return a String representing the Document...
  }
}
```

A lot of design happens here – in this example, it's assumed our Document and all of its tracked changes are encoded as Strings. In practice, this may not be the case.

FileWorker

```
public class FileWorker implements Runnable {
  private final Document docToSave;

  public FileWorker(Document docToSave) {
    this.docToSave = docToSave;
  }

  @Override
  public void run() {
    try {
      BufferedWriter bufferedWriter =
          Files.newBufferedWriter(docToSave.getPath());
      bufferedWriter.write(docToSave.toString());
      bufferedWriter.close();
    } catch (IOException e) {
      e.printStackTrace();
    }
  }
}
```

AutoSaveExecutor: Implementing a timed save interval

- We want the AutoSaveExecutor to create FileWorker threads on a fixed interval.
- Using the Thread.sleep mechanism, we can put the executor thread to sleep when it doesn't need to be executing (i.e. spawning worker threads).

AutoSaveExecutor: save interval

```
public class AutoSaveExecutor implements Runnable {
  private int saveInterval;

  public AutoSave(int saveInterval) {
    this.saveInterval = saveInterval;
  }

  @Override
  public void run() {
    while(!Thread.interrupted()) {
      try {
        Thread.sleep(saveInterval);
      } catch (InterruptedException e) {
        e.printStackTrace();
      }
    }
  }
}
```

AutoSaveExecutor: Spawning FileWorkers

Now that the AutoSaveExecutor wakes on an interval, we need it to dispatch FileWorker threads to perform the actual save operation.

```
@Override
public void run() {
  while (!Thread.interrupted()) {
    try {
      Thread.sleep(saveInterval);

      FileWorker fileWorker = new FileWorker(document);
      Thread fileWorkerThread = new Thread(fileWorker);
      fileWorkerThread.start();

    } catch (InterruptedException e) {
      e.printStackTrace();
    }
  }
}
```

AutoSaveExecutor: Thread.join

- Consider a scenario in which the time to complete a file write exceeds the interval at which FileWorker threads are spawned.
- What happens if we accidentally spawn several FileWorkers?

AutoSaveExecutor: Thread.join

- Consider a scenario in which the time to complete a file write exceeds the interval at which FileWorker threads are spawned.
- What happens if we accidentally spawn several FileWorkers?
  - answer: memory inconsistency and errors associated with several threads attempting to write to a single file at once
- Note: in many (if not most) cases, executors are designed to work with many worker threads running concurrently.
  - ex: a server using a thread pool executor and worker threads to handle concurrent client requests

AutoSaveExecutor: Thread.join

The join operation waits for the active thread on which it's called to die before proceeding.

```
@Override
public void run() {
  while(!Thread.interrupted()) {
    try {
      Thread.sleep(saveInterval);
      FileWorker fileWorker = new FileWorker(document);
      Thread fileWorkerThread = new Thread(fileWorker);
      fileWorkerThread.start();

      fileWorkerThread.join();

      System.out.println ("Write completed at "
                          + System.currentTimeMillis() );
    } catch (InterruptedException e) {
      e.printStackTrace();
    }
  }
}
```

Editor: Thread.interrupt

If our user wants to quit, we need to halt or interrupt the AutoSaveExecutor thread and join after the interrupt is processed

```
public void disableAutoSave() {
  autoSaveThread.interrupt();

  try {
    autoSaveThread.join();
  } catch (InterruptedException e) {
    e.printStackTrace();
  }
}
```

Threads: Priority & Scheduling

- The priority of a thread determines the amount of processing resources it will be allotted by the Java Virtual Machine (JVM).
- To ensure UI updates are scheduled favorably (given more resources) and auto-saves are scheduled less-favorably, we can assign priorities to respective threads after creating them.

```
AutoSaveExecutor autoSaveExec =
    new AutoSaveExecutor(60000, curDoc);
autoSaveThread = new Thread(autoSaveExec);
autoSaveThread.setPriority(1);
autoSaveThread.start();
```