Parallel Programming

Recitation Session 7

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Executive Summary

- Determining when a thread has finished
- The Volatile Returns
- Solution to the last assignment
- Semaphores
- Implementing Monitors with Semaphores
- `wait()`, `notify()`, `notifyAll()`
- Hints for assignment 7

Outline

isAlive()

```
// Create and start a thread
Thread thread = new MyThread();
thread.start();

// Check if the thread has finished
// in a non-blocking way
if (thread.isAlive()) {
   // Thread has not finished
} else {
   // Finished
}
```

join(delayMillis)

```
// Wait for the thread to finish but don't
// wait longer than a specified time
long delayMillis = 5000; // 5 seconds
try {
   thread.join(delayMillis);
   if (thread.isAlive()) {
      // Timeout occurred,
      // thread has not finished
   } else {
      // Finished
   }
} catch (InterruptedException e) {
   // Thread was interrupted
}
```

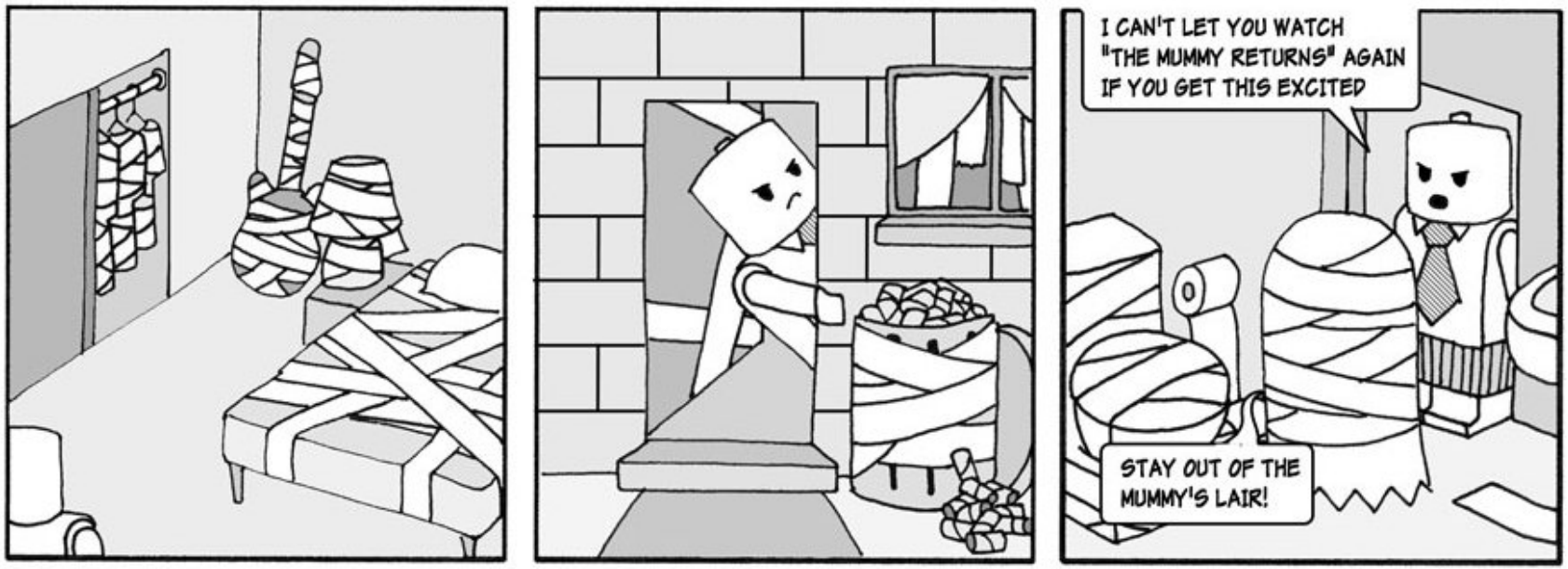
join()

```
// Wait indefinitely for the thread to finish
try {
   thread.join();
   // Finished
} catch (InterruptedException e) {
   // Thread was interrupted
}
```

Outline

The Volatile Returns

- Volatile variables are not cached in registers or in caches where they are hidden from other processors
- A read of a volatile variable always returns the most recent write by any thread



Source: `http://thescope.ca/comics/everybodycheerup/the-mummy-returns`

Example

```
public class ShutdownDriver {
  boolean shutdown = false;

  public static void main(String[] args) throws InterruptedException {
    ShutdownDriver driver = new ShutdownDriver();
    new BusyTask(driver).start();
    Thread.sleep(2000);
    driver.shutdown = true;
  }
}

public class BusyTask extends Thread {
  private ShutdownDriver driver;

  public BusyTask(ShutdownDriver driver) {
    this.driver = driver;
  }

  public void run() {
    while (!driver.shutdown) {}
    System.out.println("Busy task stopped!");
  }
}
```

Example: Volatile

```
public class ShutdownDriver {
  volatile boolean shutdown = false;

  public static void main(String[] args) throws InterruptedException {
    ShutdownDriver driver = new ShutdownDriver();
    new BusyTask(driver).start();
    Thread.sleep(2000);
    driver.shutdown = true;
  }
}

public class BusyTask extends Thread {
  private ShutdownDriver driver;

  public BusyTask(ShutdownDriver driver) {
    this.driver = driver;
  }

  public void run() {
    while (!driver.shutdown) {}
    System.out.println("Busy task stopped!");
  }
}
```

Synchronization

Reading

Reading a volatile field is like acquiring a lock: The working memory is invalidated and the volatile field's current value is reread from memory

Writing

Writing a volatile field is like releasing a lock: the volatile field is immediately written back to memory

Limitations

- Although reading and writing a volatile field has the same effect on memory consistency as acquiring and releasing a lock, multiple reads and writes are not atomic
- For example, if `x` is a volatile variable, the expression `x++` will not necessarily increment `x` if concurrent threads can modify `x`
- One common usage pattern for volatile variables occurs when a field is read by multiple threads, but only written by one

No Atomicity!

`volatile` alone is not strong enough to implement a counter, some form of mutual exclusion is needed as well

Outline

Code

```
A1 // non-critical section
A2 turn0.flag = 0;
A3 while(true)
     if(turn1.flag == 1)
       break;
A4   turn0.flag = 1;
A5   turn0.flag = 0;
   }
A6 // critical section
A7 turn0.flag = 1;
```

```
B1 // non-critical section
B2 turn1.flag = 0;
B3 while(true) {
     if(turn0.flag == 1)
       break;
B4   turn1.flag = 1;
B5   turn1.flag = 0;
   }
B6 // critical section
B7 turn1.flag = 1;
```

Invariants

1. `at(A6)` $\rightarrow$ `turn0.flag == 0`
2. `at(B6)` $\rightarrow$ `turn1.flag == 0`
3. `not [at(A6) AND at(B6)]`

We use the notation "`at(S)`" to indicate that execution is "at statement (location) `S`" $\Rightarrow$ all previous statements have executed while `S` has not yet started to execute

Proof (1)

- `at(A1)`, `at(A2)`, `at(A3)`, `at(A4)`, `at(A5)`, `at(A7)`: antecedent `at(A6)` is false
- `at(A6)`:
  - can only get to `A6` via `A3`;
  - can only get to `A3` via `A2`;
  - `A2` sets `turn0.flag` to `0`
- Thread `B` does not modify `turn0`

Proof (2)

Same way. Please do it if you had trouble with proof of (1).

Proof (3): By Contradiction

- Assume thread `A` is at state `A6`:
  - Hence `turn0.flag == 0` (invariant (i))
  - After some time, thread `B` wants to enter `B6`, which would require `turn0.flag == 1`
- Contradiction: `turn0.flag` cannot be `0` and `1` at the same time
- Equivalent proof for thread `B`

Outline

Semaphores

- Special integer variable with two atomic operations
  - `P()`: Passeren, wait/up
  - `V()`: Vrijgeven/Verhogen, signal/down
- Names of operations reflect the Dutch origin of the inventor...

Source: `http://en.wikipedia.org/wiki/File:Mechanical-signalling-north-geelong.jpg`

Class Semaphore

```
public class Semaphore {
  private int value;
  public Semaphore() {
    value = 0;
  }
  public Semaphore(int k) {
    value = k;
  }
  public synchronized void P() {
    /* see later */
  }
  public synchronized void V() {
    /* see later */
  }
}
```

P() Operation

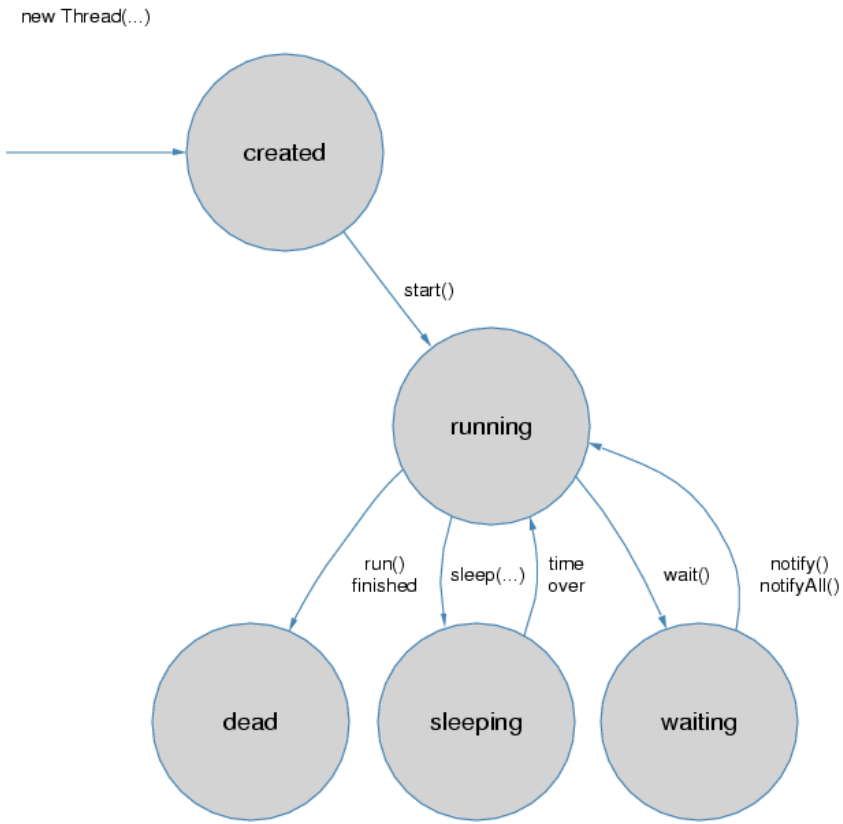
```
public synchronized void P() {
  while (value == 0) {
    try {
      wait();
    }
    catch (InterruptedException e) {
    }
  }
  value--;
}
```

V() Operation

```
public synchronized void V() {
  ++value;
  notifyAll();
}
```

wait(), notify(), notifyAll()

- `wait()` tells the calling thread to give up the monitor and go to sleep until some other thread enters the same monitor and calls `notify()`
- `notify()` wakes up a single thread that is waiting on this object's monitor. The choice is arbitrary and occurs at the discretion of the implementation.
- `notifyAll()` wakes up all threads that are waiting on this object's monitor



Comments

- You can only modify the value of a semaphore instance using the `P()` and `V()` operations.
  - Initialize in constructor
- Effect
  - `P()` may block
  - `V()` never blocks
- Application of semaphores:
  - Mutual exclusion
  - Conditional synchronization

Semaphores

- Binary semaphore
  - Value is either 0 or 1
  - Supports implemention of mutual exclusion:

```
Semaphore s = new Semaphore(1);
s.P()
//critical section
s.V()
```

- Counting (general) semaphore
  - Value can be any positive integer value

Fairness

- A semaphore is considered to be "fair" if all threads that execute a `P()` operation eventually succeed
- Semaphore is "unfair": a thread blocked in the `P()` operation must wait forever while other threads (that executed the operation later) succeed.

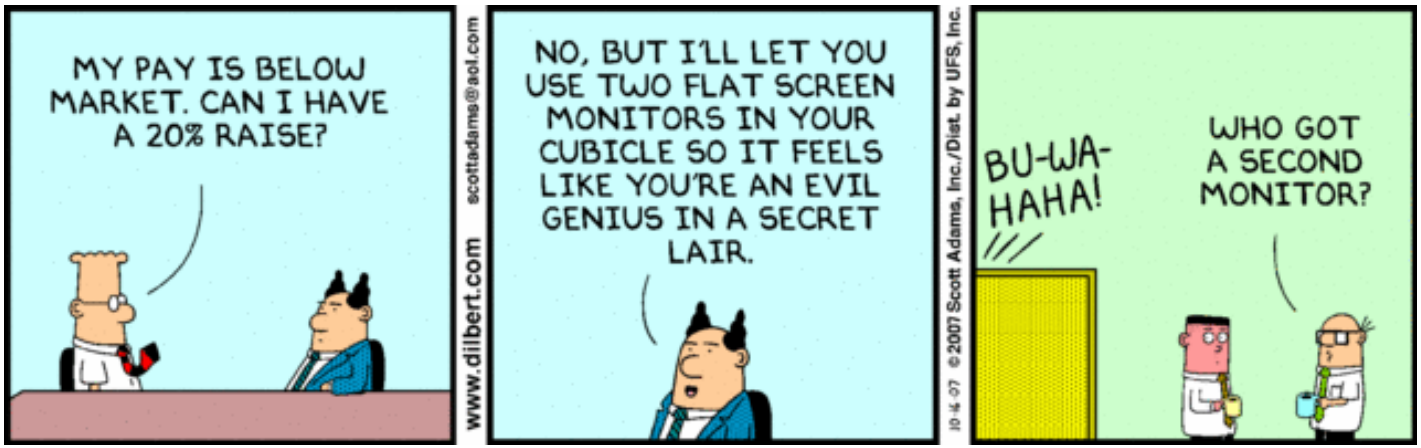
Semaphores in Java

- `java.util.concurrent.Semaphore`
  - `acquire()` instead of `P()`
  - `release()` instead of `V()`
- Constructors
  - `Semaphore(int permits)`
  - `Semaphore(int permits, boolean fair)`
    - `permits`: initial value
    - `fair`: if true then the semphore uses a FIFO to manage blocked threads

Outline

Semaphores and Monitors

- Monitor: model for synchronized methods in Java
- Both constructs are equivalent
- One can be used to implement the other



Example

See slides from March 18 for context

Buffer using condition queues

```
class BoundedBuffer extends Buffer {
  public BoundedBuffer(int size) {
    super(size);
  }
  public synchronized void insert(Object o)
    throws InterruptedException {
    while (isFull())
      wait();
    doInsert(o);
    notifyAll();
  }
  public synchronized Object extract()
    throws InterruptedException {
    while (isEmpty())
      wait();
    Object o = doExtract();
    notifyAll();
    return o;
  }
}
```

Emulation of monitor with semaphores

We need 2 semaphores:

- One to make sure that only one synchronized method executes at any given time
  - call this the "access semaphore" `access`
  - binary semaphore
- One semaphore to line up threads that are waiting for some condition
  - call this the "condition semaphore" `cond`
  - counting (general) semaphore
  - threads that wait must do an "acquire"

For convenience

Counter `waitThread` to count number of waiting threads i.e., threads in queue for `cond`

Basic idea

1. Frame all synchronized methods with `access.acquire()` and `access.release()`
   - This ensures that only one thread executes a synchronized method at any point in time
   - Recall: `access` is binary.
2. Translate `wait()` and `notifyAll()` to give threads waiting in line a chance to progress (these threads use `cond`)
   - To simplify the implementation, we require that `notifyAll()` is the last action in a synchronized method
   - Java does not enforce this requirement but the mapping of synchronized methods into semaphores is simplified

Buffer with auxiliary fields

```
class BoundedBuffer extends Buffer {
  public BoundedBuffer(int size) {
    super(size);
    access = new Semaphore(1);
    cond = new Semaphore(0);
  }

  private Semaphore access;
  private Semaphore cond;
  private int waitThread = 0;

  // continued
```

(1) Framing all methods

```
public void insert(Object o)
  throws InterruptedException {
  access.acquire(); // ensure mutual exclusion

  while (isFull())
    wait();

  doInsert(o);
  notifyAll();

  access.release();
}
```

Notes

- There is one semaphore for all synchronized methods of one instance of `BoundedBuffer`:
  - Must make sure that insert and extract don't overlap
- There must be separate semaphore to deal with waiting threads:
  - Imagine the buffer is full. A thread that attempts to insert an item must wait. But it must release the access semaphore. Otherwise a thread that wants to remove an item will not be able to executed the (synchronized!) extract method.

(2) Translate `wait()`

```
waitThread++;

// other threads can execute
// synchronized methods
access.release();

// wait till condition changes
cond.acquire();
access.acquire();

waitThread--;
```

(2) Translate `notifyAll()`

```
if (waitThread > 0) {
  for (int i=0; i < waitThread; i++) {
    cond.release();
  }
}
```

- All threads waiting are released and will compete to (re)acquire `access`
- They decrement `waitThread` after they leave `cond.acquire()`
- Note that to enter the line (i.e., increment `waitThread`) the thread must hold the access semaphore `access`

(2) Translate `wait()` and `notifyAll()`

- Recall that `access.release()` is done at the end of the synchronized method
- So all the threads that had lined up waiting for `cond` compete to get access to `access`
- No thread can line up while the `cond.release()` operations are done since this thread holds `access`

Note

- We wake up all threads – they might not be able to enter their critical section if the condition they waited for does not hold, but all threads get a chance.
- This approach is different from what we discussed in the lecture

Translate `wait()`

```
public void insert(Object o)
  throws InterruptedException {
  access.acquire();
  while (isFull()) {
    waitThread++;
    access.release(); // let other thread access object
    cond.acquire(); // wait for change of state
    access.acquire()
    waitThread--;
  }
  doInsert(o);
  notifyAll();
  access.release();
}
```

Translate `notifyAll()`

```
public void insert(Object o)
  throws InterruptedException {
  access.acquire();
  while (isFull()) {
    waitThread++;
    access.release(); // let other thread access object
    cond.acquire(); // wait for change of state
    access.acquire()
    waitThread--;
  }
  doInsert(o);
  if (waitThread > 0) {
    for (int i; i < waitThread; i++) {
      cond.release();
    }
  }
  access.release();
}
```

Example

Consider the buffer, one slot is empty, four operations

1. `insert I1`
2. `insert I2`
3. `insert I3`
4. `extract E`

Example

- I1 – `access.acquire()`
- I2 – `access.acquire()`: blocks on access
- I3 – `access.acquire()`: blocks on access
- I1 – `waitThread == 0`
- `I1.release`
- I2 – `access.acquire()` completes
- I2 – buffer full
- `waitThread = 1`
- I2 – `access.release()`
- I2 – `cond.acquire()` – blocks on `cond`
- I3 – `access.acquire()` completes
- I3 – buffer full

Example

- `waitThread = 2`
- I3 – `access.release()`
- I3 – `cond.acquire` – blocks on `cond`
- E – `access.acquire()`
- remove item
- E – `cond.release()`
- E – `cond.release()`
- E – `access.release()`

One of I2 or I3 will succeed with `access.acquire()` and be able to insert the next item

Exercise

How would the method `extract` look like if we used semaphores to emulate monitors?

Outline

Read/Write Lock

- Many shared objects have the property that most method calls return information about the object's state without modifying the object (**readers**) while only a small number of calls actually modify the object (**writers**)
- There is no need for readers to synchronize with one another
  - It is perfectly safe for them to access the object concurrently
- Writers, on the other hand, must lock out readers as well as other writers
- A Read/Write Lock allows multiple readers or a single writer to enter the critical section concurrently

Overview

- Your task is to implement a Read/Write Lock
- At most four threads
- At most two reader threads (shared access is allowed) and one writer thread
- A thread that executes `read()` is a reader
  - At a later time it can be a writer...

Challenges

- No starvation
- Efficient implementation
  - If there are fewer than two readers and no waiting writers then the next reader must be allowed to proceed
  - If there is no contention then a thread must be allowed to proceed immediately
- Your implementation must be fair:
  - You may want to use `FIFOQueue.java` (part of the skeleton)

Comments

- Keep your solution as simple as possible
- Decide what you want to use:
  - Monitors (synchronized methods)
  - Semaphores
    (see `http://java.sun.com/javase/6/docs/api/`)
- Only change class `Monitor.java` (part of the skeleton)
  - If you feel it's necessary to change other files, please let us know
- Please comment your code!

Hints

- `Thread.currentThread()` returns a handle to the current thread and might be useful for the assignment.
- `Thread.currentThread().getId()`:
  - `waitList.enq(Thread.currentThread().getId())`
  - `waitList.getFirstItem() == Thread.currentThread().getId()`

Summary

- Different ways to determine if a thread finished
- Volatile
- Semaphores
- Equivalence of Semaphores and Monitors
- Read/Write Lock