Java concurrency (lecture 7)

INF4140 - Models of concurrency

Java concurrency, lecture 7

Høsten 2013

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Outline

1. Monitors: review
2. Threads in Java:
   - Thread classes and Runnable interfaces
   - Interference and Java threads
   - Synchronized blocks and methods: (atomic regions and monitors)
3. Example The ornamental garden
4. Thread communication & Condition synchronization (wait and signal)
5. Example: Mutual exclusion
6. Example: Readers/writers

- monitor encapsulates data, which can only be observed and modified by the monitor's procedures
  - Contains variables that describe the *state*
  - variables can be accesses/changed only through the available *procedures*
- Implicit mutex: Only a procedure may be active at a time.
  - 2 procedures in the same monitor: never executed concurrently
- Condition synchronization: block a process until a particular condition holds) is given by *condition variables*.

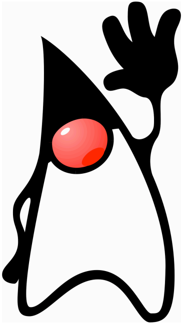
Signaling disciplines

- Signal and Wait (SW): the signaller waits, and the signalled process gets to execute immediately
- Signal and Continue (SC): the signaller continues, and the signalled process executes later

Java

From Wikipedia:[1]

" ... Java is a general-purpose, concurrent, class-based, object-oriented language ..."



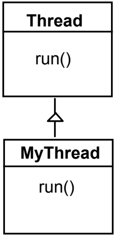
[1] But it's correct nonetheless . . .

A thread in Java

- unit of concurrency[2]
- identity, accessible via static method `Thread.CurrentThread()`[3]
- has it's own stack / execution context
- access to shared state
- shared mutable state: heap structured into objects
  - privacy restrictions possible
  - what are `private` fields?
- may be created (and deleted) dynamically

[2] as such, roughly corresponding to the concept of "processes" from previous lecctures

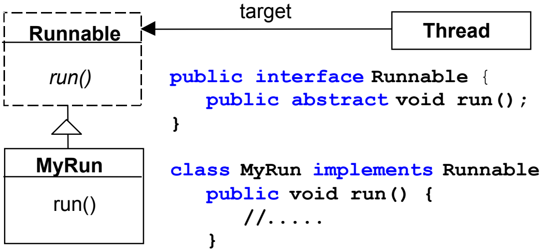
[3] What's the difference to `this`?



The Thread class executes instructions from its method `run()`. The actual code executed depends on the implementation provided for `run()` in a derived class.

```
class MyThread extends Thread {
  public void run() {
    // ......
  }
}
  // Creating a thread object:
  Thread a = new MyThread();
  a.start();
```

Since Java does not permit multiple inheritance, we often implement the `run()` method in a class not derived from `Thread` but from the interface `Runnable`.




```java
public interface Runnable {
    public abstract void run();
}

class MyRun implements Runnable{
    public void run() {
        //.....
    }
}
```

```java
// Creating a thread object:
Runnable b = new MyRun();
new Thread(b).start();
```

steps to *create* a thread in Java and get it running:

1. Define class that
   - *extends* the Java Thread class or
   - *implements* the Runnable interface
2. define *run* method inside the new class[4]
3. create an instance of the new class.
4. *start* the thread.

[4] overriding, late-binding.

```
...
class Store {
  private int data = 0;
  public void update() { data++; }
}
...

// in a method:
Store s = new Store(); // the threads below have access to s
t1 = new FooThread(s); t1.start();
t2 = new FooThread(s); t2.start();
```

t1 and t2 execute s.update() concurrently!

Interference between t1 and t2 $\Rightarrow$ may lose updates to data.

avoid interference ⇒ threads "synchronize" access to shared data

1. One unique lock for each object o.
2. mutex: at most one thread t can lock o at any time.[5]
3. 2 "flavors"

"synchronized block"

```
synchronized (o) { B }
```

synchronized method

whole method body of m "protected"[a]:

```
synchronized Type m(...) { ... }
```

[a] assuming that other methods play according to the rules as well etc.

[5] but: in a re-entrant manner!

Solution to earlier problem: lock the Store objects before executing problematic method:

```
class Store {
  private int data = 0;

  public void update() {
    synchronized (this) { data++; }
  }
}
```

or

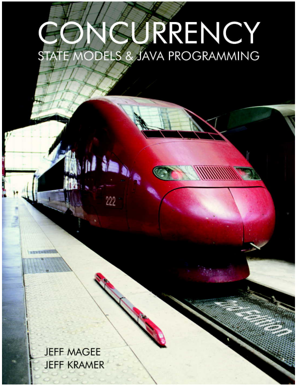
```
class Store {
  private int data = 0;

  public synchronized void update() {data++; }
}
...

// inside a method:
Store s = new Store();
```

Book:

Concurrency: State Models & Java Programs, 2nd Edition

Jeff Magee & Jeff Kramer

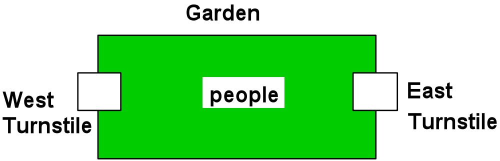
Wiley



Examples in Java:

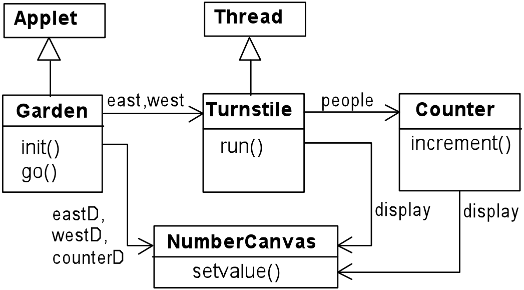
`http://www.doc.ic.ac.uk/~jnm/book/`

- people enter an ornamental garden through either of two turnstiles.
- problem: the number of people present at any time.



The concurrent program consists of:

- 2 threads
- shared counter object



The `Turnstile` thread simulates the periodic arrival of a visitor to the garden every second by sleeping for a second and then invoking the `increment()` method of the `counter` object.

```
class Counter {

    int value = 0;
    NumberCanvas display;

    Counter(NumberCanvas n) {
       display = n;
       display.setvalue(value);
     }

     void increment() {
        int temp = value;                  // read[v]
        Simulate.HWinterrupt();
        value = temp + 1;                  // write[v+1]
              display.setvalue(value);
        }
 }
```

Turnstile

```
class Turnstile extends Thread {
  NumberCanvas display;    // interface
  Counter people;          // shared data

  Turnstile(NumberCanvas n, Counter c) { // constructor
     display = n;
     people = c;
  }

  public void run() {
     try {
        display.setvalue(0);
        for (int i = 1; i <= Garden.MAX; i++) {
          Thread.sleep(500); // 0.5 second
          display.setvalue(i);
          people.increment();  // increment the counter
        }
     } catch (InterruptedException e) { }
   }
}
```

The Counter object and Turnstile threads are created by the go() method of the Garden applet:

```
private void go() {
  counter = new Counter(counterD);
  west = new Turnstile(westD, counter);
  east = new Turnstile(eastD, counter);
  west.start();
  east.start();
}
```

DEMO

After the `East` and `West` turnstile threads have each incremented its counter 20 times, the garden people counter is not the sum of the counts displayed. `Counter` increments have been lost. Why?

Avoid interference by synchronization

```
class SynchronizedCounter extends Counter {

  SynchronizedCounter(NumberCanvas n) {
    super(n);
  }

  synchronized void increment() {
    super.increment();
  }
}
```

DEMO

- *each* object
  - has attached to it a unique *lock*
  - and thus: can act as monitor
- 3 important monitor operations[6]
  - *o*.wait(): release lock on *o*, enter *o*'s wait queue and wait
  - *o*.notify(): wake up one thread in *o*'s wait queue
  - *o*.notifyAll(): wake up all threads in *o*'s wait queue
- executable by a thread "inside" the monitor represented by *o*
- executing thread must hold the lock of *o*/ executed within synchronized portions of code
- typical use: `this.wait()` etc.
- note: notify does *not* operate on a thread-identity[7]

⇒

```
Thread t = new MyThread();
...
t.notify();;        // mostly to be nonsense
```

[6] there are more

[7] technically, a thread identity is represented by a "thread object" though.

- quite simple/weak form of monitors in Java
- only one (implicit) condition variable per object: availability of the lock. threads that wait on o (o.wait()) are in this queue.
- ordering of wait "queue": implementation-dependent (usually FIFO)
- signaling discipline: S & C
- awakened thread: no advantage in competing for the lock to o.
- no built-in support for general-purpose condition variables.
- note: monitor-protection not enforced
  - `private` field modifier $\neq$ instance private
  - not all methods need to be synchronized[8]
  - besides that: there's re-entrance!

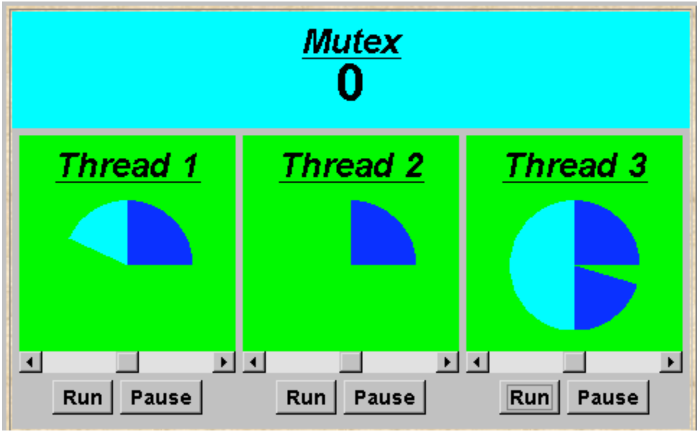
[8] remember: `find` of oblig-1.

A semaphore implementation in Java

```java
// down() = P operation
// up()   = V operation

public class Semaphore {
    private int value;

    public Semaphore (int initial) {
        value = initial;
    }

    synchronized public void up() {
        ++value;
        notifyAll();}

    synchronized public void down() throws InterruptedException {
        while (value==0) wait();
        --value;}
}
```

- cf. also `java.util.concurrency.Semaphore` (acquire/release + more methods)

Mutual exclusion with sempahores



Mutual exclusion with sempahores

```
class MutexLoop implements Runnable {

    Semaphore mutex;

    MutexLoop (Semaphore sema) {mutex=sema;}

    public void run() {
      try {
        while(true)  {
          while(!ThreadPanel.rotate());
           // get mutual exclusion
           mutex.down();
           while(ThreadPanel.rotate()); //critical section
           //release mutual exclusion
           mutex.up();
        }
      } catch(InterruptedException e){}
    }
}
```

DEMO

Readers and writers problem (again)

A shared database is accessed by two kinds of processes. Readers execute transactions that examine the database while Writers both examine and update the database. A Writer must have exclusive access to the database; any number of Readers may concurrently access it.

Interface R/W

```
interface ReadWrite {
    public void acquireRead() throws InterruptedException;
    public void releaseRead();
    public void acquireWrite() throws InterruptedException;
    public void releaseWrite();
}
```

Reader client code

```
class Reader implements Runnable {

    ReadWrite monitor_;

    Reader(ReadWrite monitor) {
      monitor_ = monitor;
     }

     public void run() {
       try {
         while(true)  {
              while(!ThreadPanel.rotate());
              // begin critical section
              monitor_.acquireRead();
              while(ThreadPanel.rotate());
              monitor_.releaseRead();
         }
       } catch (InterruptedException e){}
     }
}
```

```java
class Writer implements Runnable {

    ReadWrite monitor_;

    Writer(ReadWrite monitor) {
      monitor_ = monitor;
     }

     public void run() {
       try {
         while(true)  {
              while(!ThreadPanel.rotate());
              // begin critical section
              monitor_.acquireWrite();
              while(ThreadPanel.rotate());
              monitor_.releaseWrite();
         }
       } catch (InterruptedException e){}
     }
}
```

R/W monitor (regulate readers)

```
class ReadWriteSafe implements ReadWrite {
  private int readers =0;
  private boolean writing = false;

  public synchronized void acquireRead()
              throws InterruptedException {
    while (writing) wait();
    ++readers;
  }

  public synchronized void releaseRead() {
    --readers;
    if(readers==0) notifyAll();
  }

  public synchronized void acquireWrite() {...}

  public synchronized void releaseWrite() {...}
}
```

R/W monitor (regulate readers)

```
class ReadWriteSafe implements ReadWrite {
  private int readers =0;
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  public synchronized void acquireRead()
               throws InterruptedException {
    while (writing) wait();
    ++readers;
  }

  public synchronized void releaseRead() {
    --readers;
    if(readers==0) notifyAll();
  }

  public synchronized void acquireWrite() {...}

  public synchronized void releaseWrite() {...}
}
```
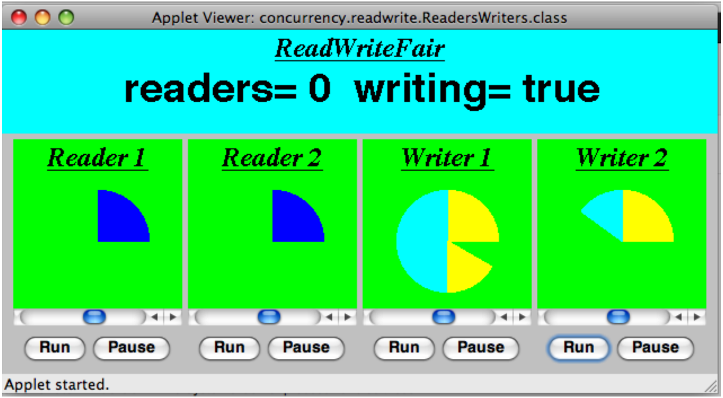

R/W monitor (regulate writers)

```
class ReadWriteSafe implements ReadWrite {
  private int readers =0;
  private boolean writing = false;

  public synchronized void acquireRead() {...}

  public synchronized void releaseRead() {...}

  public synchronized void acquireWrite()
              throws InterruptedException {
    while (readers>0 || writing) wait();
    writing = true;
  }

  public synchronized void releaseWrite() {
    writing = false;
    notifyAll();
  }
}
```

DEMO

Fairness



Applet Viewer: concurrency.readwrite.ReadersWriters.class
ReadWriteFair
readers= 0 writing= true
Reader 1
Reader 2
Writer 1
Writer 2
Run
Pause
Run
Pause
Run
Pause
Run
Pause
Applet started.

```
class ReadWriteFair implements ReadWrite {

    private int readers =0;
    private boolean writing = false;
    private int waitingW = 0; // no of waiting Writers.
    private boolean readersturn = false;

    synchronized public void acquireRead()
    throws InterruptedException {
        while (writing || (waitingW>0 && !readersturn)) wait();
        ++readers;
      }

    synchronized public void releaseRead() {
        --readers;
        readersturn=false;
        if(readers==0) notifyAll();
    }

    synchronized public void acquireWrite() {...}
    synchronized public void releaseWrite() {...}
 }
```

"Fairness": regulating writers

```
class ReadWriteFair implements ReadWrite {

    private int readers =0;
    private boolean writing = false;
    private int waitingW = 0; // no of waiting Writers.
    private boolean readersturn = false;

    synchronized public void acquireRead() {...}
    synchronized public void releaseRead() {...}

    synchronized public void acquireWrite()
    throws InterruptedException {
        ++waitingW;
        while (readers>0 || writing) wait();
        --waitingW; writing = true;
      }

    synchronized public void releaseWrite() {
        writing = false; readersturn=true;
        notifyAll();
    }
 }
```

Readers and Writers problem

DEMO

- there's (much) more to it than what we discussed (synchronization, monitors) (see `java.util.concurrency`)
- Java's memory model: since Java 1: loooong, hot debate
- connections to
  - GUI-programming (swing/awt/events) and to
  - RMI etc.
- major *clean-up*/repair since Java 5
- better "thread management"
- `Lock` class (allowing `new Lock()` and non block-structured locking)
- one simplification here: Java has a (complex!) weak memory model (out-of-order execution, compiler optimization)
- not discussed here `volatile`

shared, mutable state is more than a bit tricky,[a] watch out!

- work thread-local if possible
- make variables *immutable* if possible
- keep things local: encapsulate state
- learn from tried-and-tested concurrent design patterns

[a] and pointer aliasing and a weak memory model makes it worse.

golden rule

never, ever allow (real, unprotected) races

- unfortunately: no silver bullet
- for instance: "synchronize everything as much as possible": not just inefficient, but mostly nonsense

$\Rightarrow$ concurrent programmig remains a bit of an art

see for instance [GPB+06] or [Lea99]

[And00] Gregory R. Andrews.
Foundations of Multithreaded, Parallel, and Distributed Programming.
Addison-Wesley, 2000.

[GPB+06] Briand Goetz, Tim Peierls, Joshua Bloch, Josheph Bowbeer, David Holmes, and Doug Lea.
Java Concurrency in Practice.
Addison-Wesley, 2006.

[Lea99] Doug Lea.
Concurrent Programming in Java: Design Principles and Patterns.
Addison-Wesley, 2d edition, 1999.

[MK99] Jeff Magee and Jeff Kramer.
Concurrency: State Models and Java Programs.
Wiley & Sons, 1999.