Outline

1. Opening
2. Concurrency
3. Basics of concurrency in Java
4. Closing
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2. Concurrency
3. Basics of concurrency in Java
4. Closing
Homework from Monday

1. Read This
The instructions for the APL written coursework assignment.  
https://is.gd/apl18coursework

2. Write This
The outline draft for your assignment, following in detail the instructions above.
What’s in the course?

The lectures cover four sample areas of “advances in programming languages”:

- Types: Parameterized, Polymorphic, Dependent, Refined
- Programming for Concurrency
- Augmented Languages for Correctness and Certification
- Programming for Memory and Thread Safety with Rust
This is the first of a block of lectures looking at programming-language techniques for concurrent programs and concurrent architectures.

- Introduction, basic Java concurrency
- Concurrency abstractions
- Concurrency in different languages
- Current challenges in concurrency
The free lunch is over

For the past 30 years, computer performance has been driven by Moore’s Law; from now on, it will be driven by Amdahl’s Law.

Doron Rajwan, Intel Power Management Architect

42 Years of Microprocessor Trend Data

Transistors (thousands)

Single-Thread Performance (SpecInt x 10^3)

Frequency (MHz)

Typical Power (Watts)

Number of Logical Cores

Year


Ian Stark
APL / Lecture 8: Concurrency
2016-10-11
The free lunch is over

For the past 30 years, computer performance has been driven by Moore’s Law; from now on, it will be driven by Amdahl’s Law.

Doron Rajwan, Intel Power Management Architect
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Concurrency is the next major revolution in how we write software. . . . The vast majority of programmers today don’t grok concurrency, just as the vast majority of programmers 15 years ago didn’t yet grok objects.

Herb Sutter
Microsoft, C++ ISO chair
The free lunch is so over

https://herbsutter.com/welcome-to-the-jungle/
Why write concurrent programs?

Concurrent programming is about writing code that can handle doing more than one thing at a time. There are various motivations, such as:

- Separation of duties (fetch data, render images)
- Efficient use of mixed resources (disk, memory, network)
- Responsiveness (GUI, sensors and devices, embedded systems)
- Speed (multiprocessing, hyperthreading, multi-core, GPGPU)
- Scale (distribution, cloud, elasticity)
- Serving multiple clients (database engine, web server)

Note that the aims here are different to parallel programming, which is generally about the efficient (and speedy) processing of large sets of data.
Other computational modalities have this too
How hard can it be?

What's Wrong With Threads?

casual

all programmers

wizards

Visual Basic programmers

C programmers

C++ programmers

Threads programmers

John Ousterhout: Why Threads Are A Bad Idea (for most purposes)
USENIX Technical Conference, invited talk, 1996
It’s hard to walk and chew gum

Concurrent programming offers much, including entirely new problems.

- **Interference** — code that is fine on its own may fail if run concurrently.
- **Liveness** — making sure that a program does anything at all.
- **Starvation** — making sure that all parts of the program make progress.
- **Fairness** — making sure that everyone makes reasonable progress.
- **Scalability** — making sure that more workers means more progress.
- **Causality** — making sure that things happen in a particular order.
- **Safety** — making sure that the program always does the right thing.
- **Specification** — just working out what is “the right thing” can be tricky.

Concurrent programming is hard, and although there is considerable research, and even progress, on how to do it well, it is often wise to avoid doing it (explicitly) yourself unless absolutely necessary.

The greatest performance improvement of all is when a system goes from not-working to working — *Ousterhout*
Clients

- Abadon
- ABB
- Access Research
- Adtranz Signal
- Advanced Methods
- AGS Nynex
- Apogee Communications Technologies
- Ariel Technologies
- AT&T
- Auburn University
- BDM International Inc.
- BMC3 Engineering
- Boeing
- Boston University
- Bowe Software Solutions
- Lockheed Martin
- Logicon
- Loral
- Los Alamos National Laboratories
- Massachusetts Institute of Technology (MIT)
- McDonnell Douglas
- Mitre
- Motorola
- MRJ, Inc.
- NASA
- Newbridge Networks
- NR Pty, Ltd.
- NRI & NCC Co. Ltd.
- NSA
- Pacific States Marine Fisheries Commission
Women of NASA

By @20tauri

Celebrate the history of women in science, technology, engineering, and math!
It’s hard to walk and chew gum

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Processes, Threads, Tasks, Events

All operating systems and many programming languages provide for concurrent programming, usually through a notion of process, thread, task, or event handler.

The idea is that a process/thread/task/handler captures a single flow of control. A concurrent program will have many of these at a time.

A scheduler directs which threads are running at any time, and how control passes among them.

There are many design tradeoffs here, concerning memory separation, mutual protection, communication, scheduling, signalling, …

Usually processes are “heavyweight” (e.g., separate memory space), threads “lightweight” (shared memory) and tasks lightest. But usage is not precise or consistent. Any complete system will include multiple layers of concurrency, possibly of different kinds.

The concurrency presented to a programmer may not match that available on any particular hardware; and there will be a cost in maintaining the illusion of a persistent flow of control. I think it’s possible the model of multiple concurrent threads may itself become outdated.
A key issue with multiple explicit threads is to avoid interference through shared memory.

```java
void moveBy(int dx, int dy) {
    System.out.println("Moving by "+dx+","+dy);
    x = x+dx;
    y = y+dy;
    System.out.println("Completed move");
}

void moveTo(int newx, int newy) {
    System.out.println("Moving to "+newx+","+newy);
    x = newx;
    y = newy;
    System.out.println("Completed move");
}
```
A key issue with multiple explicit threads is to avoid interference through shared memory.

```c
void moveBy(int dx, int dy) {
    x = x+dx;
    y = y+dy;
}
```

```c
void moveTo(int newx, int newy) {
    x = newx;
    y = newy;
}
```

Because both methods access the fields x and y, it is vital that these two critical sections of code are not executing at the same time.
A key issue with multiple explicit threads is to avoid interference through shared memory.

```c
void moveBy(int dx, int dy) {
    x = x + dx;
    y = y + dy;
}

void moveTo(int newx, int newy) {
    x = newx;
    y = newy;
}
```

Interference can result in erroneous states — perhaps violating object invariants and causing crashes, or possibly going undetected until later.
Critical Section

A key issue with multiple explicit threads is to avoid interference through shared memory.

```c
void moveBy(int dx, int dy) {
    x = x + dx;
    y = y + dy;
}
```

```c
void moveTo(int newx, int newy) {
    x = newx;
    y = newy;
}
```

Debugging can be difficult because scheduling is often non-deterministic.

The only thing worse than a problem that happens all the time is a problem that doesn’t happen all the time — Ousterhout
There are many ways to ensure critical sections do not interfere, and refinements to make sure that these constraints do not disable desired concurrency.

- Locks
- Mutexes
- Semaphores
- Condition variables
- Monitors etc.

Constructs such as these can ensure *mutual exclusion* or enforce *serialization* orderings.

They are implemented on top of other underlying locking mechanisms, either in hardware (test-and-set, compare-and-swap, ...) or software (spinlock, various busy-wait algorithms).
Outline

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Concurrency in Java

Java supports concurrent programming as an integral part of the language: threading is always available, and a range of libraries provide high-level abstractions over the basic primitives.

The class **Thread** encapsulates a thread, which can run arbitrary code. Threads have unique identifiers, names, and integer priorities.

Parent code can spawn multiple child threads, and then wait for individual children to terminate or (co-operatively) interrupt them.

```java
class Watcher
    extends Thread {
        public void run() {
            // check what's going on
...
        }
    }

class WorkerJob
    implements Runnable {
        public void run() {
            // do some work
...
        }
    }

Watcher watcher = new Watcher();
watcher.start();
...
WorkerJob job = new WorkerJob();
Thread worker = new Thread(job).start();
...
work.join();
watcher.interrupt();
```
Synchronized methods

Java provides mutual exclusion for critical sections through the `synchronized` primitive.

```java
synchronized void moveBy(int dx, int dy) {
    System.out.println("Moving by "+dx+","+dy);
    x = x+dx;
    y = y+dy;
    System.out.println("Completed move");
}

synchronized void moveTo(int newx, int newy) {
    System.out.println("Moving to "+newx+","+newy);
    x = newx;
    y = newy;
    System.out.println("Completed move");
}
```
Synchronized methods

Two move methods cannot now execute at the same time on the same object.

```java
synchronized void moveBy(int dx, int dy) {
    System.out.println("Moving by "+dx+","+dy);
    x = x+dx;
    y = y+dy;
    System.out.println("Completed move");
}

synchronized void moveTo(int newx, int newy) {
    System.out.println("Moving to "+newx+","+newy);
    x = newx;
    y = newy;
    System.out.println("Completed move");
}
```
Synchronized methods

Each **synchronized** method must **acquire** a lock before starting and **release** it when finished.

```java
synchronized void moveBy(int dx, int dy) {
    System.out.println("Moving by "+dx+","+dy);
    x = x+dx;
    y = y+dy;
    System.out.println("Completed move");
}
```

```java
synchronized void moveTo(int newx, int newy) {
    System.out.println("Moving to "+newx+","+newy);
    x = newx;
    y = newy;
    System.out.println("Completed move");
}
```
Synchronized blocks

Every Java object has an implicit associated lock, used by its `synchronized` methods. This can also be used to arrange exclusive access to any block of code:

```java
void moveBy(int dx, int dy) {
    System.out.println("Moving by "+dx+","+dy);
    synchronized(this) {
        x = x+dx; // Only this section of the
        y = y+dy; // code is critical
    }
    System.out.println("Completed move");
}
```

The locking object need not be `this`. Sometimes a lock may be better on a contained (or “owned”) object, or may be needed on a containing (or “owning”) object.
Condition variables

Java refines critical regions with basic *condition variables*.

- Synchronized code that finds things are not suitable for it to proceed may `wait()` on the condition variable associated with its lock. This blocks the code and releases the lock.

- Another thread can acquire the lock and do some work. Because this may change the situation for the other thread, it should `notify()` or `notifyAll()` other threads of this.

- Threads waiting on the condition variable will be made runnable again, and can check to see if they are now ready to proceed.

Having threads block saves on busy waiting, and ensures that they only wake when there is something to check.
A simple blocking method

class Pigeonhole {

    private Object contents = null;

    synchronized void put (Object o) {

        while (contents != null) // Wait until the pigeonhole is empty
            try {
                 wait();
            } catch (InterruptedException ignore) {
                return;
            }

        contents = o; // Fill the pigeonhole
        notifyAll(); // Tell anyone who might be interested

    }

    ...

}
Summary

- Concurrency is essential (efficiency, responsiveness, speed).
- But can be tricky (interference, deadlock, fairness, ...).
- Concurrency can be in the language, in libraries, or in both.
- Java provides shared-memory concurrency in the language:
  - Locks and critical regions with `synchronized`;
  - Condition variables with `wait`, `notify` and `notifyAll`;
  - Explicit spawning of multiple threads.
- Java provides further concurrency abstractions in a library: `java.util.concurrent`.
Homework for Monday

1. Do This
Find out what a *data race* is. What happens to C or C++ code with a data race?

2. Read This
Read the first three sections of the Java Concurrency tutorial.

   http://java.sun.com/docs/books/tutorial/essential/concurrency

   Processes and Threads  •  Thread Objects  •  Synchronization

Have another Java concurrency tutorial to recommend? Great! Post on Piazza or mail me.