Shared Memory Programming

Java Threads

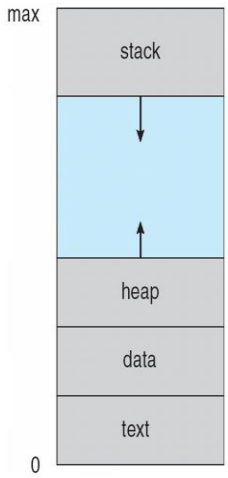
Lec 1

What is a Process?

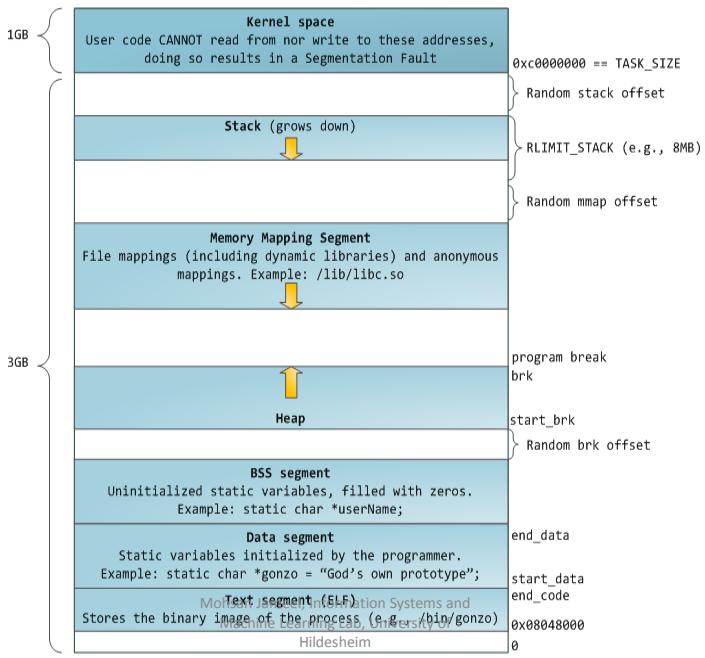
- A *process is an "instance" of a program running.*
  - **Modern OSes run multiple processes simultaneously**
- **Examples (can all run simultaneously):**
  - gcc file_A.c – compiler running on file A
  - gcc file_B.c – compiler running on file B
  - emacs – text editor
  - firefox – web browser
- **Non-examples (implemented as one process):**
  - Multiple firefox tabs are part of one process.
- **Why processes?**
  - Simplicity of programming
  - Higher throughput (better CPU utilization), lower latency

What is a Process?

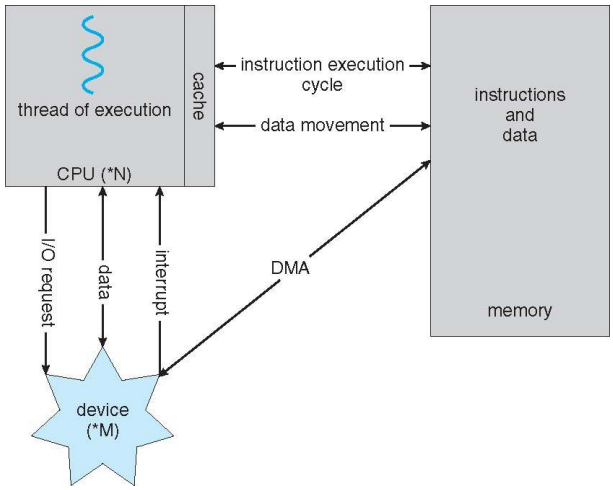
- **Each proc. P_i *has own view of machine***
  - Its own address space.
  - Its own open files.
  - Its own virtual CPU (through preemptive multitasking)
  - *(char *)0xc000 **different in P_1 & P_2**
- **Greatly simplifies programming model**
  - gcc does not care that firefox is running
- **Sometimes want interaction between processes**
  - Simplest is through files: emacs edits file, gcc compiles it
  - More complicated: Shell/command, Window manager/app.



Process Organization in Memory



Basic Execution



Basic Execution Environment

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int foo2 (int b)
{
        return b * gvar;
}

int foo1 (int a)
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        int lvar = a + gvar;
        return foo2(lvar);
}

int main ( )
{
        int var1, int var2;
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}
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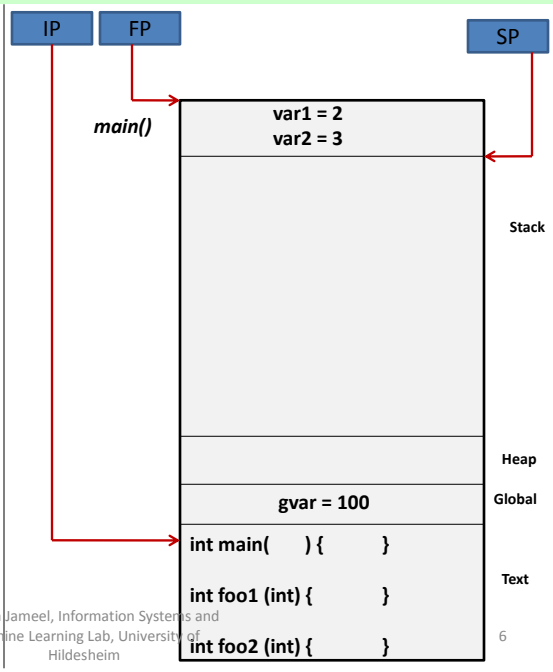

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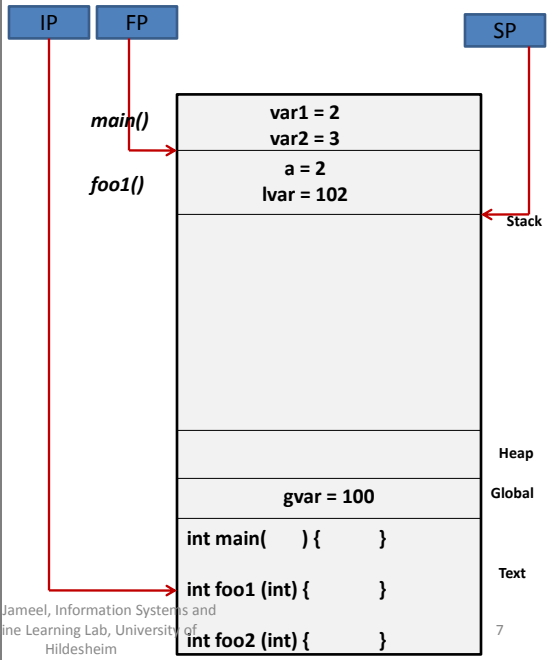

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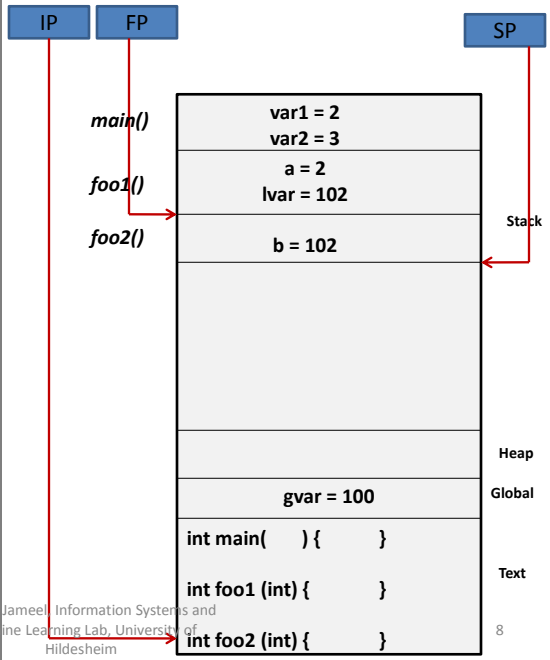

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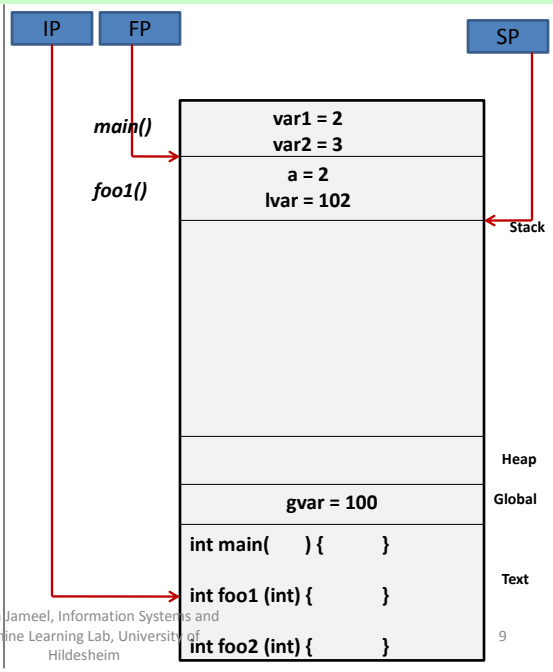

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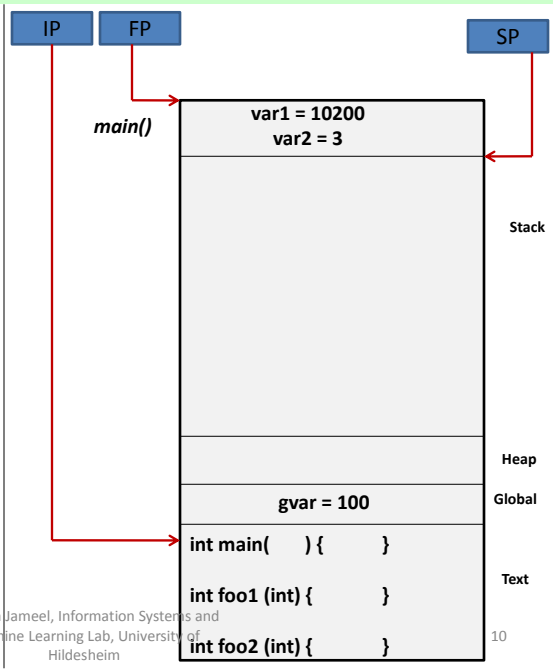

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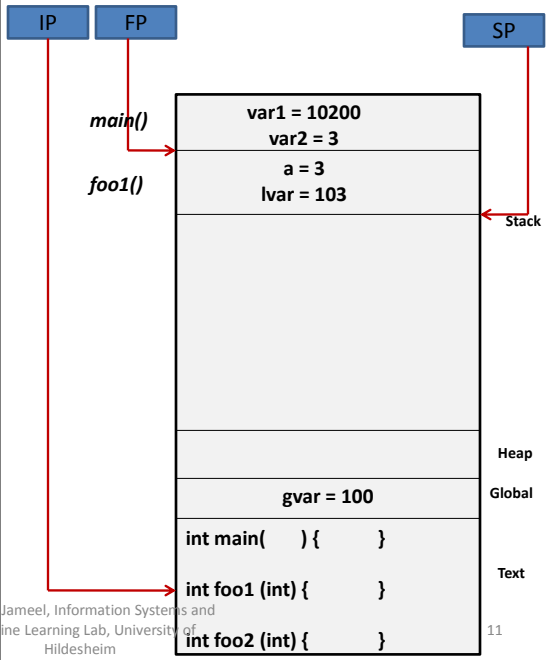

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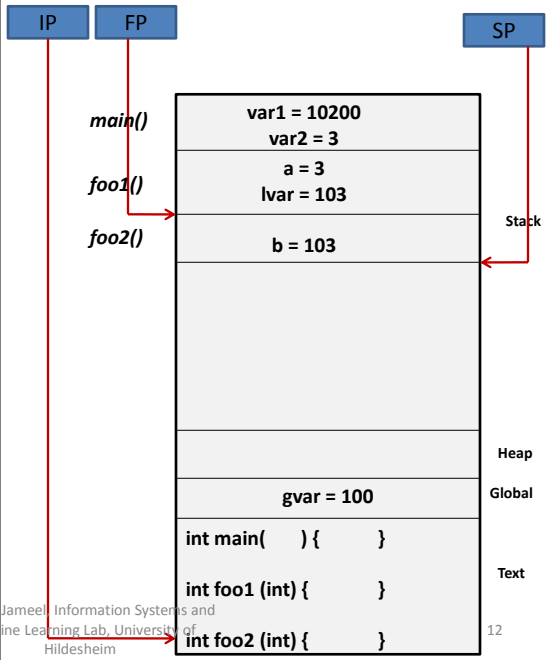

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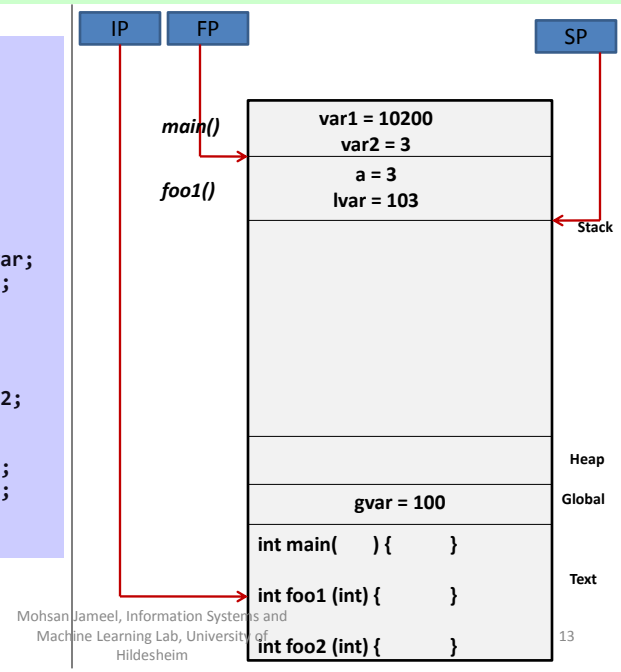

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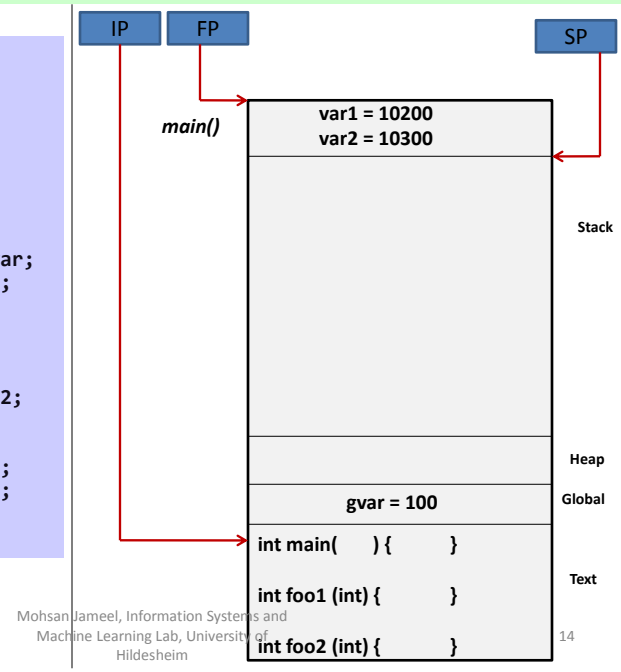
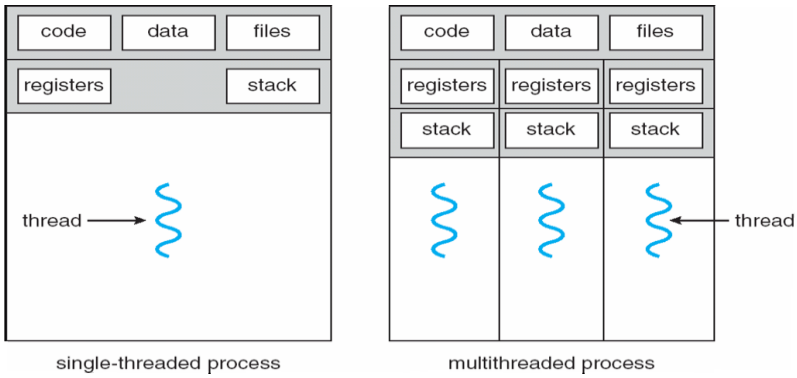
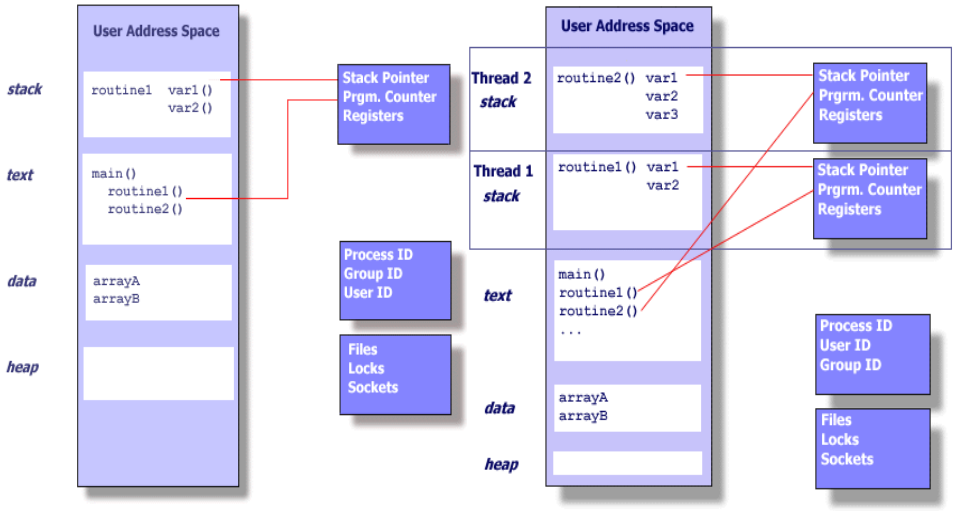


What is a thread?



- What's needed to run code on CPU
  - "execution stream in an execution context"
  - Execution stream: sequential seq. of instructions
- CPU execution context (1 thread)
  - State: stack, heap, registers
  - Position: Instruction Pointer(IP) register
- OS execution context (n threads):
  - identity + open file descriptors, page table, …

What is a thread?

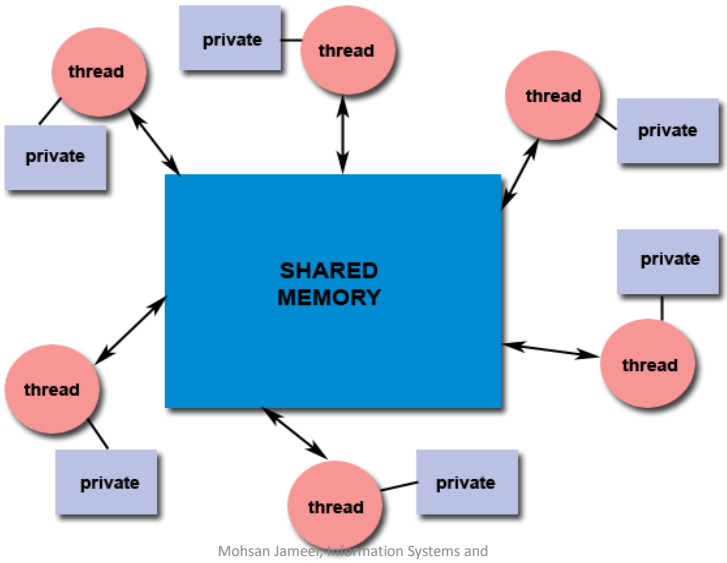


UNIX PROCESS **THREADS WITHIN A UNIX PROCESS**

What is a thread?

- All threads in a process share the same address space.
  - *(char *)0xc000 **means "the same" in thread T1 and T2.**
- All threads share the same file descriptors.
  - Which implies that they share network sockets.
- All threads have access to the same heap and same global variables.
- Write access to global variables should be protected by a synchronization mechanism.
- Each thread has its separate stack, Instruction Pointer and Local variables.
  - *Therefore each thread has its own independent flow of execution*

What is a thread?



Java Threads

Thread class

Each thread is an object of the **Thread** class.

(Java tutorial says: "Each thread is associated with an instance of the class Thread.")

Java provide two basic ways to creates a thread:

1. Define a class that extends the class **Thread**.
2. Make your class implement the **Runnable** interface

Simplest way is:

1. Define a class that extends the class Thread.
   - Object of this class is a thread.
   - Provide the method called **run** (which will override the inherited run method, which does nothing).
   - The **run** method defines the code for the thread.
   - Invoke the **start** method, which initiates the computation of the thread

Example

```
public class HelloThread extends Thread {

    public void run() {
        System.out.println("Hello from a thread!");
    }

    public static void main(String args[ ]) {

        HelloThread  myThread = new HelloThread();

        myThread.start();
        System.out.println("Hello from the Main!");
         myThread.join();
    }
}
```

Java entry point

Create Thread object

Start thread and execute run method

Example 2

```
public class SimpleThread extends Thread {
        public SimpleThread(String str) { super(str);  }
        public void run() {
          for (int i = 0; i < 10; i++) {
            System.out.println(i + " " + getName());
            try { // at this point, current thread is 'this'.
               Thread.sleep((long)(Math.random() * 1000));
            } catch (InterruptedException e) {}
          }
          System.out.println("DONE! " + getName());
        }
}
```



```
public class TwoThreadsTest {
        public static void main (String[] args) {
          new SimpleThread("Thread1").start();
          new SimpleThread("Thread2").start();
        }
}
```

possible output

```
0 Thread1
0 Thread2
1 Thread2
1 Thread1
2 Thread1
2 Thread2
3 Thread2
3 Thread1
4 Thread1
4 Thread2
5 Thread1
5 Thread2
6 Thread2
6 Thread1
7 Thread1
7 Thread2
8 Thread2
9 Thread2
8 Thread1
DONE! Thread2
9 Thread1
DONE! Thread1
```

The **Thread** class actually implements the interface called **Runnable**.

The **Runnable** interface defines the single method, **run**, meant to contain the code executed in the thread.

Alternate more powerful way to create threads:

2. Make your class explicitly implement the **Runnable** interface

```
package java.lang;
public interface Runnable {  public void run() ; }
```


Example

```
public class HelloRunnable implements Runnable {

        public void run() {
                System.out.println("Hello from a thread!");
        }

        public static void main(String args[ ]) {

                HelloRunnable  myThread = new HelloRunnable();
                Thread tr = new Thread(myThread);
                tr.start();
                 tr.join();
        }
}
```

Runnable object can subclass a class other than Thread, i.e.:

```
public class MyRunnable extends SomeClass implements Runnable {

        public void run() {
                System.out.println("Hello from a thread!");
        }
        public static void main(String args[ ]) {
                (new Thread(new HelloRunnable())).start();
        }

}
```

Note: both the Thread class and the Runnable interface are part of the standard Java libraries (java.lang package)

Java's Thread class

Various instance and class methods, setters and getters:

- Class methods:
  - **sleep()**
  - …
- Instance methods:
  - **join()**
  - **start()**
  - …

http://docs.oracle.com/javase/7/docs/api/java/lang/Thread.html

Race conditions and Synchronization

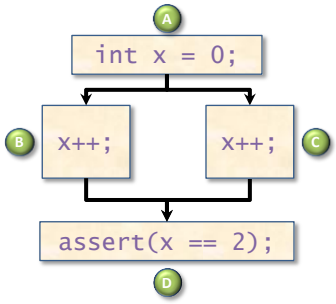
Race Conditions

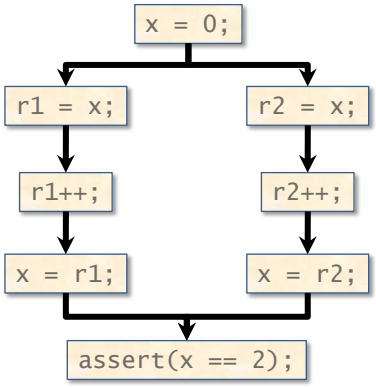
- "A race condition is a programming fault producing undetermined program state and behavior due to un-synchronized parallel program executions" – [Liang Chen's Blog]
- **Therac-25 radiation therapy machine** — killed 3 people and seriously injured many more.
- **North American Blackout of 2003** — left 50 million people without power

Race bugs are notoriously difficult to discover by conventional testing!

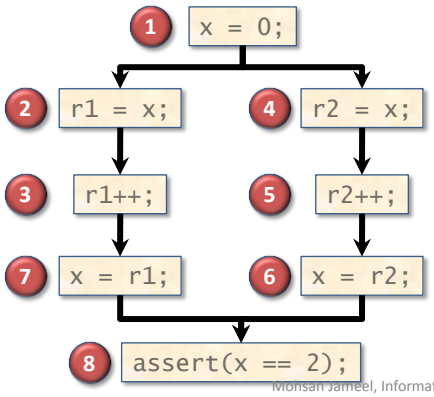
Determinacy race

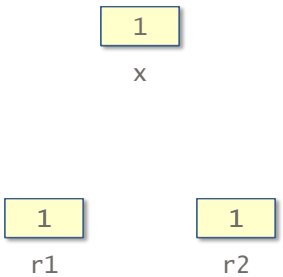
- **Definition.** A *determinacy race* occurs when two logically parallel instructions access the same memory location and at least one of the instructions performs a write.





Example





Types of Races

- For given X and Y instructions, suppose both update a memory location A. Then following scenario could occur.

X	Y	Race Type
read	read	none
read	write	read race
write	read	read race
write	write	write race

Java Synchronization

- Java provides synchronized keyword to synchronize blocks of instructions. It can be used with:
  - a block of code
  - to a method body.
- The thread first arrived at the synchronized keyword acquire lock and rest of the threads arriving later are blocked.
  - Once a lock is released, only one of the waiting thread get the lock.

Example

```
public class CounterClass {
        private int counter = 0;
        public synchronized void increment() {
                counter ++;
        }
        public synchronized void decrement() {
                counter --;
        }
        public synchronized int getValue() {
                return counter;
        }
}
```

Example using synchronized methods

On-line banking

Several entities can access account potentially simultaneously (maybe a joint account, maybe automatic debits, …)

Suppose three entities each trying to perform an operation, either:

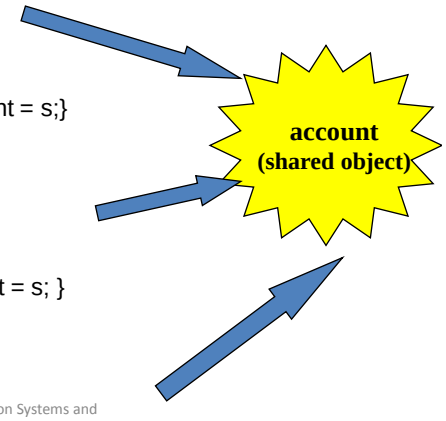
- deposit()
- withdraw()
- enquire()

Create three threads, one for each entities

```
class InternetBankingSystem {
      public static void main(String [] args  ) {
         Account accountObject = new Account ();
         Thread t1 = new Thread(new MyThread(accountObject));
         Thread t2 = new Thread(new YourThread(accountObject));
         Thread t3 = new Thread(new HerThread(accountObject));

         t1.start();
         t2.start();
         t3.start();

        // DO some other operation
         t1.join();
         t2.join();
         t3.join();

     } // end main()
}
```

Shared account

```
class MyThread implements Runnable  {
 Account account;
      public MyThread (Account s) {  account = s;}
      public void run() { account.deposit(); }
} // end class MyThread

class YourThread implements Runnable  {
 Account account;
      public YourThread (Account s) { account = s;}
      public void run() { account.withdraw(); }
} // end class YourThread

class HerThread implements Runnable  {
 Account account;
      public HerThread (Account s) { account = s; }
      public void run() {account.enquire(); }
} // end class HerThread
```



Synchronized account methods

```
class Account {
  int balance;
    // if 'synchronized' is removed, outcome unpredictable

      public synchronized void deposit( ) {
                balance += deposit_amount;
       }

       public synchronized void withdraw( ) {
                balance -= deposit_amount;
       }
       public synchronized void enquire( ) {
                display balance.
       }
}
```

Synchronized Statements

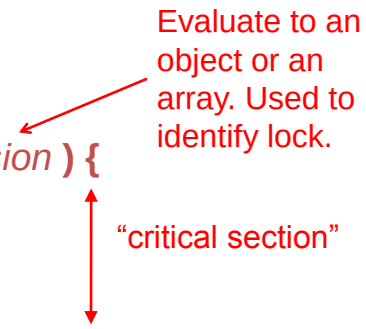
Unlike synchronized methods, synchronized statements must specify the object that provides the intrinsic lock:

Uses construct ion:

synchronized (*expression* **) {**

statements

}



Synchronized Statements

Example

```
void incCount(){
        synchronized(this){
                count3++;
        }
}
```

Only this part synchronized

atomic action

An atomic action cannot stop in the middle: it either happens completely, or it doesn't happen at all. No side effects of an atomic action are visible until the action is complete.

Read/writes can be declared atomic with the **volatile** keyword, e.g.

private volatile int x;

Generally for smaller set of instruction it can be more efficient than synchronized methods.

Coordinating threads
Wait/notify mechanism

Sometimes need a thread to stop running and wait for an event before continuing.

wait() and **notify()** methods are methods of class Object.

Every object can maintain a list of waiting threads.

wait()	When a thread calls **wait()** method of an object, any locks the thread holds are temporarily released and thread added to list of waiting threads for that object and stops running.
notify()	When another thread calls **notify()** method on the same object, object wakes up one of the waiting threads and allows it to continue.

References

- Parallel Computing
  - https://computing.llnl.gov/tutorials/parallel_comp/

- Java Threads
  - https://docs.oracle.com/javase/tutorial/essential/concurrency/runthread.html
  - http://www.wideskills.com/java-tutorial/java-threads-tutorial
  - https://computing.llnl.gov/tutorials/pthreads
  - http://se.inf.ethz.ch/old/teaching/ss2007/0284/book/Threads.pdf