Programming 2 Revision

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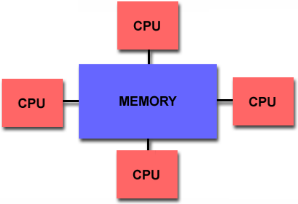
Parallel Structures

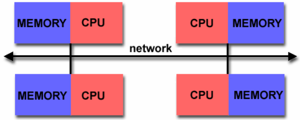
Shared Memory

- Different processes access the same memory concurrently
- Each **process** shares memory with other **processes**.
- Structure adopted by multi core PC units now commonly available.



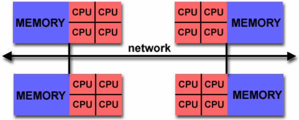
Distributed Memory

- Each CPU has its own memory.
- Messages passed between processes to coordinate their output.
- Structure adopted by High-Performance Computing (HPC) facilities.



Combined Shared/Distributed Memory

- Some CPUs share memory, some communicate via messages.
- Local processes also communicate with other groups via messaging.



Processes & Threads

- When program is launched, a process is created.
- Processes can be sent to different processors by message passing scheme.
- A thread is a portion of a process that can run independently and concurrently with other portions of the process.
- Threads within a process can share data.
- Threads rely on the OS (or other program) to determine what processor they are sent to.

Concurrent Programming

- Involves development of algorithms for running simultaneously in multiple threads.
- Java is inherently concurrent (Basic specification allows concurrent code development).
- C++ needs special library (e.g. pthreads) C# is threaded.
- Java does not allow for user controlled parallel processing.

Overview

- Any Java program has at least one thread, main.
- Any Java thread of execution is associated with an instance of the Thread class.
- Before new thread can start, a new instance of the Thread class must be instantiated.
- A java thread class implements the Runnable interface. Therefore every Thread instance has a method:

```
public void run() {...}
```

- When the Thread is started the code in the body of the run() method is executed.

Declaring Threaded Objects

Extends Thread

```
public class MyThread extends Thread{
        public void run(){
        for(int i = 0; i < 13; i++)
                System.out.println
            ("Thread Iteration " + i);
    }
}
```

- Not preferred,not defining the threads behaviour, just giving it something to run.
- Cannot inherit from this method.
- Each of your thread creates unique object and associate with it

Implements Runnable

```
public class MyRunnable implements Runnable{
        public void run(){
        for(int i = 0; i < 13; i++)
                System.out.println
            ("Runnable Iteration " + i);
    }
}
```

- Preferred method via composition with Runnable.
- Extendible, can have children classes.
- When you implement Runnable, it shares the same object to multiple threads.

Creating and Starting threaded objects

Starting Extends Thread

```
public static void main(){
        MyThread x = new MyThread();
        x.start();
    }
}
```

- Call start, not run

Starting Implements Runnable

```
public static void main(){
        MyRunnable x = new MyRunnable();
        (new Thread(x)).start();
    }
}
```

- Create the runnable object and pass it to a new Thread and call start on that.

run() vs start()

- Calling run() would just execute the code sequentially, essentially as a normal method.
- start() is a method defined in the Thread class and that calls run() method in separate threads that will run concurrently and thus thread the process.

Issues surrounding writing threaded code

- Developing the algorithms can be tough.
- Controlling the interaction of different threads:
    - Pausing for other threads to finish (join).
    - Pausing for a set time or until an exception to occurs (sleep/interrupt).
    - Waiting for another thread to notify that it's ok to continue (wait/notify).
- Controlling access to shared memory (synchronize).

Join()

Used to wait for another thread to finish

```
void join()
```

- This thread would wait for the calling thread to die before continuing.

```
void join(long millis)
```

- Waits at most, millis milliseconds for the thread to die.

```
void join(long millis, int nanos)
```

- Waits at most millis milliseconds plus nanos nanoseconds for the thread to die.

If two threads are waiting for the other to finish the process then it will never finish.

Example of join()

Code where the `void main()` method waits for two threads.

```
public static void main(string[] args) {
        MyThread t1 = new MyThread("Thread 1",1);
        MyThread t2 = new MyThread("Thread 2",2);
    t1.start();
    t2.start();
    try{
        t1.join();//Main now waits for t1 to die
        t2.join();//Main now waits for t2 to die
    }catch(InterruptedException ex){
        System.exit(0);
    }
    /*************************************************************
    * This for loop will only start when t1 and t2 have finished executing
    *************************************************************/
    for(int i = 0; i < 100000; i++) {
        if(i%1000==0)
                System.out.println("Main thread iteration: " + i);
    }

}
```

The main thread has been forced to wait for t1 and t2 to finish, but t1 and t2 are still running concurrently and therefore run completely independently.

Enforces sequential behaviour on concurrent code

Thread interaction

Threads can interact with each other either through:

- Storing references to each other (and calling methods on those references)
- Accessing shared memory: synchronisation.
    - Through the use of static variables within a threaded class.

```
public class MyThread {
        public static ArrayList<Integer> sharedMem = new ArrayList<>();

    public void run() {
        for(int i = 0; i < 400; i++) {
                if(!sharedMem.contains(i))
                sharedMem.add(i);
        }
    }
}
```

The static variable, sharedMem is accessible through any instance of MyThread, if multiple instances of MyThread exist and start() is called in quick succession, then all in this case will interact with sharedMem in a similar way.

Naively parallel algorithms

- If an algorithm can be split into sub-problems, then recombine the results from sub-problems, a thread system could be applied.
- If the threads do not interact with each other, then it is said that the problem is Naively parallel.

Concurrent sort(comparable[] ar, int n)

1. Split array into subarrays.
2. Create a thread to sort each subarray.
3. Merge sub arrays into sorted array.

Parallel sort

```
public class ThreadSort extends Thread {
        public static Comparable data[]; //Shared across all threads
    int start; //Local start position
    int end; //Local end position

    public ThreadSort(int s, int e) {
        start = s;
        end = e;
    }

    public void run() {
        Arrays.sort(data,start,end);
    }
}

public static void main(String [] args) {
        int m = 100;
        int n = 10;
    Comparable[] d = new Comparable[m];
    ThreadSort[] arr = new ThreadSort[n];
    for(int i = 0; i < n; i++) {
        arr[i] = new ThreadSort(i*m/n, (i+1)*m/n);
        arr[i].start();
    }
    //Main should join to ensure all sub sorts are complete before executing merge loop
    for(int i = 0; i < n-1; i++)
        merge(d,0,(i+1)*m/n,(i+1)*m/n,(i+2)*m/n);

}
```

Sleep/Interrupt

- sleep()
  - This pauses the thread for a fixed time or an `InterruptedException` is thrown when another thread has interrupted the current thread.
- interrupt()
  - Interrupts the thread called on. Uses an internal flag called the interrupt status. Calling the interrupt method sets the flag.
  - This only sets the internal flag, it doesn't stop the thread, or do anything if the thread is not sleeping.

Synchronization

- Synchronization involves locking an object so that it can only be accessed by one thread at a time.
- Allows enforcing mutual exclusion between threads.
- Mutual exclusion is implemented through monitor locks. All objects in java have a monitor lock that can be owned by other objects.
    - If one object owns the monitor lock of another object, then it has exclusive access to that object, until it gives up the lock.
- Synchronization is enforced using the synchronized keyword. Any synchronized method or statement can only be accessed by one thread at any time.
- When a thread invokes a synchronized method, it automatically acquired the monitor lock for that method's object and release it when the method returns.

Claiming monitor lock

- Direct synchronized block:

```
private SharedMemClass names;
public void run() {
        synchronized(names){ //Nothing else can touch names until after this block
        names.alter();
    }
}
```

- synchronized methods:

```
public class SharedMemClass {
        synchronized public void alter(){}//Synchronized method
}
public class Modifier extends Thread() {
    private SharedMemClass names;
    public void run() {
//Instance of Modifier claims Monitor lock because of synchronized method
        names.alter();
    }
}
```

block vs methods

Sometimes a method only needs mutual exclusion for a part, such as to read the memory, then update the memory. Only updating the memory needs to be synchronized via a block, opposed to the whole method.

- Direct class monitor lock:

```
public class SharedMemClass {
        synchronized public void alter(){}//Synchronized method
    public static ArrayList<String> str = new ArrayList<>();
}
public class Modifier extends Thread() {
    private SharedMemClass names;
    public void run() {
//This instance of Modifier claims lock on the whole class, locking all static variables
//of the class
                synchronized(SharedMemClass.class);
    }
}
```

- Synchronized static methods:

```
public class SharedMemClass {
        synchronized static public void alter(){}//Synchronized method
    public static ArrayList<String> str = new ArrayList<>();
}
public class Modifier extends Thread() {
    private SharedMemClass names;
    public void run() {
//This instance of Modifier claims lock on the whole class, locking all static variables
//of the class, because alter() is static and synchronized
                SharedMemClass.alter();
    }
}
```

Volatile Variables

- Atomic actions are actions that occur all at once and have no chance of being interrupted or partially complete.
- This means it is impossible for threads to interfere with eachother when performing atomic actions.
- In Java read and write operations on a single variable can be made atomic by using the access modifier volatile.
- volatile variables act as though it is enclosed in a synchronized block, synchronized on itself.
- volatile variables are often used to signal between threads.
- All operations on the variable, happen straight to the variable, it is never cached locally to a thread.

Characteristic	Synchronized	Volatile
Type of variable	Object	Object or primitive
Null allowed?	No	Yes
Can block?	Yes	No
All cached variables synchronized on access?	Yes	From Java 5 onwards
When synchronization happens	When you explicitly enter/exit a synchronized block	Whenever a volatile variable is accessed.
Can be used to combined several operations into an atomic operation?	Yes	Pre-Java 5, no. Atomic get-set of volatiles possible in Java 5.

Monitor Locks vs Semaphores

- When a thread enters a synchronized statement, it owns the monitor lock for the object.
- monitor locks restrict access to an object to one single thread. semaphores can restrict access to an object to more than one thread.

Wait Notify

- Sometimes want a thread to wait for something in another object to happen before continuing.
- A thread can wait for an object to notify when something occurs.
- This can only be the case if the thread owns a monitor lock on the object it is waiting to be notified by and therefore must occur in a synchronized block.

```
if(something)//Check condition before waiting.
        someObject.wait();
//Continues from here after notify
doSomethingElse();
```

- This means that the calling object will wait for someObject to call notify before continuing.

wait()

- The calling thread waits for an event to occur in the object called upon. The event could be from another thread or some other operating system event.
- Throws an Unchecked InterruptException if interrupted and not notified.
- Can be timed passing a long, similar to sleep.
- Must be in a synchronized block.

notify() and notifyAll()

- notify()
  - Notifies one random thread. No control in which one.
- notifyAll()
  - Notifies all waiting threads. No reason can be given for the notification.
- Both must be in synchronized blocks.

Wait/Notify-Textual Example

Producer

Creates goods at random intervals and notifies consumers.

1. Sleep for random interval.
2. Make a product.
3. Notify any thread waiting.

Consumer

Waits for a producer to make a good, then purchase it.

1. Synchronize on Producer.
2. Wait for a notification.
3. Buy Product.

Wait/Notify-Code example - Producer

```
public class Producer extends Thread {
        Product good=null;
    int nosGoods = 0;
    public void run() {
        while(!endOfSimulation()) {
//1) Sleep for random interval.
                try{
                sleep((long)(Math.random()*2000));
            }catch(InterruptedException e) {//Should not happen}
            makeGood();
        }
    }
    //Synchronized so only one good can be made at a time.
    public synchronized void makeGood() {
        if(good == null) {
//2) Make a product.
                good = new Product(nosGoods);
            nosGoods++;
            System.out.println("Making a good");
//3) Notify waiting thread.
            notify();
        }
    }
}
```

Wait/Notify-Code example - Consumer

```
public class Consumer extends Thread {
        Producer p;
    ArrayList<Product> goods;
    public Consumer(Producer p) {
        this.p =  p;
        goods = new ArrayList<>();
    }
    public void run() {
        while(!p.endSimulation()) {
                if(p.hasGood()) {
//1) Synchronize Producer
                synchronize(p){
                        try{
//2) Wait for notificaation
                        p.wait();
                    }catch(InterruptedException e){//Shouldn't
                        happen}
                }
            }
//3) Buy Product.
            goods.add(p.buy());
        }
    }
}
```

Wait/Notify Common Problems

- You need to check the condition before waiting otherwise risk of never being notified.
- Waking from wait doesn't mean the condition waiting for has been satisfied, may need a loop of waiting to condition has definitely been satisfied.
- The timed wait, waits forever if given 0 as a time.
- Calling wait releases lock on object being waited on, but not on other objects locked by the class:

```
synchronized (object1);
synchronized (object2) {
        object2.wait();//object2 lock released. object1 still
            locked
}
```

Wait vs Sleep

- `Thread.sleep()` is a static method that sends thread into the "not runnable" state for a set time.
- `lock.wait()` is called on an Object (lock), not a thread.
  - This causes the current thread to wait for the object. **It does not cause `lock` to wait**.
- Before `lock.wait()` is called, the thread must synchronize on the `lock` object.
- `lock.wait()` releases the lock on the object and adds the thread to the "wait list" associated with `lock`.
- Another thread can synchronize the same `lock` object and call `lock.notify()` that wakes up the original, waiting thread.
- Essentially `wait()/notify()` is like `sleep()/interrupt()`, only the active thread does not need a direct reference to the sleeping thread, but only to the shared `lock` object.

Deadlock

- Deadlock describes a situation where two threads are waiting for each other to finish and never complete.
- synchronization is vital but it can lead to deadlock.
  1. A starts executing and is locked.
  2. B starts executing and is locked.
  3. A calls B and waits for B to finish
  4. B calls A and waits for A to finish

Starvation

- Starvation is where a thread is continually denied access to resources and is therefore unable to progress.
- This happens when "greedy" threads take resources for long periods.
- Essentially a DDOS on a thread and can drastically slow down a program.
- Can be caused by threads being given a high priority. A deterministic priority queue can cause starvation.

Livelock

- Threads often act in response to an action of another thread.
- If the other threads action is also a response to the action of another thread, then livelock may occur.
- Unable to make progress.
- In this case the threads are not blocked, just responding to each other in a loop.
- Comparable to the awkward two people passing in a corridor going the same way each time.

Summary

- Made threaded by `extends Thread` or `implements Runnable`.
- `run` methods run concurrently.
- Threads claim monitor lock through keyword synchronized.
- Threads can effect each others run time behaviour through the `wait/notify && sleep/interrupt`. `wait/notify` requires synchronization.
- Presents new potential problems

The End