COMP 322: Fundamentals of Parallel Programming

Lecture 24: Java Threads, Java synchronized statement

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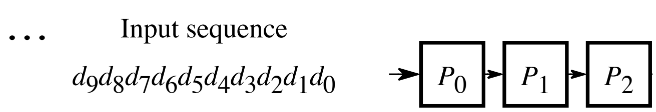
Worksheet #23: Analyzing Parallelism in an Actor Pipeline

Consider a three-stage pipeline of actors (as in slide 5), set up so that P0.nextStage = P1, P1.nextStage = P2, and P2.nextStage = null. The process() method for each actor is shown below. Assume that 100 non-null messages are sent to actor P0 after all three actors are started, followed by a null message. What will the total WORK and CPL be for this execution? Recall that each actor has a sequential thread.

Solution: WORK = 300, CPL = 102




```
protected void process(final Object msg) {
  if (msg == null) {
    exit(); //actor will exit after returning from process()
  } else {
    doWork(1); // unit work
  }
  if (nextStage != null) {
    nextStage.send(msg);
  }
} // process()
```

Introduction to Java Threads and the java.lang.Thread class

- Execution of a Java program begins with an instance of Thread created by the Java Virtual Machine (JVM) that executes the program's main() method.
- Parallelism can be introduced by creating additional instances of class Thread that execute as parallel threads.

```
public class Thread extends Object implements Runnable {
  Thread() { ... } // Creates a new Thread
  Thread(Runnable r) { ... } // Creates a new Thread with Runnable object r
  void run() { ... } // Code to be executed by thr
   // Case 1: If this thread was
   //         then that object's run method
   // Case 2: If this class is subclassed, t
   //         in the subclass is called
  void start() { ... } // Causes this thread to
  void join() { ... } // Wait for this thread to die
  void join(long m) // Wait at most m milliseconds for thread to die
  static Thread currentThread() // Returns currently executing thread
  . . .
}
```

A lambda can be passed as a Runnable

start() and join() methods

- A Thread instance starts executing when its start() method is invoked
  - start() can be invoked at most once per Thread instance
  - As with async, the parent thread can immediately move to the next statement after invoking t.start()
- A t.join() call forces the invoking thread to wait till thread t completes.
  - Lower-level primitive than finish since it only waits for a single thread rather than a collection of threads
  - No restriction on which thread performs a join on which thread, so it is possible to create a deadlock cycle using join() even when there are no data races
    - Declaring thread references as final does not help because the new() and start() operations are separated for threads (unlike futures, where they are integrated)

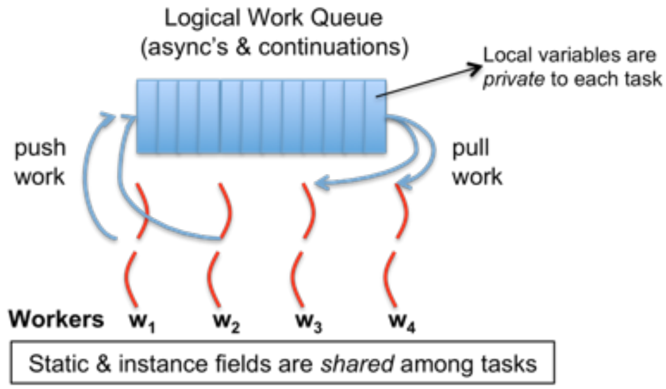
Two-way Parallel Array Sum using Java Threads

```
// Start of main thread
sum1 = 0 sum2 = 0; // sum1 & sum2 are static fields
Thread t1 = new Thread(() -> {
    // Child task computes sum of lower half of array
    for(int i=0; i < X.length/2; i++) sum1 += X[i];
  });
t1.start();
// Parent task computes sum of upper half of array
for(int i=X.length/2; i < X.length; i++) sum2 += X[i];
// Parent task waits for child task to complete (join)
t1.join();
return sum1 + sum2;
```


Compare with Two-way Parallel Array Sum using HJ-Lib's finish & async API's

```
// Start of Task T0 (main program)
sum1 = 0; sum2 = 0; // sum1 & sum2 are static fields
finish(() -> {
  async(() -> {
    // Child task computes sum of lower half of array
    for(int i=0; i < X.length/2; i++) sum1 += X[i];
  });
  // Parent task computes sum of upper half of array
  for(int i=X.length/2; i < X.length; i++) sum2 += X[i];
});
// Parent task waits for child task to complete (join)
return sum1 + sum2;
```

HJlib runtime uses Java threads as workers



- **HJlib runtime creates a small number of worker threads in a *thread pool*, typically one per core**
- **Workers push async's/continuations into a logical work queue**
  - **when an async operation is performed**
  - **when an end-finish operation is reached**
- **Workers pull task/continuation work item when they are idle**

Objects and Locks in Java --- synchronized statements and methods

- Every Java object has an associated *lock* acquired via:
  - `synchronized` statements
    - synchronized(foo) { // acquire foo's lock
      // execute code while holding foo's lock
      } // release foo's lock
  - `synchronized` methods
    - public synchronized void op1() { // acquire 'this' lock
      // execute method while holding 'this' lock
      } // release 'this' lock
- Java language does not enforce any relationship between object used for locking and objects accessed in isolated code
  - If same object is used for locking and data access, then the object behaves like a monitor
- Locking and unlocking are automatic
  - Locks are released when a synchronized block exits
    - By normal means: end of block reached, return, break
    - When an exception is thrown and not caught

Locking guarantees in Java

- It is preferable to use java.util.concurrent.atomic or HJlib isolated constructs, since they cannot deadlock
- Locks are needed for more general cases. Basic idea is for JVM to implement **synchronized(a) <stmt>** as follows:
    1. Acquire lock for object a
    2. Execute <stmt>
    3. Release lock for object a
- The responsibility for ensuring that the choice of locks correctly implements the semantics of isolation lies with the programmer.
- The main guarantee provided by locks is that only one thread can hold a given lock at a time, and the thread is blocked when acquiring a lock if the lock is unavailable.

Deadlock example with Java synchronized statement

- The code below can deadlock if `leftHand()` and `rightHand()` are called concurrently from different threads
    - Because the locks are not acquired in the same order

```
public class ObviousDeadlock {
    . . .
    public void leftHand() {
        synchronized(lock1) {
            synchronized(lock2) {
                for (int i=0; i<10000; i++)
                    sum += random.nextInt(100);
            }
        }
    }
    public void rightHand() {
        synchronized(lock2) {
            synchronized(lock1) {
                for (int i=0; i<10000; i++)
                    sum += random.nextInt(100);
            }
        }
    }
}
```

Deadlock avoidance in HJ with object-based isolation

- HJ implementation ensures that all locks are acquired in the same order
- ==> no deadlock

```
public class NoDeadlock1 {
   . . .
   public void leftHand() {
       isolated(lock1, lock2) {
               for (int i=0; i<10000; i++)
                   sum += random.nextInt(100);

       }
   }
   public void rightHand() {
       isolated(lock2,lock1) {
               for (int i=0; i<10000; i++)
                   sum += random.nextInt(100);
           }
       }
   }
}
```


Dynamic Order Deadlocks

- There are even more subtle ways for threads to deadlock due to inconsistent lock ordering
  — Consider a method to transfer a balance from one account to another:

```
public class SubtleDeadlock {
       public void transferFunds(Account from,
                                 Account to,
                                 int amount) {
             synchronized (from) {
                 synchronized (to) {
                     from.subtractFromBalance(amount);
                     to.addToBalance(amount);
                 }
             }
       }
   }
```

  — What if one thread tries to transfer from A to B while another tries to transfer from B to A ?

  Inconsistent lock order again – Deadlock!

Avoiding Dynamic Order Deadlocks

- The solution is to induce a lock ordering
  — Here, uses an existing unique numeric key, acctId, to establish an order

```
public class SafeTransfer {

    public void transferFunds(Account from, Account to, int amount) {

        Account firstLock, secondLock;
         if (fromAccount.acctId == toAccount.acctId)
             throw new Exception("Cannot self-transfer");
         else if (fromAccount.acctId < toAccount.acctId) {
             firstLock = fromAccount;
             secondLock = toAccount;
         }
         else {
             firstLock = toAccount;
             secondLock = fromAccount;
         }
         synchronized (firstLock) {

           synchronized (secondLock) {

              from.subtractFromBalance(amount);

              to.addToBalance(amount);

           }

        }

    }
  }
```


Java's Object Locks are Reentrant

- Locks are granted on a per-thread basis
  — Called reentrant or recursive locks
  — Promotes object-oriented concurrent code
- A synchronized block means execution of this code requires the current thread to hold this lock
  — If it does — fine
  — If it doesn't — then acquire the lock
- Reentrancy means that recursive methods, invocation of super methods, or local callbacks, don't deadlock

```
public class Widget {
   public synchronized void doSomething() { ... }
}
public class LoggingWidget extends Widget {
   public synchronized void doSomething() {
       Logger.log(this + ": calling doSomething()");
       super.doSomething();  // Doesn't deadlock!
    }
 }
```