COMP 322: Fundamentals of Parallel Programming

Lecture 30: Java Synchronizers, Dining Philosophers Problem

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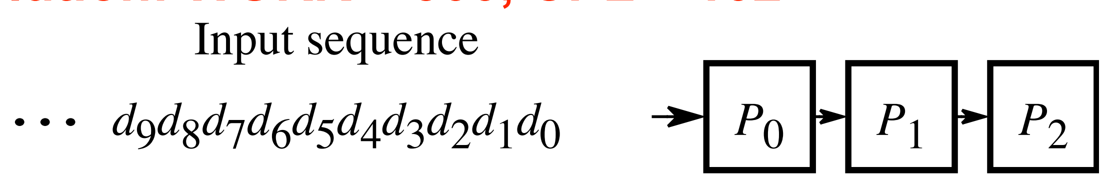
Worksheet #29: Analyzing Parallelism in an Actor Pipeline

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()
```

Outline

- Java Synchronizers

- Dining Philosophers Problem

Key Functional Groups in java.util.concurrent

- Atomic variables
  - The key to writing lock-free algorithms
- Concurrent Collections:
  - Queues, blocking queues, concurrent hash map, …
  - Data structures designed for concurrent environments
- Locks and Conditions
  - More flexible synchronization control
  - Read/write locks
- Executors, Thread pools and Futures
  - Execution frameworks for asynchronous tasking
- Synchronizers: Semaphore, Latch, Barrier, Exchanger
  - Ready made tools for thread coordination

j.u.c Synchronizers --- common patterns in HJ's phaser construct

- Class library includes several state-dependent synchronizer classes
  - `CountDownLatch` – waits until latch reaches terminal state
  - `Semaphore` – waits until permit is available
  - `CyclicBarrier` – like barriers in HJlib forall loops
  - `Phaser` – inspired by Habanero phasers
  - `FutureTask` – like futures in HJlib
  - `Exchanger` – waits until two threads rendezvous (special synchronization)
- These typically have three main groups of methods
  - Methods that block until the object has reached the right state
    - Timed versions will fail if the timeout expired
    - Many versions can be cancelled via interruption
  - Polling methods that allow non-blocking interactions
  - State change methods that may release a blocked method
- WARNING: synchronizers should only be used in Java threads, not HJlib tasks

`CountDownLatch`

- A counter that releases waiting threads when it reaches zero
  - —Allows one or more threads to wait for one or more events
  - —Initial value of 1 gives a simple gate or latch

`CountDownLatch(int initialValue)`

- `await`: wait (if needed) until the counter is zero
  - —Timeout version returns false on timeout
- `countDown`: decrement the counter if > 0
- Query: `getCount()`
- Very simple but widely useful:
  - —Replaces error-prone constructions ensuring that a group of threads all wait for a common signal

Example: using j.u.c.CountDownLatch to implement finish

- Problem: Run N tasks concurrently in N threads and wait until all are complete
  - Use a `CountDownLatch` initialized to the number of threads

```
public static void runTask(int numThreads, final Runnable task)
        throws InterruptedException {
  final CountDownLatch done = new CountDownLatch(numThreads);
  for (int i=0; i<numThreads; i++) {
      Thread t = new Thread() {
          public void run() {
              try {
               task.run();
              }
              finally { done.countDown();}
          }};
      t.start();
  }
  done.await();   // wait for all threads to finish
}
```

Old-fashioned way of specifying lambdas in Java!

Semaphores

- Conceptually serve as "permit" holders
  - Construct with an initial number of permits
  - `acquire`: waits for permit to be available, then "takes" one
  - `release`: "returns" a permit
  - But no actual permits change hands
    - The semaphore just maintains the current count
    - No need to acquire a permit before you release it
- "fair" variant hands out permits in FIFO order
- Supports balking and timed versions of `acquire`
- Applications:
  - Resource controllers
  - Designs that otherwise encounter missed signals
    - Semaphores 'remember' how often they were signalled

Bounded Blocking Concurrent List Example

- Concurrent list with fixed capacity
  - Insertion blocks until space is available
- Tracking free space, or available items, can be done using a Semaphore
- Demonstrates composition of data structures with library synchronizers
  - Easier than modifying implementation of concurrent list directly

Bounded Blocking Concurrent List

```
public class BoundedBlockingList {
 final int capacity;
 final ConcurrentLinkedList list = new ConcurrentLinkedList();
 final Semaphore sem;
 public BoundedBlockingList(int capacity) {
  this.capacity = capacity;
  sem = new Semaphore(capacity);
 }
public void addFirst(Object x) throws InterruptedException {
   sem.acquire();
   try { list.addFirst(x); }
   catch (Throwable t){ sem.release(); rethrow(t); }
 }
 public boolean remove(Object x) {
   if (list.remove(x)) {  sem.release(); return true; }
   return false;
 }
 … } // BoundedBlockingList
```

Summary of j.u.c. libraries

- Atomics: java.util.concurrent.atomic
  - Atomic[Type]
  - Atomic[Type]Array
  - Atomic[Type]FieldUpdater
  - Atomic{Markable,Stampable}Reference
- Concurrent Collections
  - ConcurrentMap
  - ConcurrentHashMap
  - CopyOnWriteArray{List,Set}
- Locks: java.util.concurrent.locks
  - Lock
  - Condition
  - ReadWriteLock
  - AbstractQueuedSynchronizer
  - LockSupport
  - ReentrantLock
  - ReentrantReadWriteLock
- *Executors*
  - *ExecutorService*
  - *ScheduledExecutorService*
  - *Callable*
  - *Future*
  - *ScheduledFuture*
  - *Delayed*
  - *CompletionService*
  - *ThreadPoolExecutor*
  - *ScheduledThreadPoolExecutor*
  - *AbstractExecutorService*
  - *FutureTask*
  - *ExecutorCompletionService*
- Synchronizers
  - CountDownLatch
  - Semaphore
  - Exchanger
  - CyclicBarrier

Executors are the only class that we haven't studied as yet

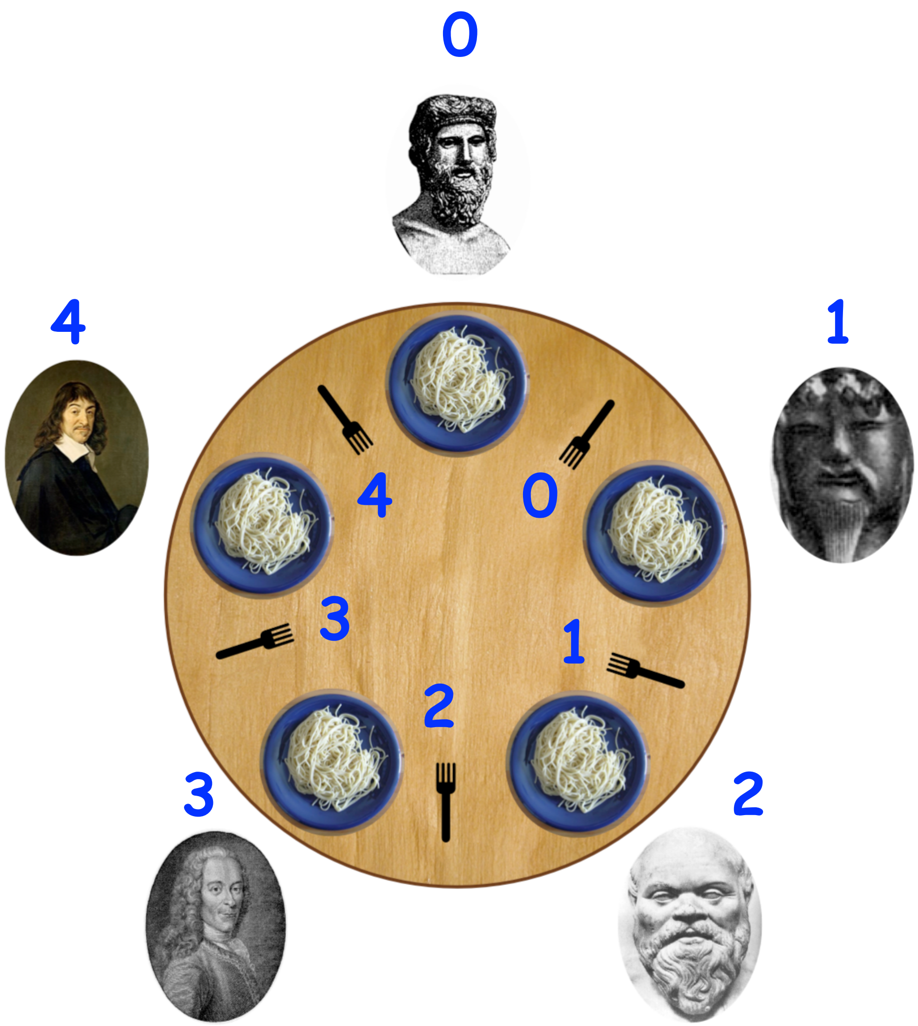
Outline

- **Java Synchronizers**

- **Dining Philosophers Problem**
  - **Acknowledgments**
    - **CMSC 330 course notes, U. Maryland**

      http://www.cs.umd.edu/~lam/cmsc330/summer2008/lectures/class20-threads_classicprobs.ppt
    - **Dave Johnson (COMP 421 instructor)**

The Dining Philosophers Problem



Constraints

- Five philosophers either eat or think
- They must have two forks to eat (chopsticks are a better motivation!)
- Can only use forks on either side of their plate
- No talking permitted

Goals

- Progress guarantees
  - Deadlock freedom
  - Livelock freedom
  - Starvation freedom
  - Maximum concurrency (no one should starve if there are available forks for them)

General Structure of Dining Philosophers Problem: PseudoCode

```
int numPhilosophers = 5;
int numForks = numPhilosophers;
Fork[] fork = ... ; // Initialize array of forks
forall(point [p] : [0:numPhilosophers-1]) {
  while(true) {
    Think ;
    Acquire forks;
      // Left fork = fork[p]
      // Right fork = fork[(p-1)%numForks]
    Eat ;
  } // while
} // forall
```

Solution 1: using Java's synchronized

```
int numPhilosophers = 5;
int numForks = numPhilosophers;
Fork[] fork = ... ; // Initialize array of forks
forall(point [p] : [0:numPhilosophers-1]) {
  while(true) {
    Think ;
    synchronized(fork[p])
      synchronized(fork[(p-1)%numForks]) {
        Eat ;
      }
    }
  } // while
} // forall
```

Solution 2: using Java's Lock library

```
int numPhilosophers = 5;
int numForks = numPhilosophers;
Fork[] fork = ... ; // Initialize array of forks
forall(point [p] : [0:numPhilosophers-1]) {
  while(true) {
    Think ;
    if (!fork[p].lock.tryLock()) continue;
    if (!fork[(p-1)%numForks].lock.tryLock()) {
      fork[p].lock.unLock(); continue;
    }
    Eat ;
    fork[p].lock.unlock();fork[(p-1)%numForks].lock.unlock();
  } // while
} // forall
```

Solution 3: using HJ's isolated

```
int numPhilosophers = 5;
int numForks = numPhilosophers;
Fork[] fork = ... ; // Initialize array of forks
forall(point [p] : [0:numPhilosophers-1]) {
  while(true) {
    Think ;
    isolated {
      Pick up left and right forks;
      Eat ;
    }
  } // while
} // forall
```

Solution 4: using HJ's object-based isolation

```
int numPhilosophers = 5;
int numForks = numPhilosophers;
Fork[] fork = ... ; // Initialize array of forks
forall(point [p] : [0:numPhilosophers-1]) {
  while(true) {
    Think ;
    isolated(fork[p], fork[(p-1)%numForks]) {
      Eat ;
    }
  } // while
} // forall
```

Solution 5: using Java's Semaphores

```
int numPhilosophers = 5;
int numForks = numPhilosophers;
Fork[] fork = ... ; // Initialize array of forks
Semaphore table = new Semaphore(4); // assume semaphores are fair
for (i=0;i<numForks;i++) fork[i].sem = new Semaphore(1);
forall(point [p] : [0:numPhilosophers-1]) {
  while(true) {
    Think ;
    table.acquire(); // At most 4 philosophers at table
    fork[p].sem.acquire(); // Acquire left fork
    fork[(p-1)%numForks].sem.acquire(); // Acquire right fork
    Eat ;
    fork[p].sem.release(); fork[(p-1)%numForks].sem.release();
    table.release();
  } // while
} // forall
```

Course Reminders

- Homework 4, Checkpoint 1 is due by 12noon on Monday, April 4th

- Location of final exam is confirmed: Herzstein Hall Auditorium

- Data and time for final exam unchanged from what was announced earlier: Tuesday, 3-MAY-2016, 9:00AM - 12:00PM

- Have a great recess!

Worksheet #30: Characterizing Solutions to the Dining Philosophers Problem

Name: ______________________ **Netid:** ______________________

For the five solutions studied in today's lecture, indicate in the table below which of the following conditions are possible and why:

1. Deadlock: when all philosopher tasks are blocked (neither thinking nor eating)
2. Livelock: when all philosopher tasks are executing but ALL philosophers are starved (never get to eat)
3. Starvation: when one or more philosophers are starved (never get to eat)
4. Non-Concurrency: when more than one philosopher cannot eat at the same time, even when resources are available

	Deadlock	Livelock	Starvation	Non-concurrency
Solution 1: **synchronized**				
Solution 2: **tryLock/ unLock**				
Solution 3: **isolated**				
Solution 4: **object-based isolation**				
Solution 5: **semaphores**				