COMP 322: Fundamentals of Parallel Programming

Lecture 22: Actors

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https://wiki.rice.edu/confluence/display/PARPROG/COMP322

Worksheet #21 solution: Abstract Metrics with Isolated Constructs

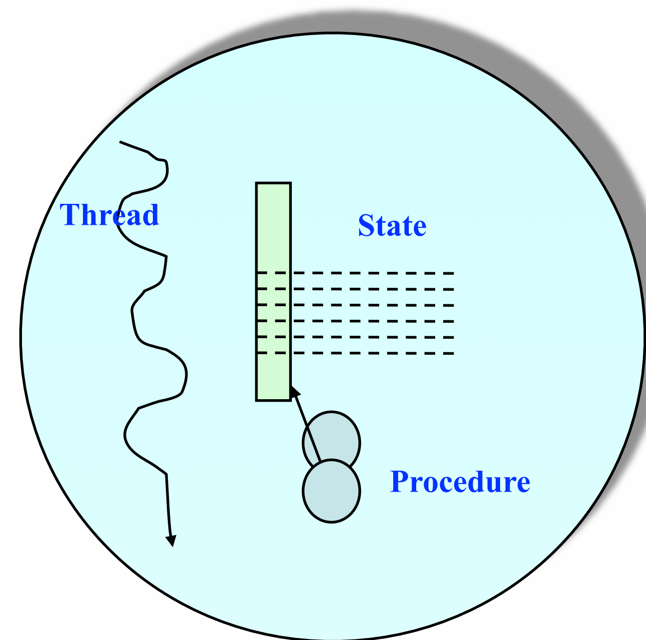
Q: Compute the WORK and CPL metrics for this program. Indicate if your answer depends on the execution order of isolated constructs.

```
1.    finish(() -> {
2.         for (int i = 0; i < 5; i++) {
3.             async(() -> {
4.                     doWork(2);
5.                     isolated(() -> { doWork(1); });
6.                     doWork(2);
7.                 }); // async
8.         } // for
9.     }); // finish
```

Answer: WORK = 25, CPL = 9. These metrics do not depend on the execution order of isolated constructs.

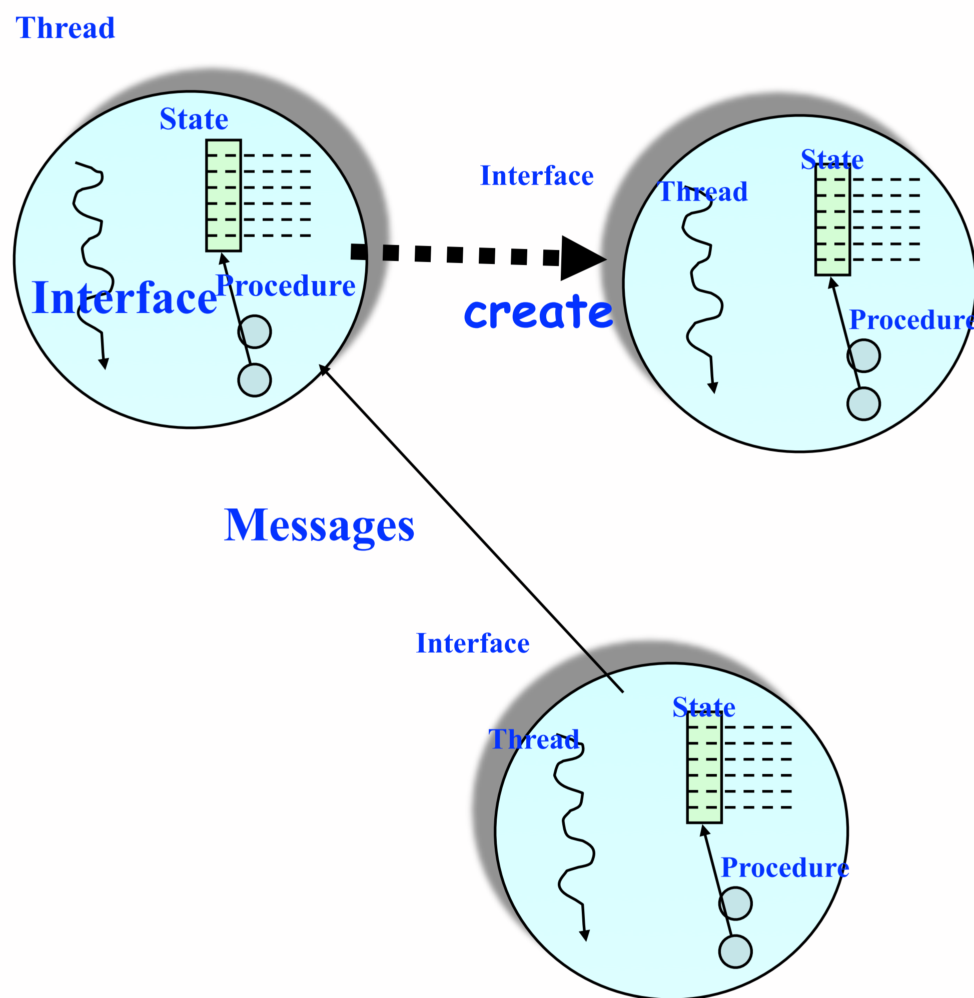
Actors as concurrent objects

- **An actor is an autonomous, interacting component of a parallel system.**
- **An actor has:**
  - an immutable identity (name, global id)
  - *a single logical thread of control*
  - mutable local state (isolated by default)
  - procedures to manipulate local state (interface)

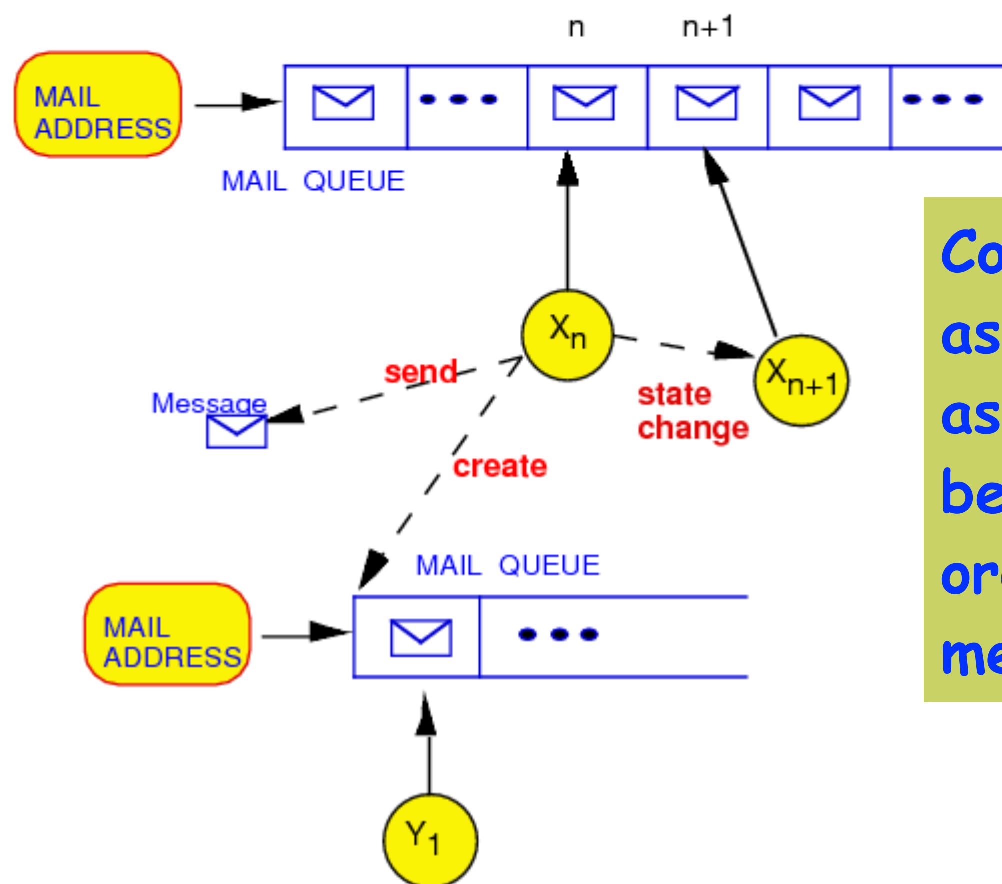


The Actor Model: Fundamentals

- An actor may:
  - process messages
  - send messages
  - change local state
  - create new actors



Arrival Order Nondeterminism



Communication is asynchronous: no assumption can be made about order of message delivery

Actor Model

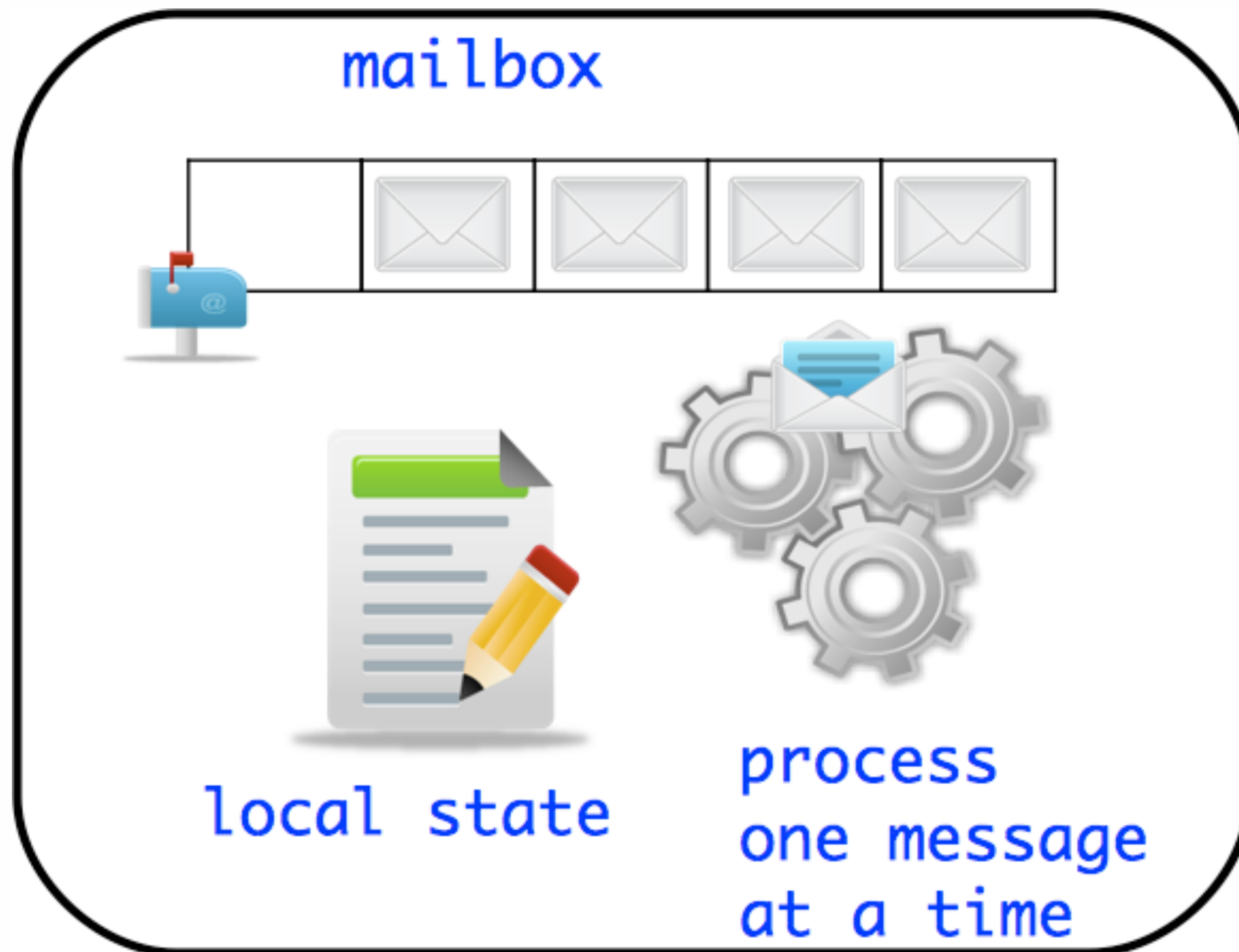
- A message-based concurrency model to manage mutable shared state
- First defined in 1973 by Carl Hewitt

  Further theoretical development by Henry Baker and Gul Agha
- Key Ideas:
  - Everything is an Actor!
  - Analogous to "everything is an object" in OOP
  - Encapsulate shared state in Actors
  - Mutable state is not shared
- Other important features (we will get to these later)
  - Asynchronous message passing
  - Non-deterministic ordering of messages

Actors' Behavior

- **Actors are passive and lazy**
  - **Only respond if messages are sent to them**
    - **Messages may come from other actors or from main program (environment)**
  - **Only process one message at a time**
    - **Pending messages are stored in a "*mailbox*"**
    - ***Parallelism comes from multiple actors processing messages in parallel***
  - Mutate local state **only** while processing a message
  - **Mutating local state can result in actor responding differently to subsequent messages**

Actor



Actor Analogy - Email

- Email accounts are a good simple analogy to Actors
- To notify some information to (i.e. change some state of) A1 another account A2 sends an email (i.e. sends a message) to A1
- A1 has a mailbox to store all incoming messages
- A1 can read (i.e. process) one email at a time
  - At least that is what normal people do :)
- Reading an email can change how you respond to a subsequent email
  - e.g. receiving pleasant news while reading current email can affect the response to a subsequent email
- Actor creation (stretching the analogy)
  - Create a new email account that can send/receive messages

Actor Life Cycle

Actor states

- New: Actor has been created
    - e.g., email account has been created
- Started: Actor can receive and process messages
    - e.g., email account has been activated
- Terminated: Actor will no longer processes messages
    - e.g., termination of email account after graduation

Using Actors in HJ-Lib

- Create your custom class which extends edu.rice.hj.runtime.actors.Actor<Object> ,and implement the void process() method

```
class MyActor extends Actor<Object> {
  protected void process(Object message) {
    System.out.println("Processing " + message);
} }
```

- Instantiate and start your actor

```
    Actor<Object> anActor = new MyActor();
   anActor.start()
```

- Send messages to the actor

```
anActor.send(aMessage); //aMessage can be any object in general
```

- Use a special message to terminate an actor

```
protected void process(Object message) {
  if (message.someCondition()) exit();
}
```

- Actor execution implemented as async tasks in HJ
- Can use finish to await completion of an actor!

Hello World Example

```
1.  public class HelloWorld {
2.    public static void main(final String[] args) {
3.      finish(()-> {
4.        EchoActor actor = new EchoActor();
5.        actor.start(); // don't forget to start the actor
6.        actor.send("Hello"); // asynchronous send (returns immediately)
7.        actor.send("World");
8.        actor.send(EchoActor.STOP_MSG);
9.      });
10.   }
11.   private static class EchoActor extends Actor<Object> {
12.     static final Object STOP_MSG = new Object();
13.     private int messageCount = 0;
14.     protected void process(final Object msg) {
15.       if (STOP_MSG.equals(msg)) {
16.          println("Message-" + messageCount + ": terminating.");
17.          exit(); // never forget to terminate an actor
18.        } else {
             messageCount += 1;
19.          println("Message-" + messageCount + ": " + msg);
20.   } } } }
```

Sends are asynchronous in actor model, but HJ Actor library <u>preserves order of messages between same sender and receiver</u>

Integer Counter Example

Without Actors:

```
1.   int counter = 0;
2.   public void foo() {
3.     // do something
4.     isolated(() -> {
5.       counter++;
6.     });
7.     // do something else
8.   }
9.   public void bar() {
10.    // do something
11.    isolated(() -> {
12.      counter--;
13.    });
14.  }
```

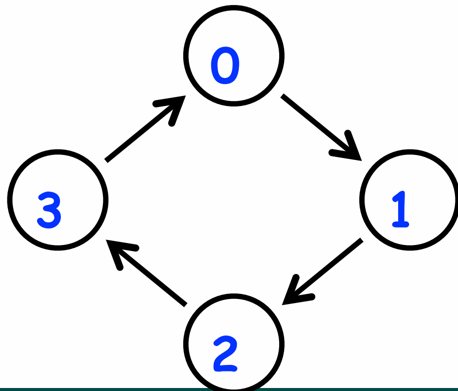
- Can also use atomic variables instead of isolated construct

With Actors:

```
14. class Counter extends Actor<Message> {
15.       private int counter = 0; // local state
16.       public void process(Message msg) {
17.       if (msg instanceof IncMessage) {
18.         counter++;
19.       } else if (msg instanceof DecMessage){
20.         counter--;
21. } } }
22.    . . .
14.      Counter counter = new Counter();
15.      public void foo() {
16.       // do something
17.         counter.send(new IncrementMessage(1));
18.       // do something else
19.      }
20.      public void bar() {
21.        // do something
22.        counter.send(new DecrementMessage(1));
23.      }
```

ThreadRing (Coordination) Example

```
1. finish(() -> {
2.   int numThreads = 4;
3.   int numberOfHops = 10;
4.   ThreadRingActor[] ring =
       new ThreadRingActor[numThreads];
5.   for(int i=numThreads-1;i>=0; i--) {
6.     ring[i] = new ThreadRingActor(i);
7.     ring[i].start();
8.     if (i < numThreads - 1) {
9.       ring[i].nextActor(ring[i + 1]);
10.  } }
11.  ring[numThreads-1].nextActor(ring[0]);
12.  ring[0].send(numberOfHops);
13.}); // finish
```

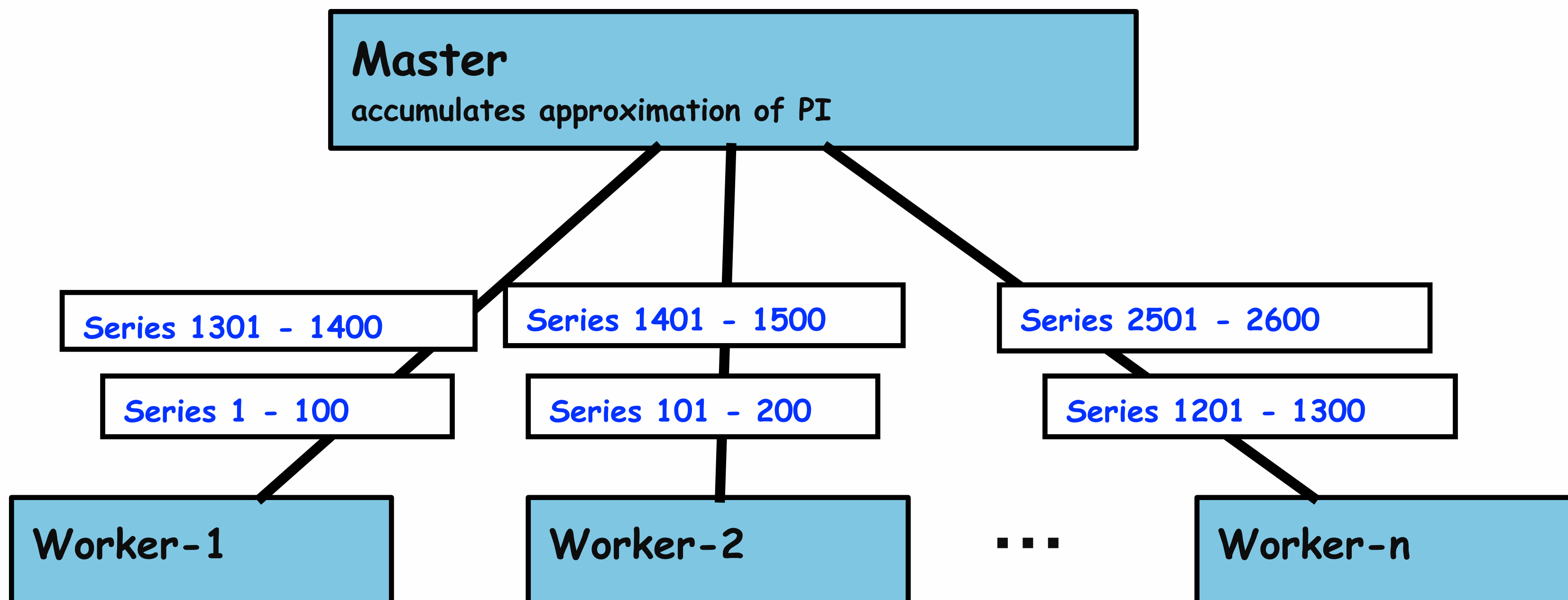



```
14.class ThreadRingActor
15.     extends Actor<Object> {
16.   private Actor<Object> nextActor;
17.   private final int id;
18.   ...
19.   public void nextActor(
        Actor<Object> nextActor) {...}
20.   void process(Object theMsg) {
21.     if (theMsg instanceof Integer) {
22.       Integer n = (Integer) theMsg;
23.       if (n > 0) {
24.         println("Thread-" + id +
25.           " active, remaining = " + n);
26.         nextActor.send(n - 1);
27.       } else {
28.         println("Exiting Thread-"+ id);
29.         nextActor.send(-1);
30.         exit();
31.       }
32.     } else {
33.     /* ERROR - handle appropriately */
34.} } }
```

Pi Computation Example

$$\pi = 4\sum_{k=0}^{\infty}\frac{(-1)^k}{2k+1} = \frac{4}{1} - \frac{4}{3} + \frac{4}{5} - \frac{4}{7} + \frac{4}{9} - \cdots.$$

- **Use Master-Worker technique:**



Source: http://www.enotes.com/topic/Pi

Pi Calculation --- Master Actor

```
1.  class Master extends Actor<Object> {
2.    private double result = 0; private int nrMsgsReceived = 0;
3.    private Worker[] workers;
4.    Master(nrWrkrs, nrEls, nrMsgs) {...} // constructor
5.    void onPostStart() {
6.      // Create and start workers
7.      workers = new Worker[nrWrkrs];
8.      for (int i = 0; i < nrwrkrs; i++) {
9.        workers[i] = new Worker();
10.       workers[i].start();
11.     }
12.     // Send messages to workers
13.     for (int j = 0; j < nrMsgs; j++) {
14.       someWrkr = ... ; // Select worker for message j
15.       someWrkr.send(new Work(...));
16.     }
17.   } // start()
```

Pi Calculation --- Master Actor (contd)

```
19.    void onPostExit() {
20.      for (int i = 0; i < nrWrkrs; i++)
21.        workers[i].send(new Stop());
22.    } // exit()
23.    void process(final Object msg) {
24.      if (msg instanceof Result) {
25.        result += ((Result) msg).result;
26.        nrMsgsReceived += 1;
27.        if (nrMsgsReceived == nrMsgs) exit();
28.      }
29.      // Handle other message cases here
30.    } // process()
31.  } // Master
32.   . . .
33.   // Main program
34.   Master master = new Master(w, e, m);
35.   finish(() -> { master.start(); });
36.   println("PI = " + master.getResult());
```

Pi Calculation --- Worker Actor

```
1.   class Worker extends Actor<Object> {
2.     void process(final Object msg) {
3.       if (msg instanceof Stop)
4.         exit();
5.       else if (msg instanceof Work) {
6.         Work wm = (Work) msg;
7.         double result = calculatePiFor(wm.start, wm.end)
8.         master.send(new ResultMessage(result));
9.     } } // process()
10.
11.    private double calculatePiFor(int start, int end) {
12.      double acc = 0.0;
13.      for (int i = start; i < end; i++) {
14.        acc += 4.0 * (1 - (i % 2) * 2) / (2 * i + 1);
15.      }
16.      return acc;
17.    }
18.  } // Worker
```

Actors – Global Consensus

- Global consensus is simple with barriers/phasers but can be complex with actors e.g.,
  - First send message from master actor to participant actors signaling intention
  - Wait for all participants to reply they are ready. Participants start ignoring messages sent to them apart from the master
  - Once master confirms all participants are ready, master sends the request to each participant and waits for reply from each
  - Master notifies participants that consensus has been reached, everyone can go back to normal functioning

Limitations of Actor Model

- Deadlocks possible
  - Deadlock occurs when all started (but non-terminated) actors have empty mailboxes
- Data races possible when messages include shared objects
- Simulating synchronous replies requires some effort
  - e.g., does not support addAndGet()
- Implementing truly concurrent data structures is hard
  - No parallel reads, no reductions/accumulators
- Difficult to achieve global consensus
  - Finish and barriers not supported as first-class primitives

==> Some of these limitations can be overcome by using a hybrid model that combines task parallelism with actors

Worksheet #22: Interaction between finish and actors

Name: ______________________ Netid: ______________________

What would happen if the end-finish operation from slide 14 was moved from line 13 to line 11 as shown below?

```
1.  finish(() -> {
2.     int numThreads = 4;
3.     int numberOfHops = 10;
4.     ThreadRingActor[] ring = new ThreadRingActor[numThreads];
5.     for(int i=numThreads-1;i>=0; i--) {
6.       ring[i] = new ThreadRingActor(i);
7.       ring[i].start();
8.       if (i < numThreads - 1) {
9.         ring[i].nextActor(ring[i + 1]);
10.      } }
11. }); // finish
12.ring[numThreads-1].nextActor(ring[0]);
13.ring[0].send(numberOfHops);
```