COMP 322: Fundamentals of Parallel Programming

Lecture 22: Introduction to the Actor Model

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Worksheet #21a solution:
bstract Metrics with Object-based Isolated Constructs

Q: Compute the WORK and CPL metrics for this program with a <u>global isolated</u> construct. Indicate if your answer depends on the execution order of isolated constructs.

```
finish(() -> {
    for (int i = 0; i < 5; i++) {
        async(() -> {
            doWork(2);
            isolated(() -> { doWork(1); });
            doWork(2);
        }); // async
    } // for
}); // finish
```

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

Worksheet #21b solution: Abstract Metrics with Isolated Constructs

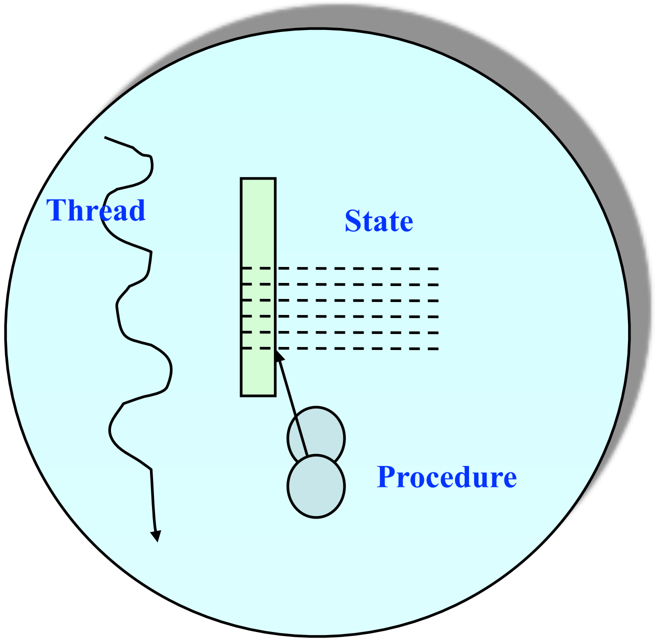
Q: Compute the WORK and CPL metrics for this program with an <u>object-based isolated</u> construct. Indicate if your answer depends on the execution order of isolated constructs.

```
finish(() -> {
     // Assume X is an array of distinct objects
     for (int i = 0; i < 5; i++) {
       async(() -> {
         doWork(2);
         isolated(X[i], X[i+1],
                  () -> { doWork(1); });
         doWork(2);
       }); // async
      } // for
  }); // finish
```

Answer: WORK = 25, CPL = 7. These metrics do not depend on the execution order of object-based isolated constructs.

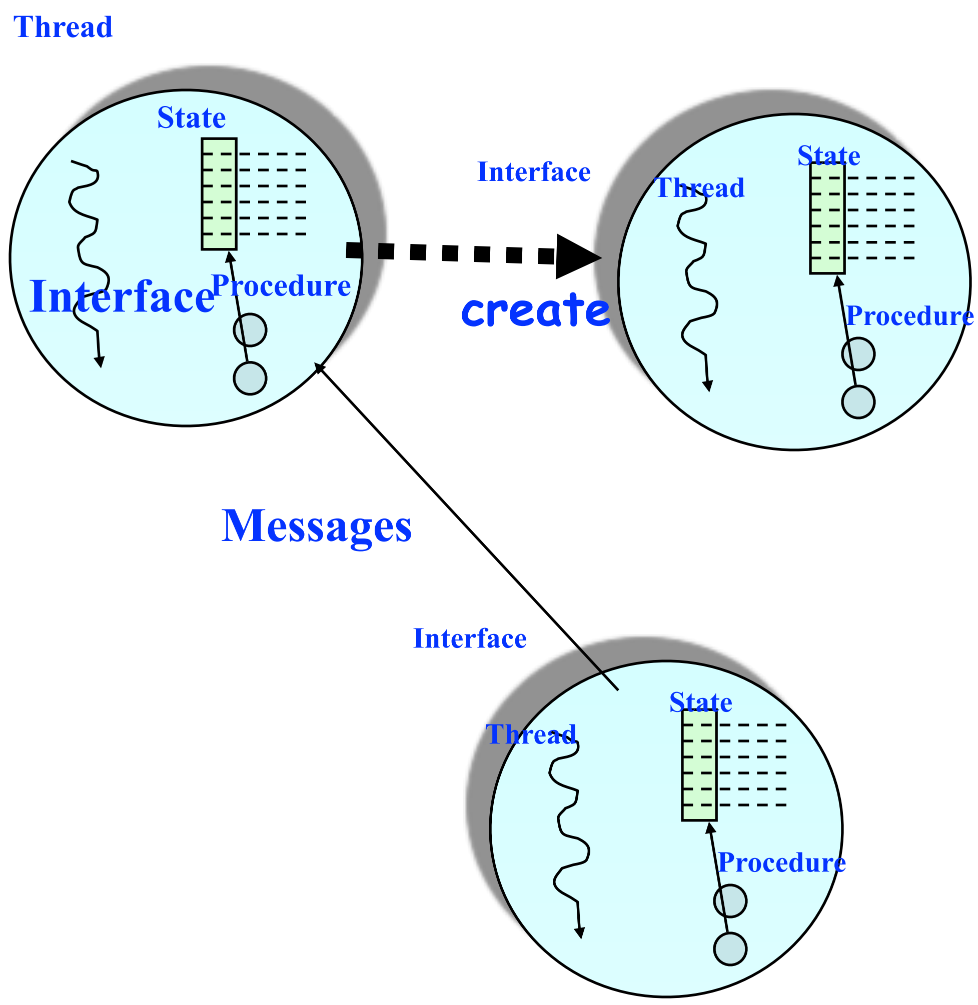
Actors: an alternative approach to isolation

- **An actor is an autonomous, interacting component of a parallel system.**
- **An actor has:**
  - — an immutable identity (global reference)
  - — *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
  - change local state
  - create new actors
  - send messages



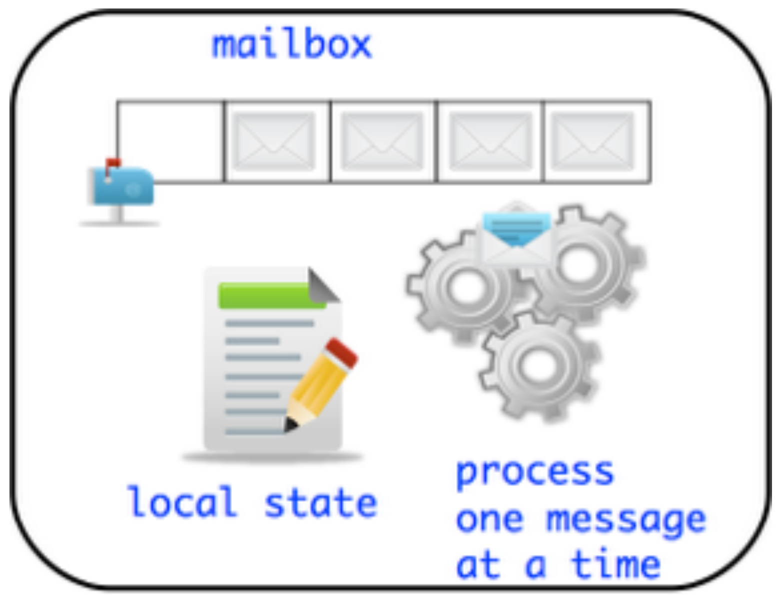
Actor Model

- 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 - i.e., no data races
- Other important features
  - Asynchronous message passing
  - Non-deterministic ordering of messages

Actor Life Cycle

Actor states

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



Actor Analogy - Email

- Email accounts are a good simple analogy to Actors
- Account A2 can can send information to account A1 via an email message
- 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

Using Actors in HJlib

- Create your custom class which extends `edu.rice.hj.runtime.actors.Actor<T>`, and implement the void `process()` method (type parameter T specifies message type)

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

- Instantiate and start your actor

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

- Send messages to the actor (can be performed by actor or non-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
  Can use `finish` to await completion of an actor, if the actor is `start`-ed inside the `finish`.

Summary of HJlib Actor API

`void process(MessageType theMsg)` // Specification of actor's "behavior" when processing messages

`void send(MessageType msg)` // Send a message to the actor

`void start()` // Cause the actor to start processing messages
`void onPreStart()` // Convenience: specify code to be executed before actor is started
`void onPostStart()` // Convenience: specify code to be executed after actor is started

`void exit()` // Actor calls exit() to terminate itself
`void onPreExit()` // Convenience: specify code to be executed before actor is terminated
`void onPostExit()` // Convenience: specify code to be executed after actor is terminated

// Later today
`void pause()` // Pause the actor, i.e. the actors stops processing messages in its mailbox
`void resume()` // Resume a paused actor, i.e. actor resumes processing messages in mailbox

See http://www.cs.rice.edu/~vs3/hjlib/doc/edu/rice/hj/runtime/actors/Actor.html for details

Hello World Example

```
public class HelloWorld {
  public static void main(final String[] args) {
    finish(()-> {
      EchoActor actor = new EchoActor();
      actor.start(); // don't forget to start the actor
      actor.send("Hello"); // asynchronous send (returns immediately)
      actor.send("World"); // Non-actors can send messages to actors
      actor.send(EchoActor.STOP_MSG);
    });
    println("EchoActor terminated.")
  }
  private static class EchoActor extends Actor<Object> {
    static final Object STOP_MSG = new Object();
    private int messageCount = 0;
    protected void process(final Object msg) {
      if (STOP_MSG.equals(msg)) {
        println("Message-" + messageCount + ": terminating.");
        exit(); // never forget to terminate an actor
      } else {
        messageCount += 1;
        println("Message-" + messageCount + ": " + msg);
} } } }
```

Though sends are asynchronous, many actor libraries (including HJlib) preserve the order of messages between the same sender actor/task and the same receiver actor

Integer Counter Example

Without Actors:

```
int counter = 0;
public void foo() {
  // do something
  isolated(() -> {
    counter++;
  });
  // do something else
}
public void bar() {
  // do something
  isolated(() -> {
    counter--;
  });
}
```

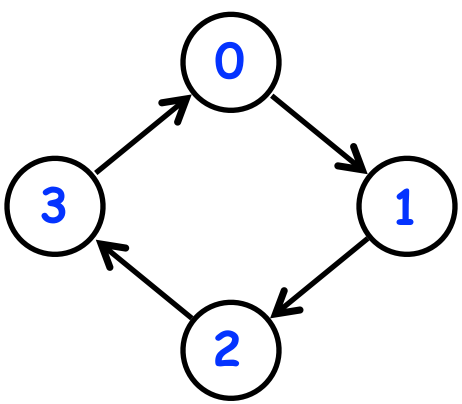
- Can also use atomic variables instead of `isolated` construct

With Actors:

```
class Counter extends Actor<Message> {
  private int counter = 0; // local state
  protected void process(Message msg) {
    if (msg instanceof IncMessage) {
      counter++;
    } else if (msg instanceof DecMessage){
      counter--;
} } }
  . . .
Counter counter = new Counter();
counter.start();
   public void foo() {
     // do something
     counter.send(new IncrementMessage(1));
     // do something else
   }
   public void bar() {
     // do something
     counter.send(new DecrementMessage(1));
   }
```

ThreadRing (Coordination) Example

```
finish(() -> {
  int threads = 4;
  int numberOfHops = 10;
  ThreadRingActor[] ring =
    new ThreadRingActor[threads];
  for(int i=threads-1;i>=0; i--) {
    ring[i] = new ThreadRingActor(i);
    ring[i].start();
    if (i < threads - 1) {
      ring[i].nextActor(ring[i + 1]);
  } }
  ring[threads-1].nextActor(ring[0]);
  ring[0].send(numberOfHops);
}); // finish
```



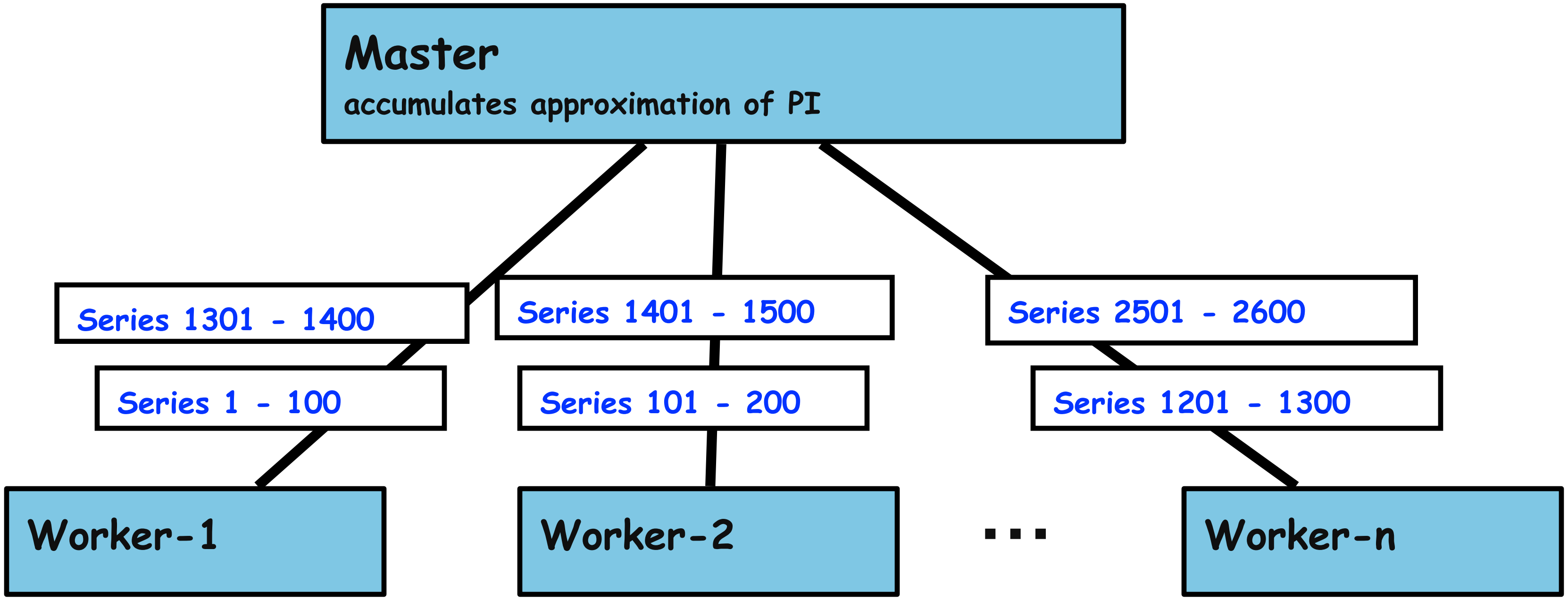

```
class ThreadRingActor
      extends Actor<Integer> {
    private Actor<Integer> nextActor;
    private final int id;
    ...
    public void nextActor(
      Actor<Object> nextActor) {...}

    protected void process(Integer n) {
      if (n > 0) {
        println("Thread-" + id +
          " active, remaining = " + n);
        nextActor.send(n - 1);
      } else {
        println("Exiting Thread-"+ id);
        nextActor.send(-1);
        exit();
} } }
```

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

```
class Master extends Actor<Object> {
  private double result = 0; private int nrMsgsReceived = 0;
  private Worker[] workers;
  Master(nrWrkrs, nrEls, nrMsgs) {...} // constructor
  protected void onPostStart() {
    // Create and start workers
    workers = new Worker[nrWrkrs];
    for (int i = 0; i < nrwrkrs; i++) {
      workers[i] = new Worker();
      workers[i].start();
    }
    // Send messages to workers
    for (int j = 0; j < nrMsgs; j++) {
      someWrkr = ... ; // Select worker for message j
      someWrkr.send(new Work(...));
    }
  } // start()
```

Pi Calculation --- Master Actor (contd)

```
   protected void onPostExit() {
     for (int i = 0; i < nrWrkrs; i++)
       workers[i].send(new Stop());
   } // post-exit()
   protected void process(final Object msg) {
     if (msg instanceof Result) {
       result += ((Result) msg).result;
       nrMsgsReceived += 1;
       if (nrMsgsReceived == nrMsgs) exit();
     }
     // Handle other message cases here
   } // process()
 } // Master
  . . .
  // Main program
  Master master = new Master(w, e, m);
  finish(() -> { master.start(); });
  println("PI = " + master.getResult());
```

Pi Calculation --- Worker Actor

```
class Worker extends Actor<Object> {
  protected void process(final Object msg) {
    if (msg instanceof Stop)
      exit();
    else if (msg instanceof Work) {
      Work wm = (Work) msg;
      double result = calculatePiFor(wm.start, wm.end)
      master.send(new ResultMessage(result));
  } } // process()

  private double calculatePiFor(int start, int end) {
    double acc = 0.0;
    for (int k = start; k < end; k++) {
      acc += 4.0 * (1 - (k % 2) * 2) / (2 * k + 1);
    }
    return acc;
  }
} // Worker
```

$$4\sum_{k=s}^{e-1} \frac{(-1)^k}{2k+1}$$

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 (more on this in the next lecture!)

Worksheet #22: Interaction between finish and actors

Name: ______________________ Net ID: ______________________

What output will be printed if the end-finish operation from slide 13 is moved from line 13 to line 11 as shown below?

```
1.   finish(() -> {
2.     int threads = 4;
3.     int numberOfHops = 10;
4.     ThreadRingActor[] ring = new ThreadRingActor[threads];
5.     for(int i=threads-1;i>=0; i--) {
6.       ring[i] = new ThreadRingActor(i);
7.       ring[i].start();
8.       if (i < threads - 1) {
9.         ring[i].nextActor(ring[i + 1]);
10.      } }
11.  }); // finish
12. ring[threads-1].nextActor(ring[0]);
13. ring[0].send(numberOfHops);
14.
```