COMP 322: Fundamentals of Parallel Programming

Lecture 22: Introduction to the Actor Model

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Worksheet #21a solution: Abstract Metrics with Isolated Constructs

Q: Compute the WORK and CPL metrics for this program with a global isolated construct. 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.

Worksheet #21b solution: Abstract Metrics with Object-based Isolated Constructs

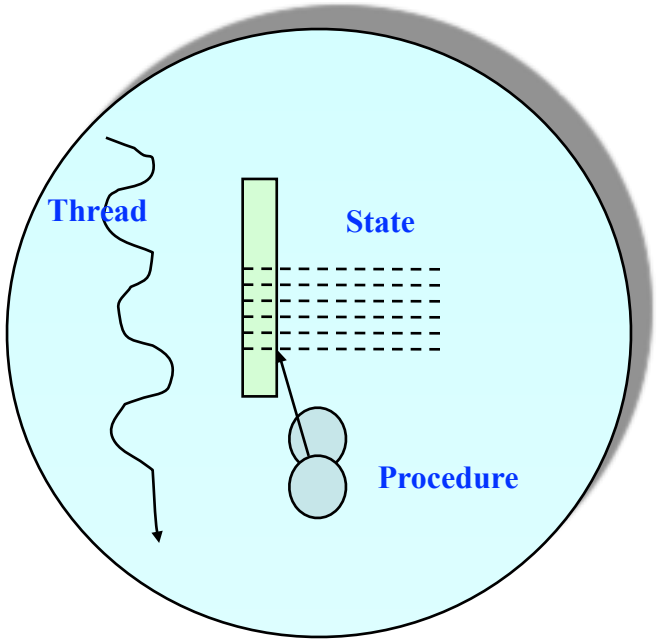
Q: Compute the WORK and CPL metrics for this program with an object-based isolated construct. Indicate if your answer depends on the execution order of isolated constructs.

```
1.    finish(() -> {
2.         // Assume X is an array of distinct objects
3.         for (int i = 0; i < 5; i++) {
4.           async(() -> {
5.             doWork(2);
6.             isolated(X[i], X[i+1],
7.                      () -> { doWork(1); });
8.             doWork(2);
9.           }); // async
10.        } // for
11.    }); // finish
```

Answer: WORK = 25, CPL = 7. These metrics depend on the execution order of isolated constructs.

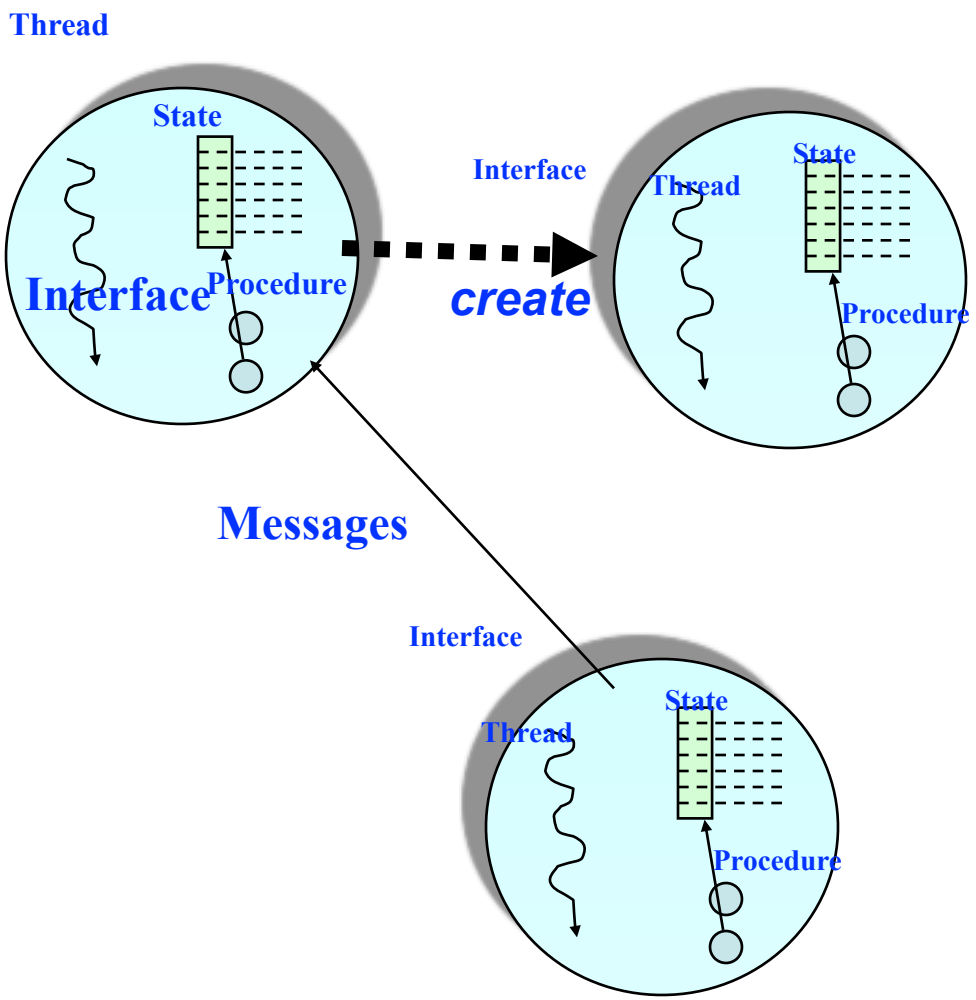
Actors: an alternative approach to isolation

- 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



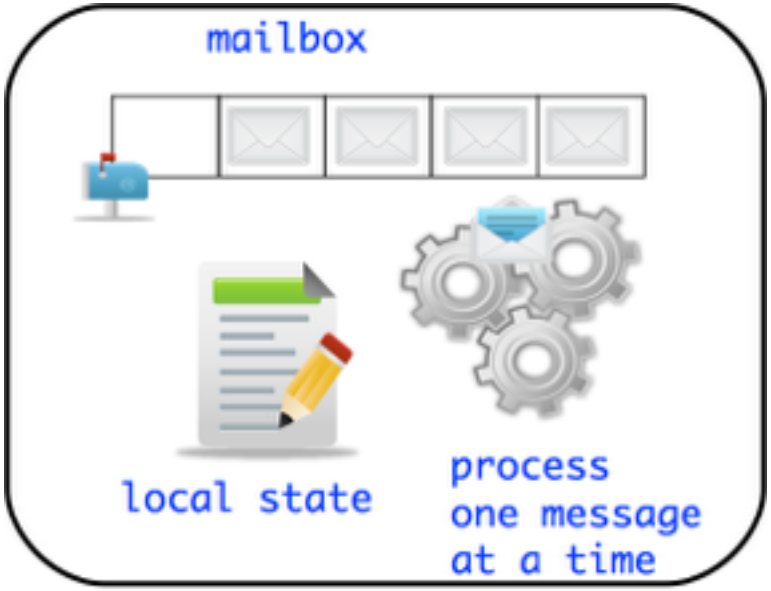
Actor Model

- 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

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

// Next lecture
`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

```
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"); // Non-actors can send messages to actors
8.        actor.send(EchoActor.STOP_MSG);
9.      });
10.     println("EchoActor terminated.")
11.   }
12.   private static class EchoActor extends Actor<Object> {
13.     static final Object STOP_MSG = new Object();
14.     private int messageCount = 0;
15.     protected void process(final Object msg) {
16.       if (STOP_MSG.equals(msg)) {
17.         println("Message-" + messageCount + ": terminating.");
18.         exit(); // never forget to terminate an actor
19.       } else {
            messageCount += 1;
20.         println("Message-" + messageCount + ": " + msg);
21. } } } }
```

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:

```
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. }
```

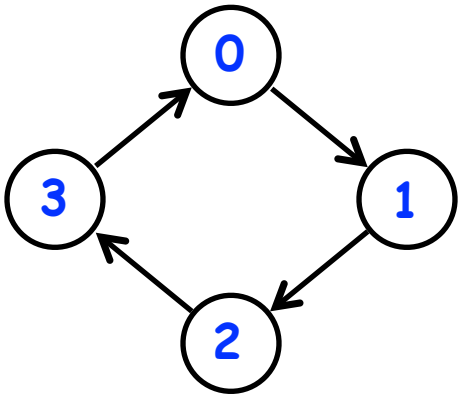
- Can also use atomic variables instead of `isolated` construct

With Actors:

```
15. class Counter extends Actor<Message> {
16.   private int counter = 0; // local state
17.   protected void process(Message msg) {
18.     if (msg instanceof IncMessage) {
19.       counter++;
20.     } else if (msg instanceof DecMessage){
21.       counter--;
22. } } }
23.   . . .
24. Counter counter = new Counter();
25. counter.start();
26.    public void foo() {
27.      // do something
28.      counter.send(new IncrementMessage(1));
29.      // do something else
30.    }
31.    public void bar() {
32.      // do something
33.      counter.send(new DecrementMessage(1));
34.    }
```


ThreadRing (Coordination) Example

```
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.   ring[threads-1].nextActor(ring[0]);
12.   ring[0].send(numberOfHops);
13. }); // finish
```



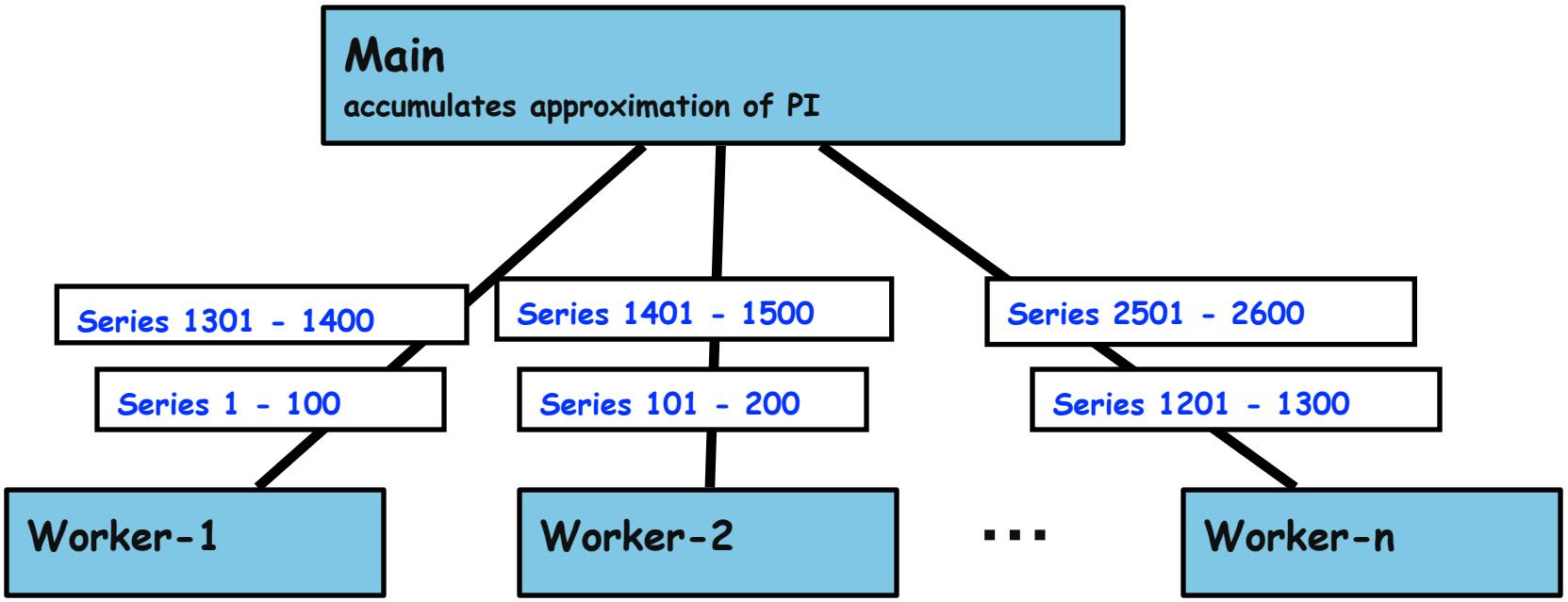

```
14. class ThreadRingActor
15.     extends Actor<Integer> {
16.   private Actor<Integer> nextActor;
17.   private final int id;
18.   ...
19.   public void nextActor(
        Actor<Object> nextActor) {...}

21.   protected void process(Integer n) {
22.     if (n > 0) {
23.       println("Thread-" + id +
24.         " active, remaining = " + n);
25.       nextActor.send(n - 1);
26.     } else {
27.       println("Exiting Thread-"+ id);
28.       nextActor.send(-1);
29.       exit();
30. } } }
```


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 Main-Worker technique:**



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

Pi Calculation --- Main Actor

```
1.  class Main extends Actor<Object> {
2.    private double result = 0; private int nrMsgsReceived = 0;
3.    private Worker[] workers;
4.    Main(nrWrkrs, nrEls, nrMsgs) {...} // constructor
5.    protected 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 --- Main Actor (contd)

```
19.     protected void onPostExit() {
20.       for (int i = 0; i < nrWrkrs; i++)
21.         workers[i].send(new Stop());
22.     } // post-exit()
23.     protected 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.   } // Main actor
32.    . . .
33.    // Start of program
34.    Main star = new Main(w, e, m);
35.    finish(() -> { star.start(); });
36.    println("PI = " + star.getResult());
```


Pi Calculation --- Worker Actor

```
1.   class Worker extends Actor<Object> {
2.     protected 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.         star.send(new ResultMessage(result));
9.     } } // process()
10.
11.    private double calculatePiFor(int start, int end) {
12.      double acc = 0.0;
13.      for (int k = start; k < end; k++) {
14.        acc += 4.0 * (1 - (k % 2) * 2) / (2 * k + 1);
15.      }
16.      return acc;
17.    }
18.   } // 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!)