COMP 322: Fundamentals of Parallel Programming

Lecture 21: Introduction to the Actor Model

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Worksheet #20: Sequential->Parallel Spanning Tree Algorithm

Insert finish, async, and atomic (includes a compareAndSet) constructs (pseudocode is fine) to convert the sequential spanning tree algorithm to a parallel algorithm

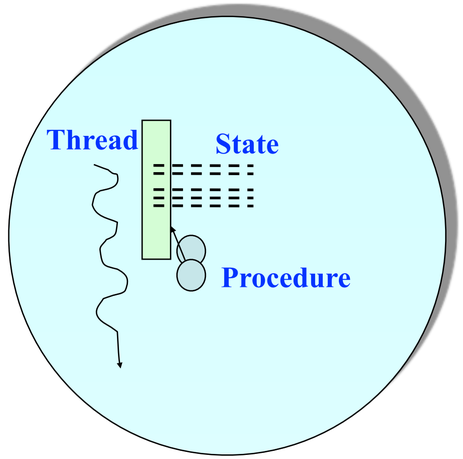
```
1.  class V  {
2.    V [] neighbors; // adjacency list for input graph
3.    V parent; // output value of parent in spanning tree
4.
5.    boolean makeParent(V n) {
6.      if (parent == null) { parent = n; return true; }
7.      else return false; // return true if n became parent
8.    } // makeParent
9.
10.   void compute() {
11.     for (int i=0; i<neighbors.length; i++) {
12.       final V child = neighbors[i];
13.       if (child.makeParent(this))
14.         child.compute(); // recursive call
15.      }
16.   } // compute
17. } // class V
18. . . . // main program
19. root.parent = root; // Use self-cycle to identify root
20. root.compute();
21. . . .
```


Atomic Variables represent a special (and more efficient) case of object-based isolation

```
1. class V  {
2.   V [] neighbors; // adjacency list for input graph
3.   AtomicReference<V> parent; // output value of parent in spanning tree
4.   boolean makeParent(final V n) {
5.     // compareAndSet() is a more efficient implementation of
6.     // object-based isolation
7.     return parent.compareAndSet(null, n);
8.   } // makeParent
9.   void compute() {
10.     for (int i=0; i<neighbors.length; i++) {
11.       final V child = neighbors[i];
12.       if (child.makeParent(this))
13.         async(() -> { child.compute(); }); // escaping async
14.      }
15.   } // compute
16. } // class V
17. . . .
18. root.parent = root; // Use self-cycle to identify root
19. finish(() -> { root.compute(); });
20. . . .
```


Actors: an alternative approach to isolation, atomics

- 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
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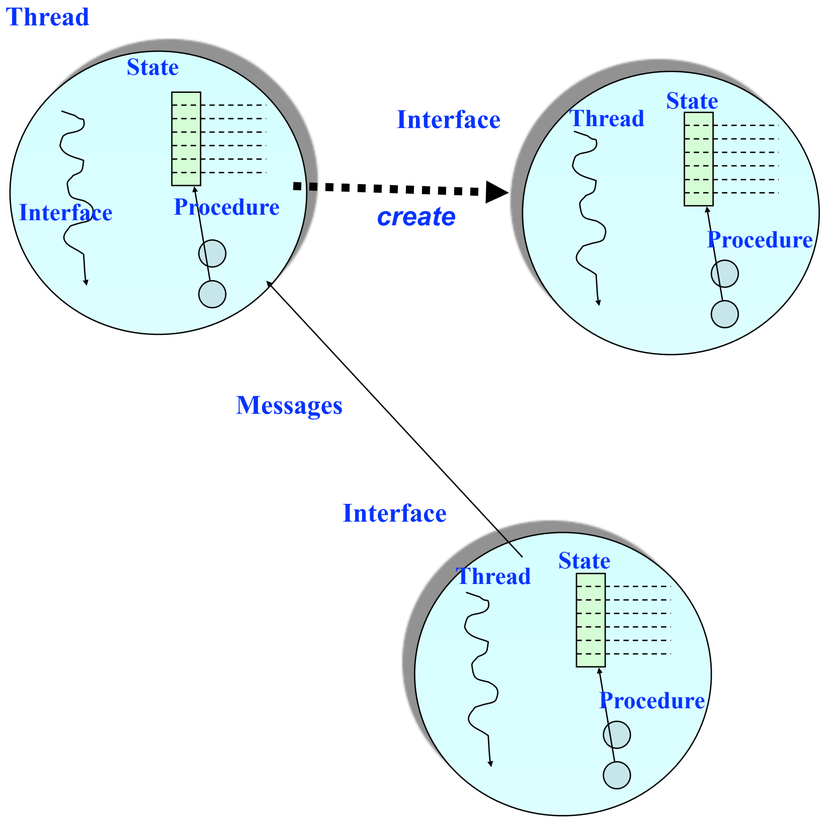


Actor Model

- 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

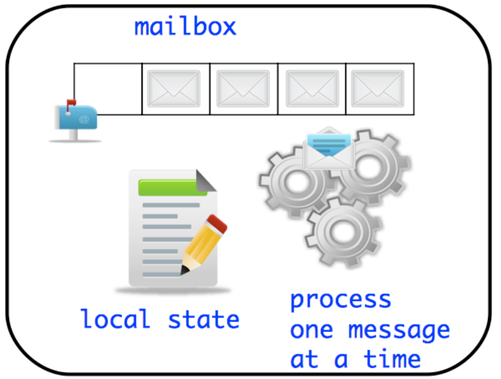
Actor Life Cycle

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 HJ-Lib

- 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:

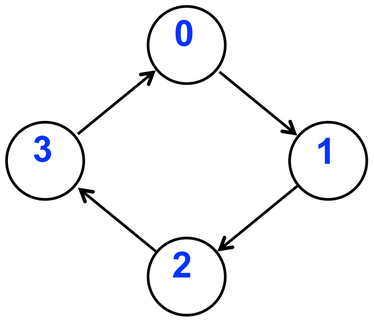
```
1. int counter = 0;
2. public void foo() {
3.   // do something
4.   isolated(() -> {
5.     counter++;
6.   });
7.   // do something else
8. }
9. public void bar() {
10.   // do something
11.   isolated(() -> {
12.     counter--;
13.   });
14. }
```

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
```




```
1.class ThreadRingActor
2.     extends Actor<Integer> {
3.   private Actor<Integer> nextActor;
4.   private final int id;
5.   ...
6.   public void nextActor(
       Actor<Object> nextActor) {...}

8.   protected void process(Integer n) {
9.     if (n > 0) {
10.      println("Thread-" + id +
11.        " active, remaining = " + n);
12.      nextActor.send(n - 1);
13.    } else {
14.      println("Exiting Thread-"+ id);
15.      nextActor.send(-1);
16.      exit();
17.} } }
```

Announcements & Reminders

- Lab 5 is tomorrow (setup before lab, try logging into NOTS)
- HW #3 CP 1 is due Wednesday, March 24th at 11:59pm
- Quiz for Unit 5 will be due Monday, March 29th at 11:59pm

Worksheet #21: Interaction between finish and actors

What output will be printed if the end-finish operation from slide 15 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.
```