COMP 322: Fundamentals of Parallel Programming

Lecture 23: Actors (contd)

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COMP 322 | Lecture 23 | 8 March 2017

Worksheet #22 solution: Interaction between `finish` and actors

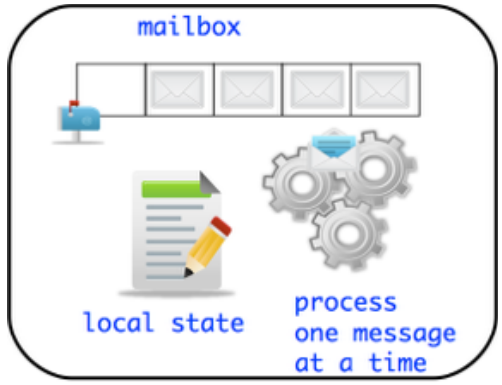
What output will be printed if the end-finish operation from slide 13 is moved from line 13 to line 11 as shown below?

```
1.  finish(() -> {
2.    int 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(); // like an async
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);
```

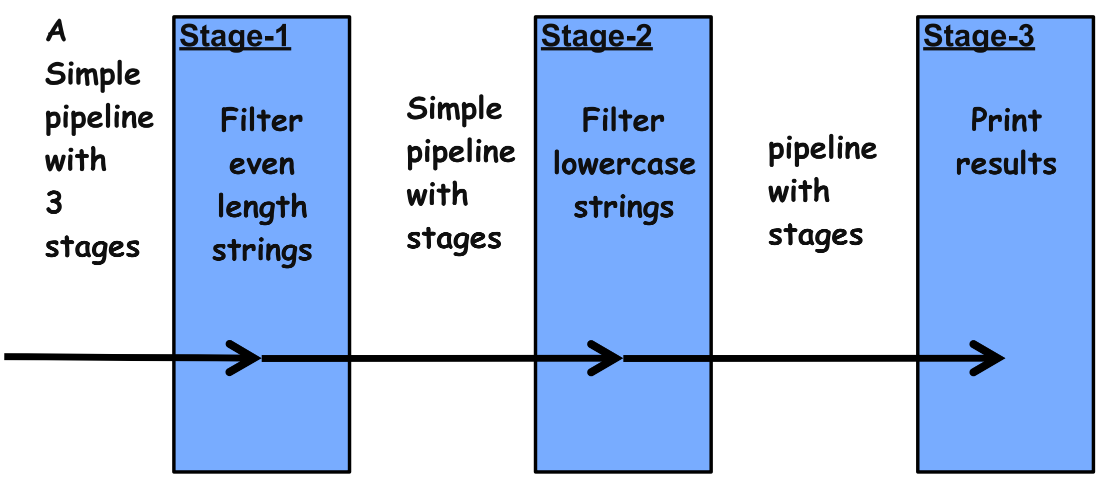
Deadlock (no output): the end-finish operation in line 11 waits for all the actors started in line 7 to terminate, but the actors are waiting for the message sequence initiated in line 13 before they call exit().

Recap of Actors

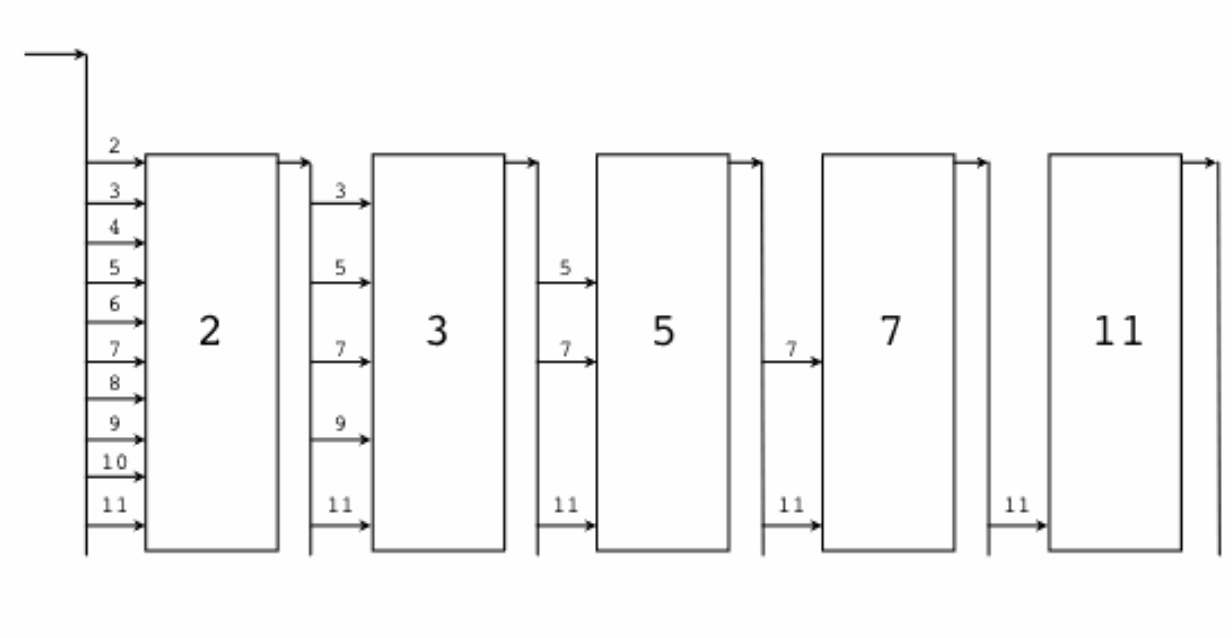
- Rely on asynchronous messaging
- Message are sent to an actor using its `send()` method
- Messages queue up in the mailbox
- Messages are processed by an actor after it is started
- Messages are processed asynchronously
  - one at a time
  - using the body of `process()`



Simple Pipeline using Actors

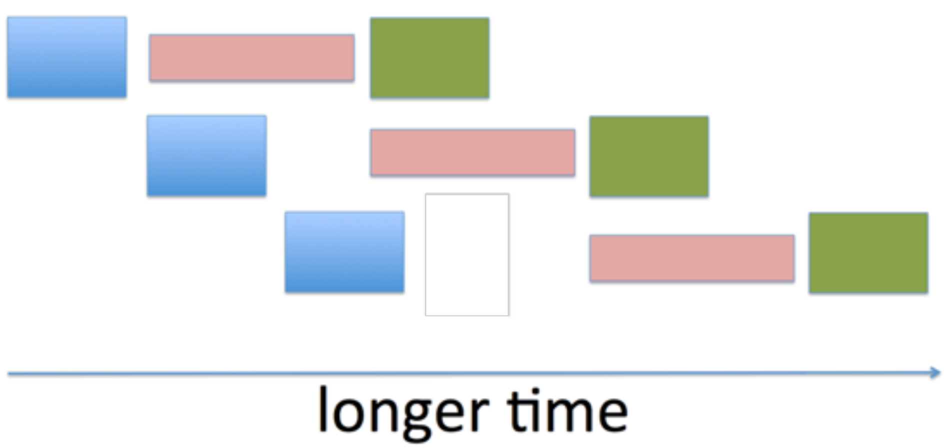


Sieve of Eratosthenes using Actors



Pipeline and Actors

- Pipelined Parallelism
  - Each stage can be represented as an actor
  - Stages need to ensure ordering of messages while processing them
  - Slowest stage is a throughput bottleneck



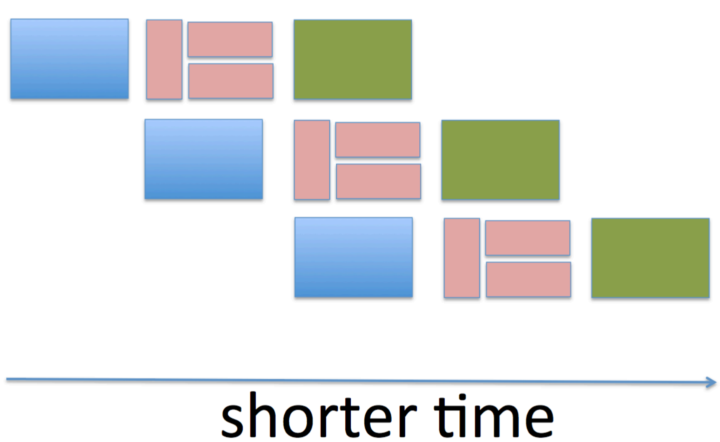
Limitations of Actor Model

- 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 synchronous get() or addAndGet()
- Implementing truly concurrent data structures is hard
  - No support for parallel reads (as in read-write isolation), or for parallel implementations of 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

Motivation for Parallelizing Actors

- Pipelined Parallelism
  - Reduce effects of slowest stage by introducing task parallelism.
  - Increases the throughput.



Parallelism within an Actor's process() method

- Use `finish` construct within `process()` body and spawn child tasks
- Take care not to introduce data races on local state!

```
class ParallelActor extends Actor<Message> {
  void process(Message msg) {
    finish(() -> {
      async(() -> { S1; });
      async(() -> { S2; });
      async(() -> { S3; });
    });
  }
}
```

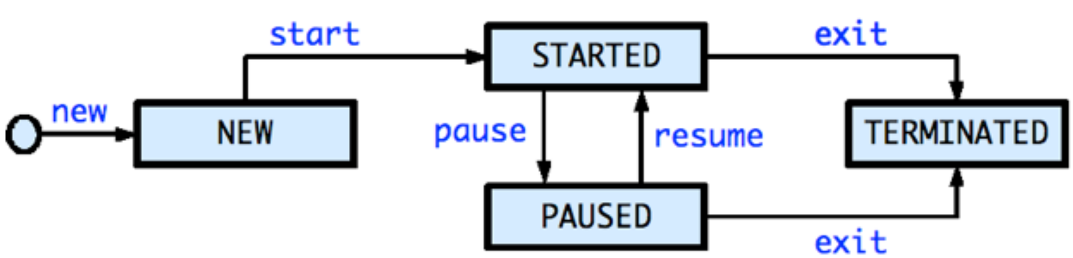

Example of Parallelizing Actors

```
class ArraySumActor extends Actor<Object> {
  private double resultSoFar = 0;
  @Override
  protected void process(final Object theMsg) {
    if (theMsg != null) {
      final double[] dataArray = (double[]) theMsg;
      final double localRes = doComputation(dataArray);
      resultSoFar += localRes;
    } else { ... }
  }
  private double doComputation(final double[] dataArray) {
    final double[] localSum = new double[2];
    finish(() -> { // Two-way parallel sum snippet
      final int length = dataArray.length;
      final int limit1 = length / 2;
      async(() -> {
        localSum[0] = doComputation(dataArray, 0, limit1);
      });
      localSum[1] = doComputation(dataArray, limit1, length);
    });
    return localSum[0] + localSum[1];
  }
}
```

Parallelizing Actors in HJlib

- **Two techniques:**
  - **Use finish construct to wrap `asyncs` in message processing body**
    - **Finish ensures all spawned `asyncs` complete before next message returning from `process()`**
  - **Allow escaping `asyncs` inside `process()` method**
    - **WAIT! Won't escaping `asyncs` violate the one-message-at-a-time rule in actors**
    - **Solution: Use `pause` and `resume`**

State Diagram for Extended Actors with Pause-Resume



- **Paused state: actor will not process subsequent messages until it is resumed**
- **Resume actor when it is safe to process the next message**
- **Messages can accumulate in mailbox when actor is in PAUSED state**

NOTE: Calls to exit(), pause(), resume() only impact the processing of the next message, and not the processing of the current message. These calls should just be viewed as “state change” operations.

Actors: pause and resume

- `pause()` operation:
  - Is a non-blocking operation, i.e. allows the next statement to be executed.
  - Calling `pause()` when the actor is already paused is a no-op.
  - Once paused, the state of the actor changes and it will no longer process messages sent (i.e. call `process(message)`) to it until it is resumed.
- `resume()` operation:
  - Is a non-blocking operation.
  - Calling `resume()` when the actor is not paused is an error, the HJ runtime will throw a runtime exception.
  - Moves the actor back to the STARTED state
    - the actor runtime spawns a new asynchronous thread to start processing messages from its mailbox.

Parallelizing Actors in HJlib

- Allow escaping `asyncs` inside process()

```
class ParallelActor2 extends Actor<Message> {
  void process(Message msg) {
    pause(); // process() will not be called until a resume() occurs
    async(() -> { S1; }); // escaping async
    async(() -> { S2; }); // escaping async
    async(() -> {
      // This async must be completed before next message
      // Can also use async-await if you want S3 to wait for S1 & S2
      S3;
      resume();
    });
  }
}
```

Synchronous Reply using Pause/Resume

- Actors are asynchronous, sync. replies require blocking operations
- We need notifications from recipient actor on when to resume
- Resumption needs to be triggered on sender actor
  - Use DDFs and `asyncAwait`

```
class SynchronousSenderActor
    extends Actor<Message> {
  void process(Msg msg) {
    ...
    DDF<T> ddf = newDDF();
    otherActor.send(ddf);
    pause(); // non-blocking
    asyncAwait(ddf, () -> {
      T synchronousReply = ddf.get();
      println("Response received");
      resume(); // non-blocking
    });
    ...
} }
```

```
class SynchronousReplyActor
    extends Actor<DDF> {
  void process(DDF msg) {
    ...
    println("Message received");
    // process message
    T responseResult = ...;
    msg.put(responseResult);
    ...
} }
```


Actors in the Real World

- Erlang - uses actors for high availability
  - Facebook chat service backend
  - Whatsapp messaging servers
  - Ericsson, Motorola, T-Mobile - call processing/SMS
  - RabbitMQ - high-performance enterprise messaging
- Akka - distributed Actor library in Scala
  - TwoSigma - customized realtime Dashboards on huge datasets
  - ResearchGate - distributed event/data propagation system
  - NBC - election reporting and analysis system
  - eBay - scalable web server monitoring and management

Announcements

- Reminder: Checkpoint #2 for Homework 3 is due by 11:59pm tonight, and the entire written + programming homework (Checkpoint #3) is due by March 22nd
- Reminder: Quiz for Unit 5 is due by this Friday (March 10th)
- The registrar has announced the schedule for the COMP 322 final exam:
  - 2-MAY-2017
  - 9:00AM - 12:00PM
  - Location TBD
- Scope of final exam (Exam 2) will be limited to Lectures 19 - 38