Favoring Isolated Mutability
The Actor Model of Concurrency

CSCI 5828: Foundations of Software Engineering
Lecture 24 — 04/11/2012

Goals

- Review the material in Chapter 8 of the Concurrency textbook
  - that deals with the fundamentals of the actor approach
  - and the use of UntypedActors in Akka
- We'll review the use of
  - TypedActors, and
  - Mixing STM with the Actor Model
- in our next lecture

“If it hurts, stop doing it”

- With concurrency, we have learned
  - that the shared mutability approach to concurrency leads to lots of problems and difficulty
- As a result, we’ve been looking at alternatives
  - With the STM model, we looked at managed mutability
    - where all values were immutable
    - but a “ref” or an “identity” could be associated with different values over time; with change occurring inside of transactions
- Now, we’ll look at the isolated mutability approach
  - as embodied in the Actor Model of Concurrency

Isolated Mutability and the Actor Model

- Isolated Mutability is a design approach in which
    - we can have mutable values
    - but we make sure that for each mutable value
        - only one thread has access to it
- The Actor Model of concurrency is one in which
    - we have multiple lightweight processes, known as actors
        - each actor can have mutable state if it wants
            - because no other actor has access to that state
    - actors instead pass immutable messages to each other if they need to communicate or coordinate
        - these messages are passed asynchronously and are processed in the order that they arrive

The Actor Model: Background

- This model has been around for a long time
  - It is built into the functional programming language, Erlang
- And was also built into Scala, a hybrid functional/OO language
  - Scala is built on top of the JVM
    - it can call Java code and Java can call Scala code
      - as we saw when working with the STM
        - The Akka framework is written in Scala

Actor Model

- To emphasize
  - Programs that use the Actor model are multithreaded
    - but each individual actor is single threaded
    - they each have access to mutable state
      - but an actor cannot access the mutable state of another actor
    - all one actor can do to another actor is send an immutable message
      - since the messages are immutable, it is safe to share them between actors
    - likewise, all an actor can do is sit and wait for messages to arrive

Actor Model == OOP++?

- The book asserts that the actor model can be seen as taking OOP to the next level
  - We have objects and they can have mutable state
    - but they each run on their own thread
    - and all we can do is send messages to them
      - we can't call their methods directly

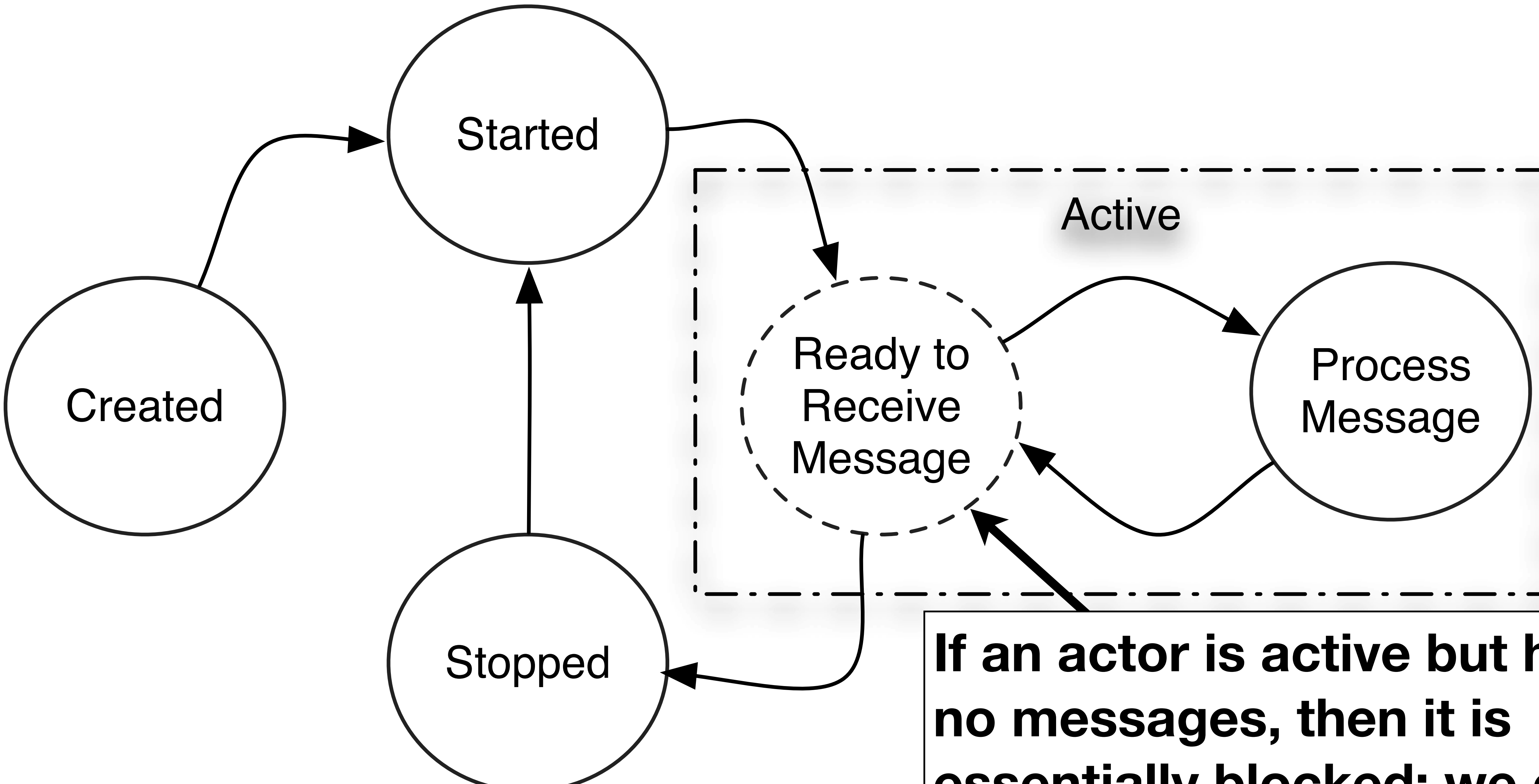
Actor Qualities (I)

- Each actor is an independent activity
  - it can receive messages
  - process them
  - and send messages
- Each actor has a built in message queue
  - it can receive multiple messages at once
  - it can send a message at the same time that other actors are sending them
  - As a result, there is plenty of opportunity for concurrency!

Actor Qualities (II)

- Actor does not equal Thread
  - Instead, think of an actor as a task
- Recall how we separated task decomposition from thread allocation?
  - Allowing us to create, for instance, a thread pool with 20 threads
    - And then allocate 100 tasks to be processed by the thread pool
- The same thing happens with actors
  - We will likely have X actors being managed by Y threads where
    - X >> Y
- We can get away with this because of the actor lifecycle

Actor Life Cycle



If an actor is active but has no messages, then it is essentially blocked; we can swap it out and let some other actor run

Creating Actors (I)

- Support for the Actor Model is built into Scala
    - as a result, Scala's syntax makes it easy to create actors and send messages to them
        - and to process messages as well
- I'm not going to cover the details of Scala in this class
    - so we are going to use the Akka framework to implement actors in Java
- As a result, the information discussed in Lecture 19 on slides 34 and 35 is relevant here
    - you will need to follow those instructions in order to compile our example programs

Creating Actors (II)

- The simplest actor in Akka has a class name of UntypedActor
  - That class is located in the akka.actor package
- We can think of it as an abstract class that has one method we need to implement:
  - public void onReceive(final Object message)
- We implement this method to indicate how our actor will handle its messages
  - Note: the parameter type for message is java.lang.Object
  - In practice, only immutable types can be sent to us
    - and we do need to perform checks at run-time to figure out what message was sent to us

Creating Actors (III)

- Our increment program lives again!
  - `public class Counter extends UntypedActor {`
    - `private int count = 0;`
    - `public void onReceive(final Object message) {`
      - `if (message instanceof Integer) {`
        - `count += (Integer)message;`
        - `System.out.println("Count: " + count);`
      - `}`
    - `}`
  - `}`

Creating Actors (IV)

- Our increment program lives again!
  - `public class Drone extends UntypedActor {`
    - `public void onReceive(final Object message) {`
      - `if (message instanceof ActorRef) {`
        - `ActorRef counter = (ActorRef)message;`
        - `for (int i = 0; i < 5; i++) {`
          - `counter.tell(new Integer(1));`
        - `}`
      - `}`
    - `}`
  - `}`

Creating Actors (V)

- To instantiate one of our actors, we make use of the Actors factory in the package akka.actors.
  - We pass the factory the class of the instance, we want created
  - We get back an ActorRef that points at our newly created Actor
- So, when we create an instance of our Counter actor
  - we do not get back a reference to Counter
  - we get back a reference to ActorRef
- We can use that reference to send messages to the Counter
  - Why? We are not supposed to have access to instances of Counter directly; if we did, Counter's mutable variables might escape!

Creating Actors (VI)

- Our increment program lives again!
  - `The full program is in Increment.java`
- Creating an ActorRef looks like this
  - `final ActorRef counter = Actors.actorOf(Counter.class);`
- To start an Actor, you call start() on the ActorRef
  - `counter.start();`
- To send an asynchronous message, use the tell() method
  - `counter.tell(new Integer(100));`
- **DEMO**

Creating Actors (VII)

- The book had several examples of creating Actors
    - **DEMO**
- One of its examples touches on creating Actors that have constructors
    - Since you are not allowed to directly instantiate an Actor class, it is difficult to pass values to an Actor's constructor
        - To do that, you need to create an anonymous instance of the UntypedActorFactory class
            - that factory has a create() method that returns instances of UntypedActor and you can pass constructor arguments there
        - You then pass the UntypedActorFactory to the actorOf() method
            - It uses the factory to create an instance and return an ActorRef

Sending Messages

- You can send messages in two ways
  - tell(final Object message) -- sends an asynchronous, immutable message
  - Future ask(final Object message) -- sends a message, provides future
- Future is NOT java.util.concurrent.Future but it operates in the same way
  - Once you get back a future
    - you call Future.await() to block until a response is available
  - You then call Future.result().get() to acquire the immutable response sent to you by the other actor
    - The call to result().get() can fail; you need to call Future.result().isDefined() and only call get() when isDefined() returns true

DEMO

Replying

- If you receive a message from another actor, how do you reply?
  - If you are within the onReceive() method of an actor, you can simply call
    - getContext().channel() to get access to an ActorRef
  - Once you have the ActorRef, you can call tell() and ask() as normal
- So, replying is really the same thing as just sending!

Handling Multiple Actors

- We already saw multiple actors in action with our simple Increment program
    - The book returns to the PrimeFinder example
    - It has a simple design
        - We are provided the upper bound of our search and the number of partitions
            - Our main program create one Actor per partition and sends it a range using ask(), which returns a Future
                - Each actor calculates the number of primes in that range and sends it back
            - Our main program loops through Future objects and calculates the total number of primes
- As you will see, the program maxes out the cores of my machine when I run the program

Coordinating Actors (I)

- To show how Actors can coordinate with each other, the book returns to the FileSize program
  - Our previous versions of this program made use of coordination mechanisms (locks) and executors
- With the isolated mutability approach of the Actor model
  - we can get a simpler solution and avoid some of the problems we encountered earlier
    - such as when we locked up the thread pool with a poor design related to spawning tasks while traversing the file hierarchy

Coordinating Actors (II)

- The design of this system depends on two types of actors
  - FileProcessors
    - actors which process the size of a single directory
    - we will create 100 of these to simulate the 100 threads we used earlier
  - SizeCollector
    - an actor who coordinates the FileProcessors and maintains a counter to keep track of the total size of the directory

Coordinating Actors (III)

- The design of this system also depends on three messages
  - RequestAFile:
    - sent by a FileProcessor to the SizeCollector
    - The effect is to tell the SizeCollector, “I’m ready!”
  - FileToProcess:
    - sent by SizeCollector to FileProcessor or vice versa
    - provides a pointer to a file or directory that needs to be processed
  - FileSize
    - sent by FileProcessor to SizeCollector
    - returns the size of a file/directory that was processed

Coordinating Actors (IV)

- Two key design points
  - When a FileProcessor starts up, it needs to tell the SizeCollector that it is available
    - It overrides a lifecycle method preStart() to do that
      - That method ensures that we send a RequestAFile message to the SizeCollector
    - A reference to the SizeCollector is passed in via FileProcessor's constructor
  - When a FileProcessor is given a directory, it does not recursively work its way through all subdirectories. Instead, as it finds subdirectories, it sends FileToProcess messages to SizeCollector

DEMO

Results

- In both cases (PrimeFinder and FileSizer), with the Actor Model, we get
  - comparable performance to the previous solutions
  - much simpler code
    - no locks
    - all code written from single threaded standpoint
      - allows for use of mutable variables with predictable behavior

Summary

- Reviewed the basics of the Actor model
  - Independent actors (which can be assigned to threads like tasks)
    - with mutable state that is NOT shared
      - with predictable semantics since the actor is single threaded
    - communicating with other actors by passing immutable messages
  - These constructs enable the isolated mutability approach to concurrency
- You get great performance with a very simple and straightforward model
  - no thread allocation, no task decomposition, no locks

Coming Up Next

- Lecture 25: Advanced Actor Model
- Lecture 26: Creating Agile Software