Advances in Programming Languages

APL16: Further language concurrency mechanisms

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Programming-Language Techniques for Concurrency

This is the second of three lectures presenting some programming-language techniques for managing concurrency.

- Basic Java concurrency
- Concurrency abstractions
- Concurrency in some other languages

Outline

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Concurrency mechanisms

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Various language paradigms have been followed, e.g.:

locks and conditions: tasks share memory and exclude and signal one another using shared memory (e.g., Java);

synchronous message passing: tasks share communication channels and use *rendezvous* to communicate (e.g., Ada, Concurrent ML);

asynchronous message passing: a task offers a *mail box* which receives messages (e.g. Erlang, Scala Actors);

lock-free algorithms or transactional memory: tasks share memory but detect and repair conflicts.

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lock-free algorithms or transactional memory: tasks share memory but detect and repair conflicts.

Language designs have also been influenced by mathematical models used to capture and analyse the essence of concurrent systems, for example, π*-calculus*, the *join calculus*, and the *ambient calculus*.

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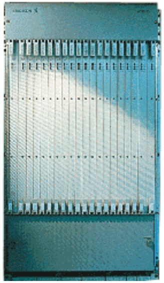
Scala and Erlang

Scala is a functional object-oriented language that compiles to the Java Virtual Machine. It allows full interoperability with Java. Scala is designed by Martin Odersky and his team at EPFL, Lausanne, Switzerland.

Scala's concurrency is based on the *Actor model* also used in several other languages. A notable commercial success story is Ericsson's language *Erlang* designed for massively concurrent telecommunications equipment.



Ericsson AXD 301 multiservice 10–160Gbit/s switch

Nortel 8661 SSL Acceleration Ethernet Routing Switch

Asynchronous message passing

An *actor* is a process abstraction that interacts with other actors by message passing. Message sending is asynchronous. Each actor has a *mail box* which buffers incoming messages. Messages are processed by matching.

Sending

```
actor ! message

// sender is the last actor
// we received from
sender ! message

// shorthand for above
reply(message)
```

Receiving

```
receive {
  case pattern => action
   ...
  case pattern => action
}
```

Example: ping pong

```
class Ping(pong: Actor)
  extends Actor {
  def act() {
    var pings = 0;
    pong ! Ping
    while (true) {
      receive {
        case Pong =>
          pong ! Ping
          pings += 1
          if (pings % 1000 == 0)
            Console.println(
                "Ping: pong "+pings)
          }
    }}}
```

```
class Pong extends Actor {
  def act() {
    var pongs = 0
    while (true) {
      receive {
        case Ping =>
          sender ! Pong
          pongs += 1
      }}}}

object pingpong
       extends Application {
  val pong = new Pong
  val ping = new Ping(pong)
  ping.start
  pong.start
}
```

Reply-response protocols

Actors often take part in sequences of message exchanges, which are more synchronous in nature. There is a special encoding for writing these.

Sending and receiving

```
actor !? message
```

is like

```
actor ! (self, message)
receive {
  case pattern => ...
}
```

Event-based actors

Actors are either *thread-based* or *event-based*. Thread based actors block on **receive** calls. Event-based actors provide an alternative which uses a more lightweight mechanism.

Event based receiving

```
react {
  case pattern => action
   ...
  case pattern => action
}
```

A **react** statement encapsulates the rest of a computation for an actor and never returns. The event-based framework generates tasks that process messages and suspend and resume actors, using *continuations* derived from the **react** blocks.

Example: bounded buffer

```
class BoundedBuffer[T](N: int) {
  private case class Put(x: T)
  private case object Get
  private case object Stop

  def put(x: T) {
     buffer !? Put(x)
  }

  def get: T =
   (buffer !? Get).asInstanceOf[T]

  def stop() {
     buffer !? Stop
  }
}
```

```
private val buffer = actor {
  val buf = new Array[T](N)
  var in = 0; var out = 0; var n = 0
  loop {
    react {
      case Put(x) if n < N =>
        buf(in) = x
        in = (in + 1) % N
        n = n + 1; reply()
      case Get if n > 0 =>
        val r = buf(out)
        out = (out + 1) % N
        n = n − 1; reply(r)
      case Stop => reply()
      exit("stopped")
    }
}}
```

Summary

Concurrency in Scala

- Concurrency in Scala is modelled with *actors*
- Each actor has a *mail box*, to which other threads can send messages asynchronously.
- Actors sift through received messages by *pattern-matching*.
- Scala actors can be either *thread-based* or *event-based*.
- Thread-based actors block JVM threads when waiting to receive a message.
- Event-based actors use task management within a JVM thread to allow cheap context switching between suspended actors.

Outline

Polyphonic C#

Polyphonic C# is a mild extension of C# which introduced novel primitives for writing concurrent programs, based on the join calculus.

The design was inspired by these ideas:

- Focus on communication rather than concurrency.
- Unify message passing with method invocation.
- Look not just for individual messages but patterns of messages.

Polyphonic C# itself is no longer maintained. The concurrency mechanisms also appear in $C\omega$, and are provided in the *Joins* library for C# other .NET languages. Similar notions have been applied in *JoCaml* and *Join Java*.

New constructs in Polyphonic C#

Asynchronous methods

Conventional method invocation in C# is *synchronous*: when code calls a method on an object, it cannot continue until that method completes.

In contrast, when code invokes an *asynchronous* method, it continues at once, and does not have to wait for the method to finish.

Chords

Standard method declarations associate one piece of code (the *body*) to each method name (up to overloading by parameter type and number).

In Polyphonic C#, a *chord* declares code that is to be executed only when a particular combination of methods are invoked.

Example: unbounded concurrent buffer

```
public class Buffer {

    public String get() & public async put(String s) { return s; }
}
```

This has two methods, get and put, jointly defined in a *chord*, with a single return statement in the body.

Consumers call get(): this blocks until a producer invokes put(s), and then the chord is complete so s is returned to the consumer.

Producers call put(s): if a consumer is waiting on get(), then the chord is complete and value is handed on; if not, the call is noted, and control returns to the producer. Either way, the async call returns at once.

Multiple put or get calls can be outstanding at any time.

Example: unbounded concurrent buffer

```
public class Buffer {

  public String get() & public async put(String s) { return s; }
}
```

- No threads are spawned: the body of the chord is executed by the caller of the synchronous get method.
- Where there are multiple threads, it is entirely thread-safe: several producers and consumers can run simultaneously.
- No critical sections, monitors or mutual exclusion: there is no shared storage for interference.
- No explicit locks: the compiler looks after the brief locking required at the moment of chord selection.

Example: unbounded concurrent buffer

```
public class Buffer {

  public String get() & public async put(String s) { return s; }
}
```

- Each chord may combine many method names.
- At most one method in a chord can be synchronous.
- Each method can appear in multiple chords.
- A chord may be entirely asynchronous.
- Synchronous calls may block; asynchronous calls return at once.
- Calls stack up until a chord is matched.

Example: one-place buffer

```
public class OnePlaceBuffer {

   public OnePlaceBuffer() { empty(); }

   public void put(String s) & private async empty() {
      contains(s);
      return;
   }

   public String get() & private async contains(String s) {
      empty();
      return s;
   }
}
```

Workings of the one-place buffer

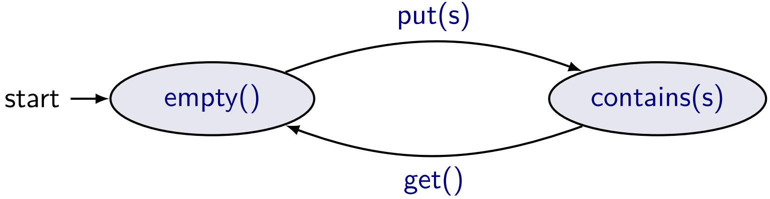
The class has four methods:

- Two public synchronous methods put(s) and get();
- Two private asynchronous methods empty() and contains(s).

There is always exactly one empty() or contains(s) call pending. No threads are needed, but where there is concurrency the code remains safe.

- Method put(s) blocks unless and until there is an empty() call.
- Method get() blocks unless and until there is a contains(s) call.

The code operates a simple state machine:



Summary

Polyphonic C# Concurrency

- Central notion of *asynchronous* computation.
- Implicit concurrency: no explicit threads, locks, mailboxes, channels,. . . ; although all these could be coded up.
- Synchronization points made explicit with *chords*.
- Declarative presentation makes compiler optimisations possible.