Concurrent Programming

Actors, SALSA, Coordination Abstractions

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Advantages of concurrent programs

- Reactive programming
  - User can interact with applications while tasks are running, e.g., stopping the transfer of a big file in a web browser.
- Availability of services
  - Long-running tasks need not delay short-running ones, e.g., a web server can serve an entry page while at the same time processing a complex query.
- Parallelism
  - Complex programs can make better use of multiple resources in new multi-core processor architectures, SMPs, LANs or WANs, e.g., scientific/engineering applications, simulations, games, etc.
- Controllability
  - Tasks requiring certain preconditions can suspend and wait until the preconditions hold, then resume execution transparently.

Disadvantages of concurrent programs

- Safety
  - *« Nothing bad ever happens »*
  - Concurrent tasks should not corrupt consistent state of program
- Liveness
  - *« Anything ever happens at all »*
  - Tasks should not suspend and indefinitely wait for each other (deadlock).
- Non-determinism
  - Mastering exponential number of interleavings due to different schedules.
- Resource consumption
  - Threads can be expensive. Overhead of scheduling, context-switching, and synchronization.
  - Concurrent programs can run *slower* than their sequential counterparts even with multiple CPUs!

Overview of concurrent programming

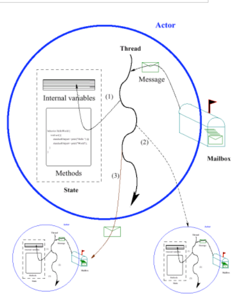
- There are four basic approaches:
  - Sequential programming (no concurrency)
  - Declarative concurrency (streams in a functional language)
  - Message passing with active objects (Erlang, SALSA)
  - Atomic actions on shared state (Java)
- The atomic action approach is the *most difficult*, yet it is the one you will probably be most exposed to!
- But, if you have the choice, which approach to use?
  - Use the simplest approach that does the job: sequential if that is ok, else declarative concurrency if there is no observable nondeterminism, else message passing if you can get away with it.

Actors/SALSA

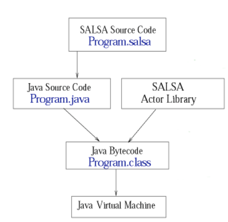
- Actor Model
  - A reasoning framework to model concurrent computations
  - Programming abstractions for distributed open systems

  G. Agha, *Actors: A Model of Concurrent Computation in Distributed Systems.* MIT Press, 1986.
- SALSA
  - Simple Actor Language System and Architecture
  - An actor-oriented language for mobile and internet computing
  - Programming abstractions for internet-based concurrency, distribution, mobility, and coordination

  C. Varela and G. Agha, "Programming dynamically reconfigurable open systems with SALSA", *ACM SIGPLAN Notices, OOPSLA 2001*, 36(12), pp 20-34.



SALSA and Java



- SALSA source files are compiled into Java source files before being compiled into Java byte code.
- SALSA programs may take full advantage of the Java API.

Hello World Example

```
module examples.helloworld;

behavior HelloWorld {

   void act( String[] args ) {

      standardOutput <- print( "Hello" ) @
      standardOutput <- println( "World!" );

   }

}
```


Hello World Example

- The `act( String[] args )` message handler is similar to the `main(...)` method in Java and is used to bootstrap SALSA programs.
- When a SALSA program is executed, an actor of the given behavior is created and an `act(args)` message is sent to this actor with any given command-line arguments.
- References to `standardOutput, standardInput` and `standardError` actors are available to all SALSA actors.

SALSA Support for Actors

- Programmers define *behaviors* for actors.
- Messages are sent asynchronously.
- State is modeled as encapsulated objects/primitive types.
- Messages are modeled as potential method invocations.
- Continuation primitives are used for coordination.

Reference Cell Example

```
module examples.cell;

behavior Cell {
   Object content;

   Cell(Object initialContent) {
         content = initialContent;
    }

   Object get() { return content; }

   void set(Object newContent) {
        content = newContent;
   }
}
```


Actor Creation

- To create an actor:

```
TravelAgent a = new TravelAgent();
```


Message Sending

- To create an actor:

```
TravelAgent a = new TravelAgent();
```

- To send a message:

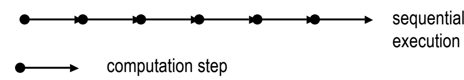
```
a <- book( flight );
```

Causal order

- In a sequential program all execution states are totally ordered
- In a concurrent program all execution states of a given actor are totally ordered
- The execution state of the concurrent program as a whole is partially ordered

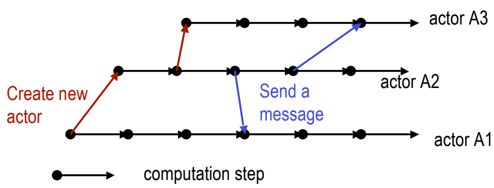
Total order

- In a sequential program all execution states are totally ordered



Causal order in the actor model

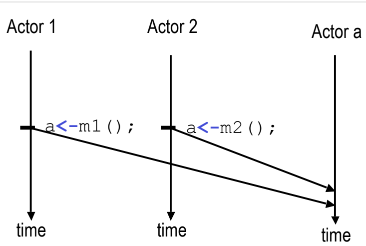
- In a concurrent program all execution states of a given actor are totally ordered
- The execution state of the concurrent program is partially ordered



Nondeterminism

- An execution is nondeterministic if there is a computation step in which there is a choice what to do next
- Nondeterminism appears naturally when there is asynchronous message passing
  - Messages can arrive or be processed in an order different from the sending order.

Example of nondeterminism



Actor `a` can receive messages `m1()` and `m2()` in any order.

Coordination Primitives

- SALSA provides three main coordination constructs:
  - Token-passing continuations
    - To synchronize concurrent activities
    - To notify completion of message processing
    - Named tokens enable arbitrary synchronization (data-flow)
  - Join blocks
    - Used for barrier synchronization for multiple concurrent activities
    - To obtain results from otherwise independent concurrent processes
  - First-class continuations
    - To delegate producing a result to a third-party actor

Token Passing Continuations

- Ensures that each message in the continuation expression is sent after the previous message has been **processed**. It also enables the use of a message handler return value as an argument for a later message (through the token keyword).
  - Example:

```
a1 <- m1() @
a2 <- m2( token );
```

Send `m1` to `a1` asking `a1` to forward the result of processing `m1` to `a2` (as the argument of message `m2`).

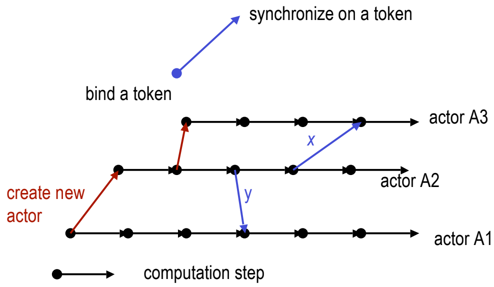
Named Tokens

- Tokens can be named to enable more loosely-coupled synchronization
  - Example:

```
token t1 = a1 <- m1();
token t2 = a2 <- m2();
token t3 = a3 <- m3( t1 );
token t4 = a4 <- m4( t2 );
a <- m(t1,t2,t3,t4);
```

Sending `m(...)` to `a` will be delayed until messages `m1()..m4()` have been processed. `m1()` can proceed concurrently with `m2()`.

Causal order in the actor model



Cell Tester Example

```
module examples.cell;

behavior CellTester {

    void act( String[] args ) {

      Cell c = new Cell("Hello");
      standardOutput <- print( "Initial Value:" ) @
      c <- get() @
      standardOutput <- println( token ) @
      c <- set("World") @
      standardOutput <- print( "New Value:" ) @
      c <- get() @
      standardOutput <- println( token );

    }
}
```


Join Blocks

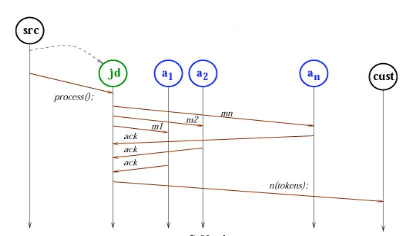
- Provide a mechanism for synchronizing the processing of a set of messages.
- Set of results is sent along as a *token* containing an array of results.
  - Example:

```
Actor[] actors = { searcher0, searcher1,
                   searcher2, searcher3 };
join {
  for (int i=0; i < actors.length; i++){
     actors <- find( phrase );
  }
} @ resultActor <- output( token );
```

Send the `find( phrase )` message to each actor in `actors[]` then after all have completed send the result to `resultActor` as the argument of an `output( … )` message.

Example: Acknowledged Multicast

```
join{ a1 <- m1(); a2 <- m2; … an <- mn(); } @
   cust <- n(token);
```



Lines of Code Comparison

	Java	Foundry	SALSA
Acknowledged Multicast	168	100	31

First Class Continuations

- Enable actors to delegate computation to a third party independently of the processing context.
- For example:

```
int m(…){
    b <- n(…) @ currentContinuation;
}
```

Ask (delegate) actor `b` *to respond to this message* `m` *on behalf of current actor (*`self`*) by processing its own message* `n`*.*

Delegate Example

```
module examples.fibonacci;

behavior Calculator {

   int fib(int n) {
        Fibonacci f = new Fibonacci(n);
        f <- compute() @ currentContinuation;
   }
   int add(int n1, int n2) {return n1+n2;}

   void act(String args[]) {
        fib(10) @ standardOutput <- println(token);
        fib(8) @ add(token,3) @
        standardOutput <- println(token);
   }
}
```

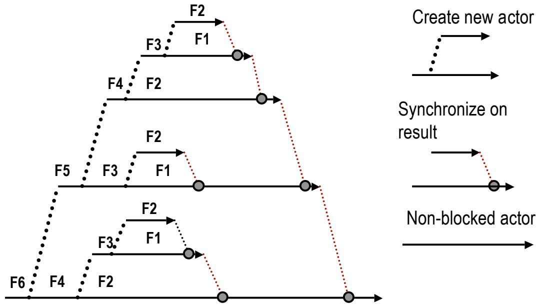

Fibonacci Example

```
module examples.fibonacci;

behavior Fibonacci {
    int n;

    Fibonacci(int n)           { this.n = n; }

    int add(int x, int y) { return x + y; }

    int compute() {
          if (n == 0)          return 0;
          else if (n <= 2)     return 1;
          else {
                    Fibonacci fib1 = new Fibonacci(n-1);
                    Fibonacci fib2 = new Fibonacci(n-2);
                    token x = fib1<-compute();
                    token y = fib2<-compute();
                    add(x,y) @ currentContinuation;
          }
    }

    void act(String args[]) {
          n = Integer.parseInt(args[0]);
          compute() @ standardOutput<-println(token);
    }
}
```


Fibonacci Example 2

```
module examples.fibonacci2;

behavior Fibonacci {

    int add(int x, int y) { return x + y; }

    int compute(int n) {
          if (n == 0)      return 0;
          else if (n <= 2) return 1;
          else {
                    Fibonacci fib = new Fibonacci();
                    token x = fib <- compute(n-1);
                    compute(n-2) @ add(x,token) @ currentContinuation;
          }
    }

    void act(String args[]) {
          int n = Integer.parseInt(args[0]);
          compute(n) @ standardOutput<-println(token);
    }
}
```


Execution of `salsa Fibonacci 6`



Scheduling

- The choice of which actor gets to execute next and for how long is done by a part of the system called the *scheduler*
- An actor is *non-blocked* if it is processing a message or if its mailbox is not empty, otherwise the actor is *blocked*
- A scheduler is fair if it does not starve a non-blocked actor, i.e. all non-blocked actors eventually execute
- Fair scheduling makes it easier to reason about programs and program composition
  – Otherwise some correct program (in isolation) may never get processing time when composed with other programs

Message Properties

- SALSA provides message properties to control message sending behavior:
  – priority
    • To send messages with priority to an actor
  – delay
    • To delay sending a message to an actor for a given time
  – waitfor
    • To delay sending a message to an actor until a token is available

Priority Message Sending

- To (asynchronously) send a message with high priority:

```
a <- book(flight):priority;
```

Message is placed at the beginning of the actor's mail queue.

Delayed Message Sending

- To (asynchronously) send a message after a given delay in milliseconds:

```
a <- book(flight):delay(1000);
```

Message is sent after one second has passed.

Synchronized Message Sending

- To (asynchronously) send a message after another message has been processed:

```
token fundsOk = bank <- checkBalance();
…
a <- book(flight):waitfor(fundsOk);
```

Message is sent after token has been produced.

Exercises

63. How would you implement the join continuation linguistic abstraction in terms of message passing?

64. Download and execute the `CellTester.salsa` example.

65. *Write a solution to the Flavius Josephus problem in SALSA. A description of the problem is at VRH Section 7.8.3 (page 558).