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


- **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

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

```java
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.
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:

```java
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.

Create new actor

Send a message

computation step
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 \texttt{m1()} and \texttt{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:

    
    \begin{align*}
    \text{token } t_1 &= a_1 \leftarrow m_1(); \\
    \text{token } t_2 &= a_2 \leftarrow m_2(); \\
    \text{token } t_3 &= a_3 \leftarrow m_3(t_1); \\
    \text{token } t_4 &= a_4 \leftarrow m_4(t_2); \\
    a &\leftarrow m(t_1,t_2,t_3,t_4);
    \end{align*}

    Sending \( m(...) \) to \( a \) will be delayed until messages \( m_1() \ldots m_4() \) have been processed. \( m_1() \) can proceed concurrently with \( m_2() \).
Causal order in the actor model

synchronize on a token

bind a token

create new actor

computation step
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 );

    }
}

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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[i] <- 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

\[
\text{join}\{ \ a_1 \leftarrow m_1(); \ a_2 \leftarrow m_2(); \ldots \ a_n \leftarrow m_n(); \} @
\]
\[
cust \leftarrow n(\text{token});
\]
## Lines of Code Comparison

<table>
<thead>
<tr>
<th>Acknowledged Multicast</th>
<th>Java</th>
<th>Foundry</th>
<th>SALSA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>168</td>
<td>100</td>
<td>31</td>
</tr>
</tbody>
</table>
First Class Continuations

• Enable actors to delegate computation to a third party independently of the processing context.

• For example:

```c
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(15) @ standardOutput <- println(token);
        fib(5) @ add(token,3) @
        standardOutput <- println(token);
    }
}

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Fibonacci Example

```java
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);
    }
}
```

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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

Create new actor

Synchronize on result

Non-blocked actor
Exercises

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

2. Download and execute the CellTester.salsa example.

3. Write a solution to the Flavius Josephus problem in SALSA. A description of the problem is at Concepts Techniques and Models of Computer Programming textbook Section 7.8.3 (page 558).