Concurrent Programming with SALSA (PDCS 9)

Actors, Coordination Abstractions: Tokens, Join Blocks, First-Class Continuations

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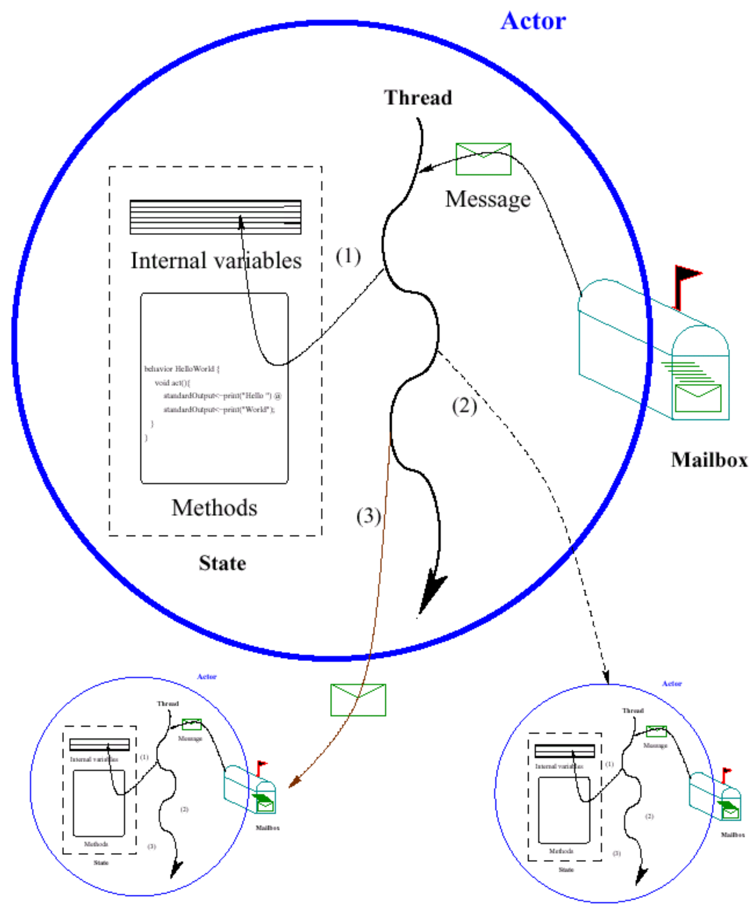
Actors/SALSA

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

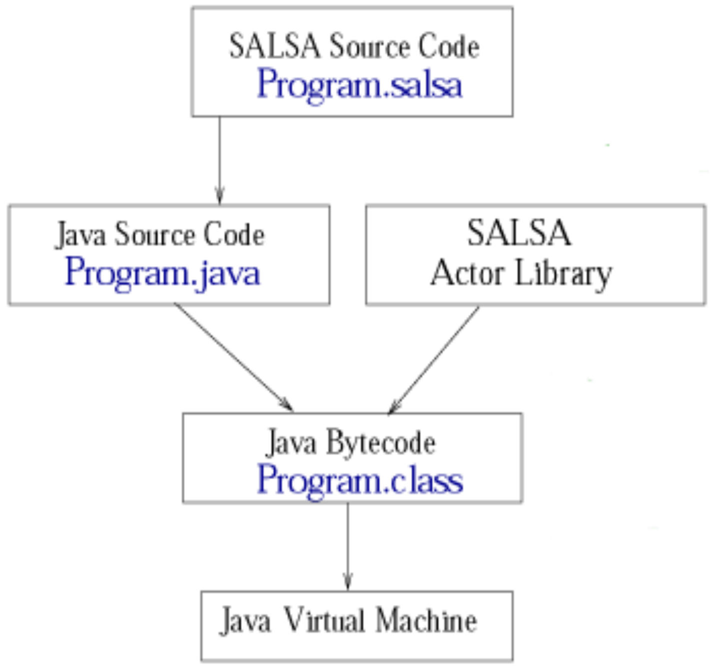
G. Agha, *Actors: A Model of Concurrent Computation in Distributed Systems.* MIT Press, 1986.

- 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 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 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

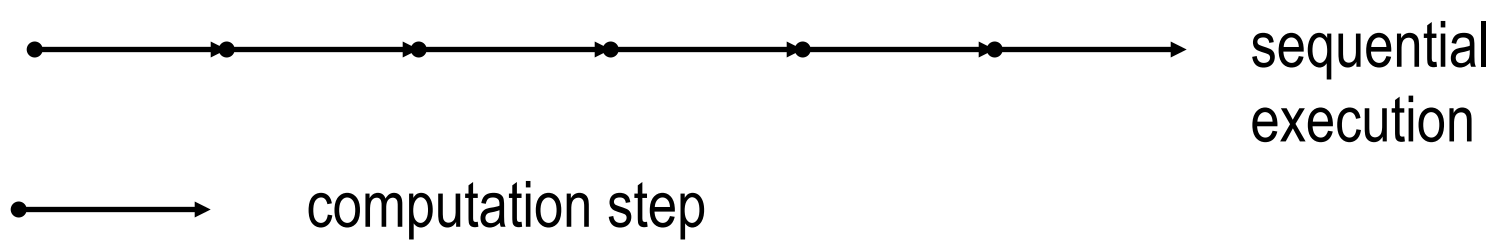
- In a sequential program all execution states are totally ordered

- 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

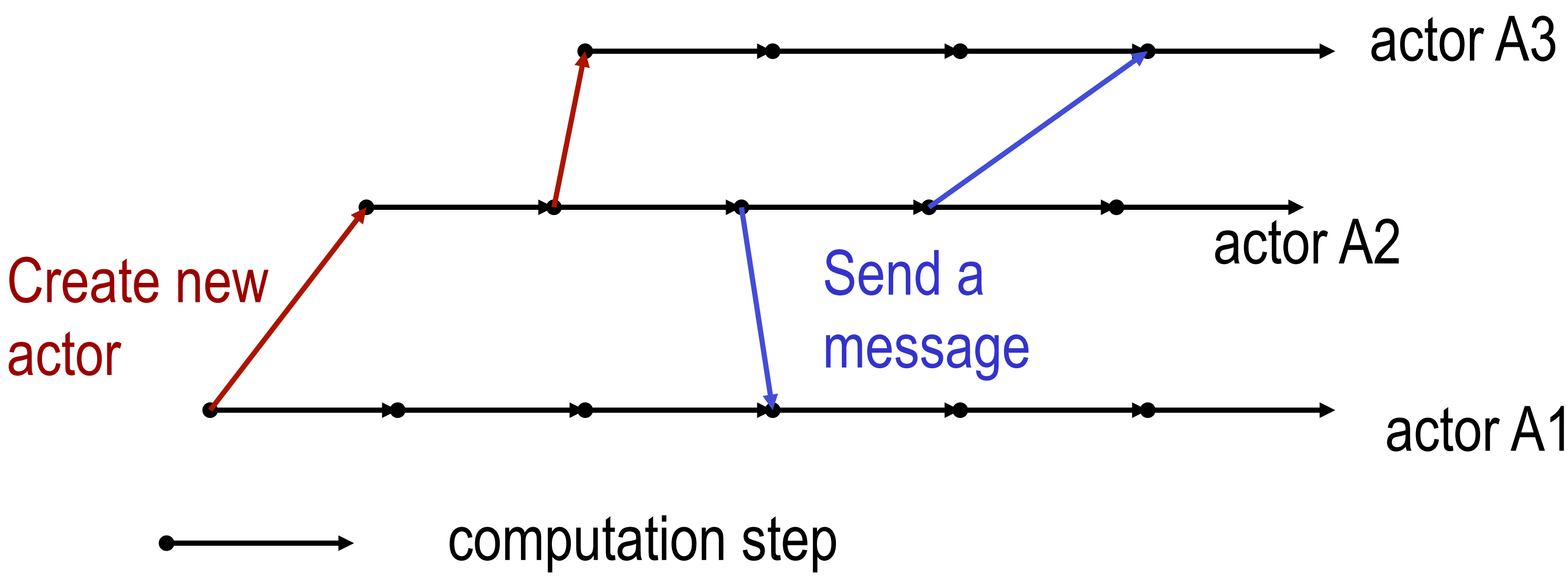
Total order

- 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

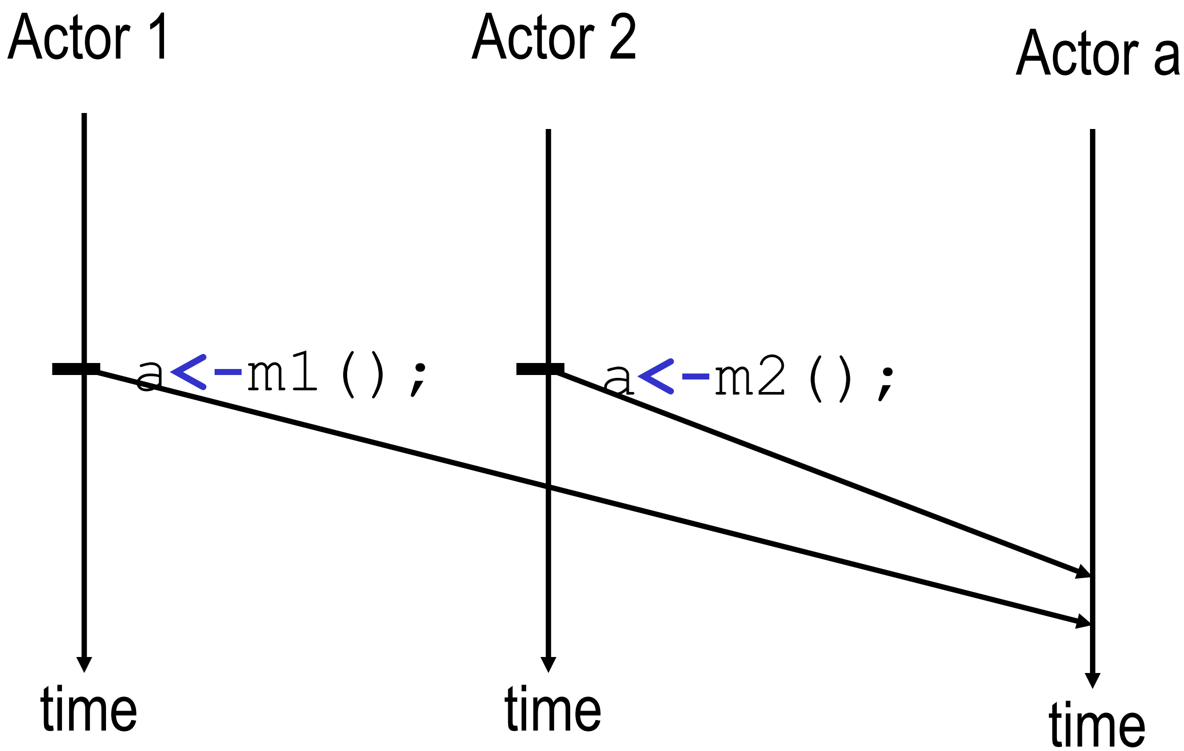


Nondeterminism

- 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 );
```

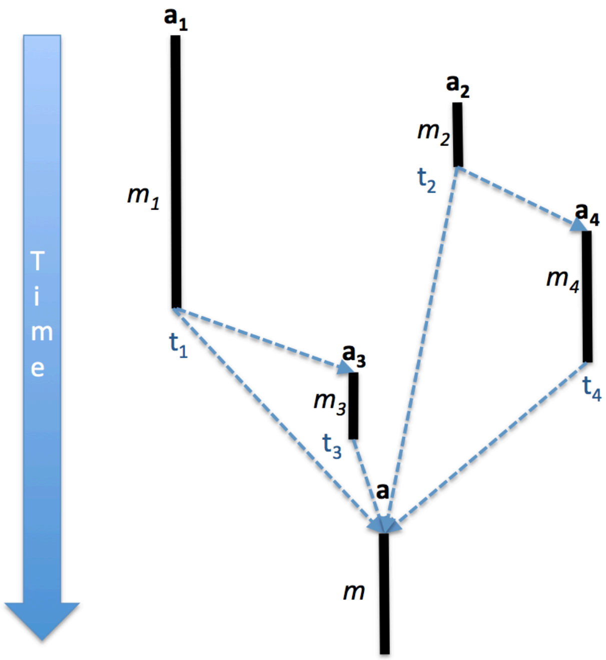
Send `m1` to `a1` asking `a1` to forward the result of processing `m1` to `a2` (as the argument of message `m2`).

Named Tokens

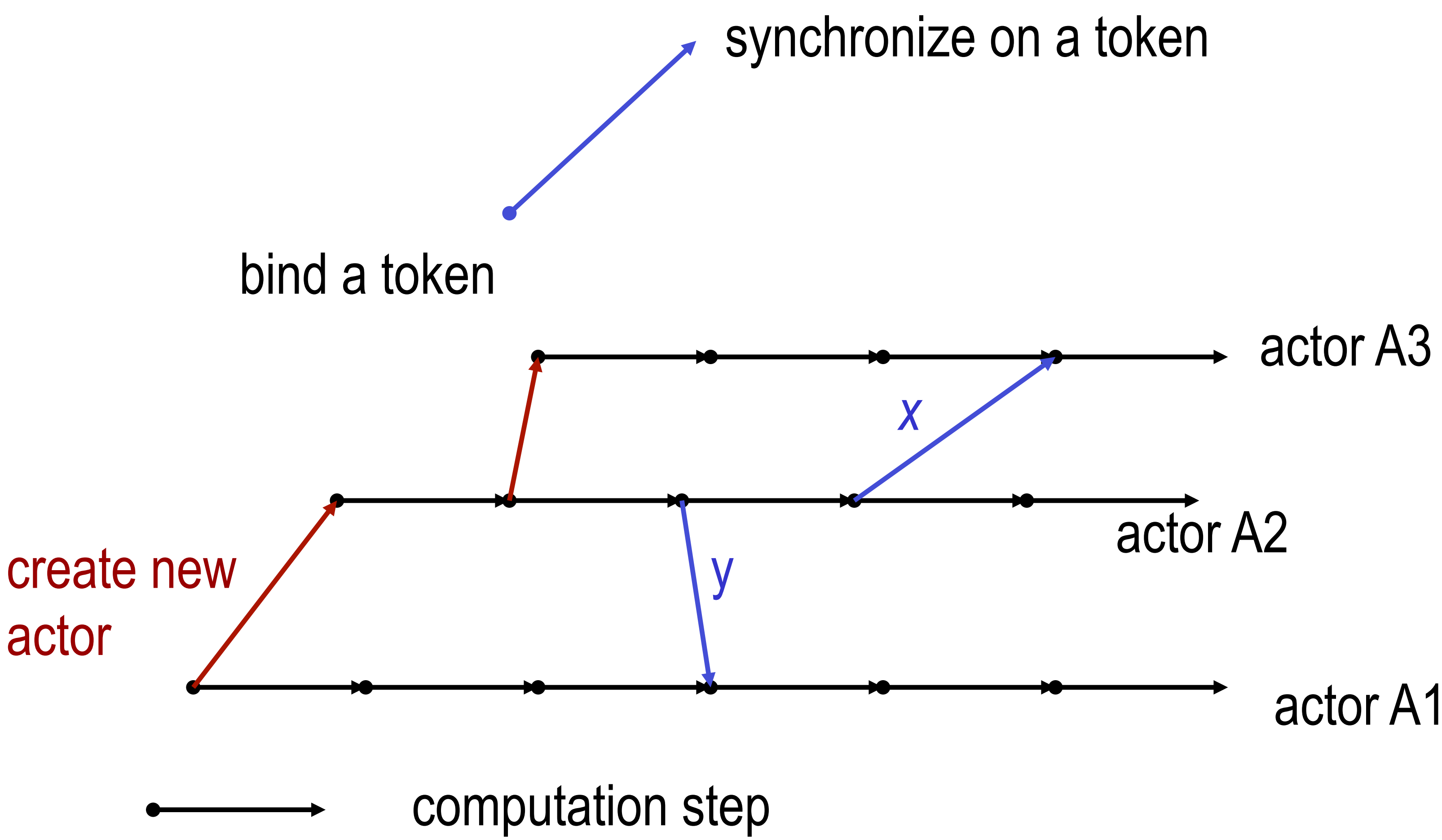
- Tokens can be named to enable more loosely-coupled synchronization
  - Example:

```
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 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 );

   }
}
```

Cell Tester Example with Named Tokens

```
module cell;

behavior TokenCellTester {

    void act(String args[]){

        Cell c = new Cell("Hello");
        token p0 = standardOutput <- print("Initial Value:");
        token t0 = c <- get();
        token p1 = standardOutput <- println(t0):waitfor(p0);
        token t1 = c <- set("World"):waitfor(t0);
        token p2 = standardOutput <- print("New Value:"):waitfor(p1);
        token t2 = c <- get():waitfor(t1);
        standardOutput <- println(t2):waitfor(p2);
    }
}
```

Join Blocks

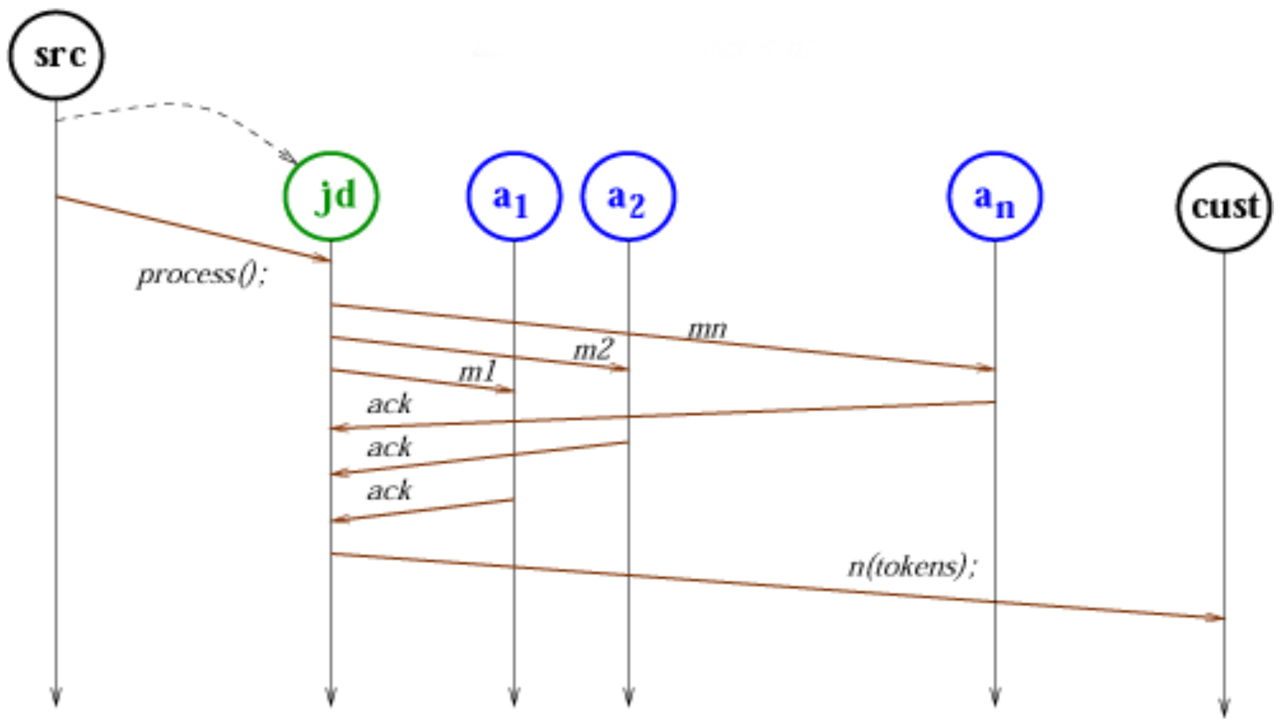
- Provide a mechanism for synchronizing the processing of a set of messages.
- Set of results is sent along as a *token* containing an array of results.
  - Example:

```
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

```
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 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);
   }
}
```

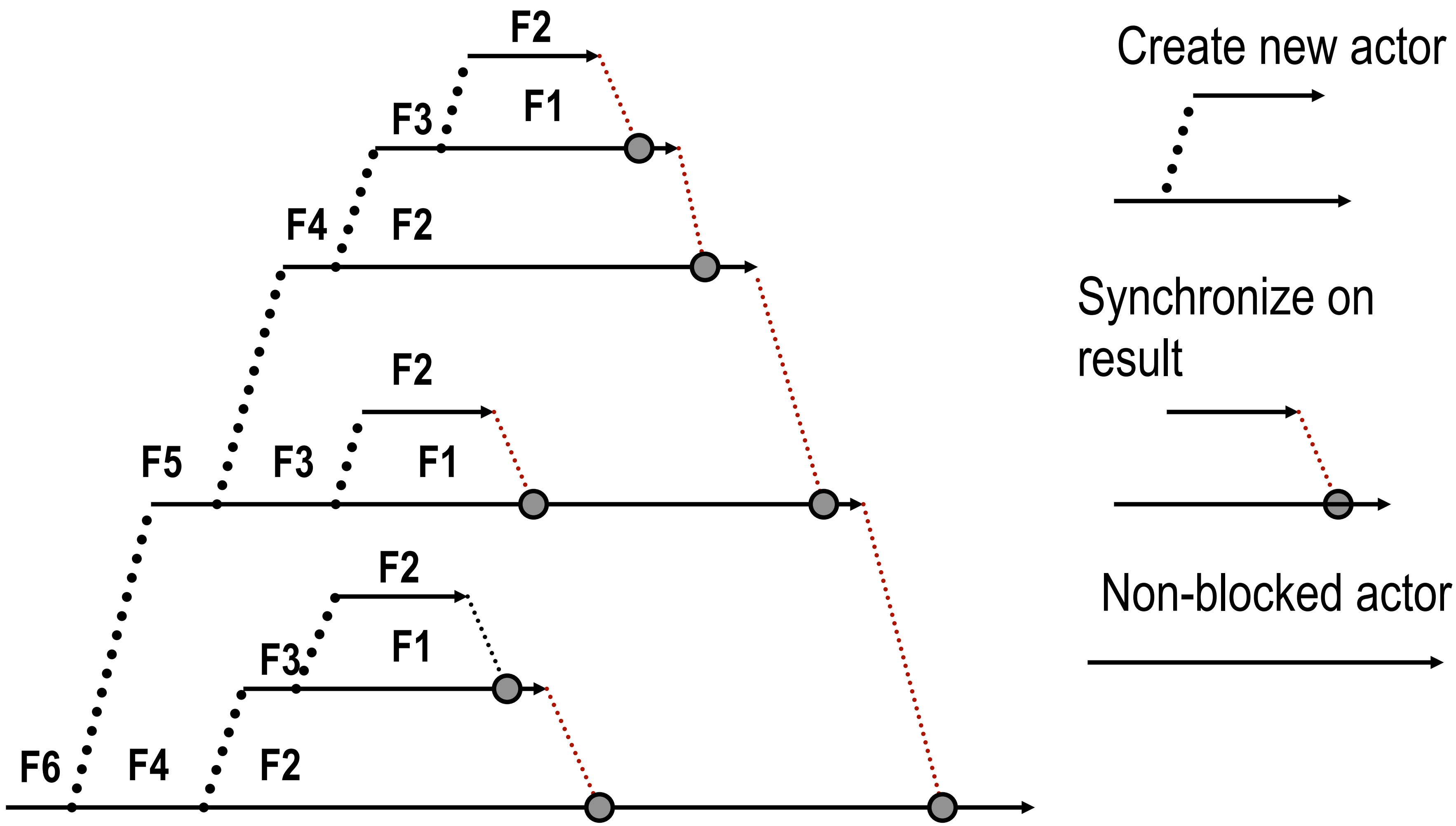
Fibonacci Example

```
module 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 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`



Exercises

74. Download and execute the `CellTester.salsa` and `TokenCellTester.salsa` examples.

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

76. PDCS Exercise 9.6.1 (page 203).

77. PDCS Exercise 9.6.6 (page 204).