Concurrent Distributed Mobile (Systems) Programming

Universal Actors, SALSA, Coordination Abstractions

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Programming distributed systems

- It is harder than concurrent programming!
- Yet unavoidable in today's information-oriented society, e.g.:
  - Internet
  - Web services
  - Grid/cloud computing
- Communicating processes with independent address spaces
- Limited network performance
  - Orders of magnitude difference between WAN, LAN, and single machine communication.
- Localized heterogeneous resources, e.g, I/O, specialized devices.
- Partial failures, e.g. hardware failures, network disconnection
- Openness: creates security, naming, composability issues.

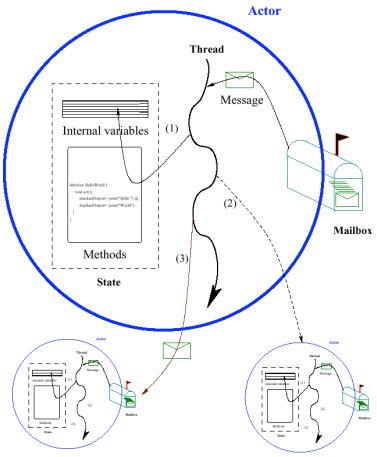
Actors/SALSA

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

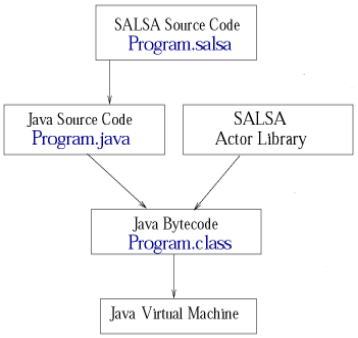
G. Agha, *Actors: A Model of Concurrent Computation in Distributed Systems*. MIT Press, 1986.

- 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

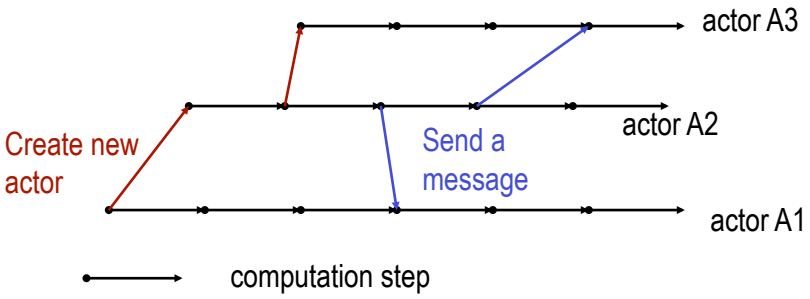
- In a sequential program all execution states are totally ordered
- In a concurrent program all execution states of a given actor are totally ordered
- The execution state of the concurrent program as a whole is partially ordered

Total order

- In a sequential program all execution states are totally ordered

Causal order in the actor model

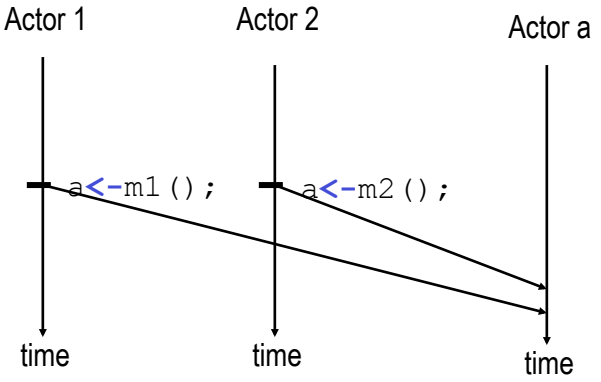
- In a concurrent program all execution states of a given actor are totally ordered
- The execution state of the concurrent program is partially ordered



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`).

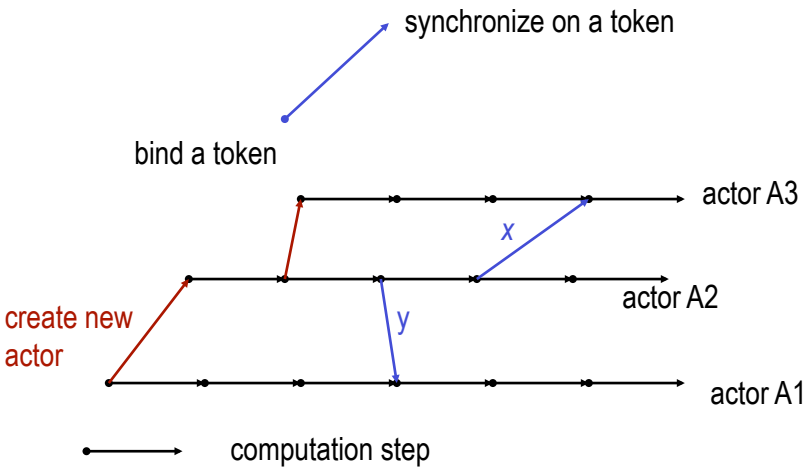
Named Tokens

- 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

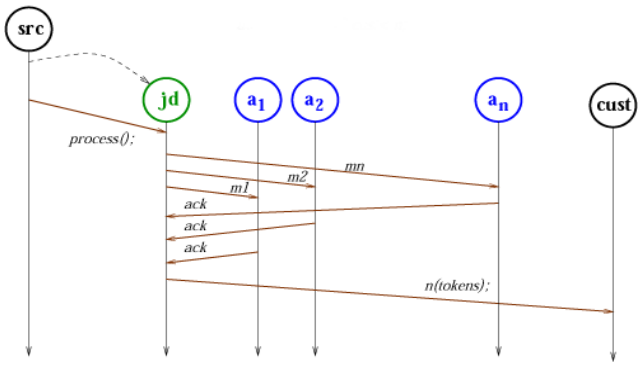
- Provide a mechanism for synchronizing the processing of a set of messages.
- Set of results is sent along as a *token* containing an array of results.
  - Example:

```
Actor[] actors = { searcher0, searcher1,
                   searcher2, searcher3 };
join {
  for (int i=0; i < actors.length; i++){
     actors[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 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);
   }
}
```

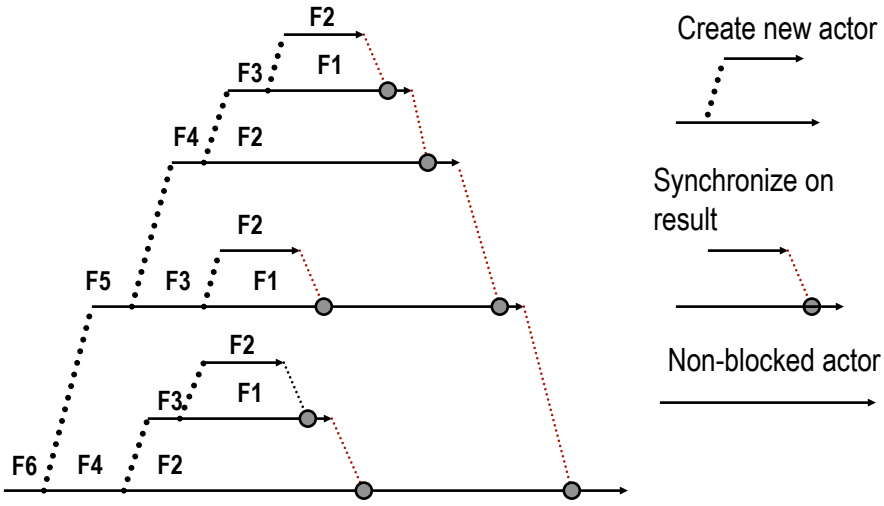

Fibonacci Example

```
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`



Worldwide Computing

- Distributed computing over the Internet.
- Access to *large number* of processors *offsets* slow communication and reliability issues.
- Seeks to create a platform for many applications.

World-Wide Computer (WWC)

- Worldwide computing platform.
- Provides a run-time system for universal actors.
- Includes naming service implementations.
- Remote message sending protocol.
- Support for universal actor migration.

Abstractions for Worldwide Computing

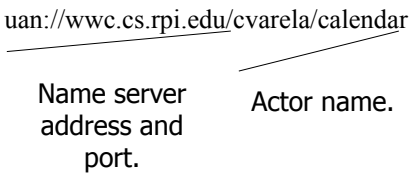
- *Universal Actors*, a new abstraction provided to guarantee unique actor names across the Internet.
- *Theaters*, extended Java virtual machines to provide execution environment and network services to universal actors:
  - Access to local resources.
  - Remote message sending.
  - Migration.
- *Naming service*, to register and locate universal actors, transparently updated upon universal actor creation, migration, recollection.

Universal Naming

- Consists of *human readable* names.
- Provides location transparency to actors.
- Name to location mappings efficiently updated as actors migrate.

Universal Actor Naming

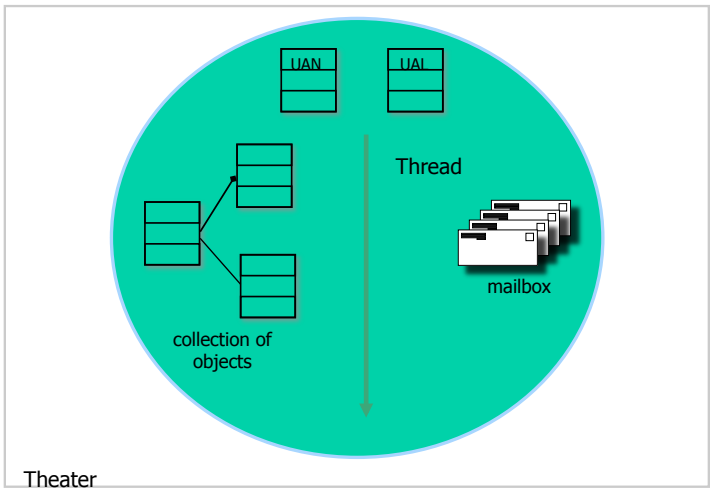
- UAN servers provide mapping between static names and dynamic locations.
  - Example:



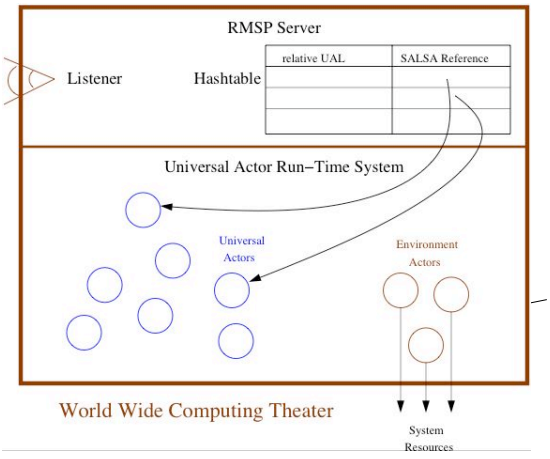
Universal Actors

- Universal Actors extend the actor model by associating a universal name and a location with the actor.
- Universal actors may migrate between theaters and the name service keeps track of their current location.

Universal Actor Implementation

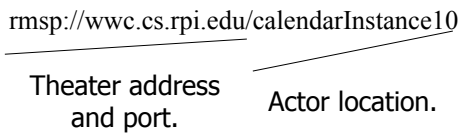


WWC Theaters



WWC Theaters

- Theaters provide an execution environment for actors.
- Provide a layer beneath actors for message passing and migration.
- Example locator:



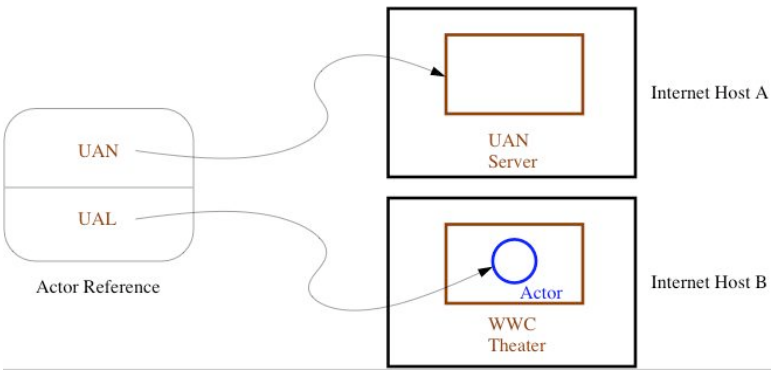
Environment Actors

- Theaters provide access to *environment actors*.
- Environment actors perform actions specific to the theater and are not mobile.
- Include standard input, output and error stream actors.

Remote Message Sending Protocol

- Messages between remote actors are sent using the Remote Message Sending Protocol (RMSP).
- RMSP is implemented using Java object serialization.
- RMSP protocol is used for both message sending and actor migration.
- When an actor migrates, its locator (UAL) changes but its name (UAN) does not.

Universal Actor Naming Protocol



Universal Actor Naming Protocol

- UANP includes messages for:
  - Binding actors to UAN, UAL pairs
  - Finding the locator of a universal actor given its UAN
  - Updating the locator of a universal actor as it migrates
  - Removing a universal actor entry from the naming service
- SALSA programmers need not use UANP directly in programs. UANP messages are transparently sent by WWC run-time system.

UANP Implementations

- Default naming service implementation stores UAN to UAL mapping in name servers as defined in UANs.
  - Name server failures may induce universal actor unreachability.
- Distributed (Chord-based) implementation uses consistent hashing and a ring of connected servers for fault-tolerance. For more information, see:

Camron Tolman and Carlos Varela. *A Fault-Tolerant Home-Based Naming Service For Mobile Agents.* In Proceedings of the XXXI Conferencia Latinoamericana de Informática (CLEI), Cali, Colombia, October 2005.

Tolman C. *A Fault-Tolerant Home-Based Naming Service for Mobile Agents*. Master's Thesis, Rensselaer Polytechnic Institute, April 2003.

SALSA Language Support for Worldwide Computing

- SALSA provides linguistic abstractions for:
  - Universal naming (UAN & UAL).
  - Remote actor creation.
  - Message sending.
  - Migration.
  - Coordination.
- SALSA-compiled code closely tied to WWC run-time platform.

Universal Actor Creation

- To create an actor locally

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

- To create an actor with a specified UAN and UAL:

```
TravelAgent a = new TravelAgent() at (uan, ual);
```

- At current location with a UAN:

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

Message Sending

```
TravelAgent a = new TravelAgent();

a <- book( flight );
```


Remote Message Sending

- Obtain a remote actor reference by name.

```
TravelAgent a = (TravelAgent)
  TravelAgent.getReferenceByName("uan://
  myhost/ta");

a <- printItinerary();
```

Reference Cell Service Example

```
module examples.cell;

behavior Cell implements ActorService{
   Object content;

   Cell(Object initialContent) {
         content = initialContent;
   }

   Object get() {
        standardOutput <- println ("Returning:"+content);
        return content;
   }

   void set(Object newContent) {
        standardOutput <- println ("Setting:"+newContent);
        content = newContent;
   }
}
```


Reference Cell Client Example

```
module examples.cell;

behavior GetCellValue {

   void act( String[] args ) {
      if (args.length != 1){
        standardOutput <- println("Usage:
          salsa examples.cell.GetCellValue <CellUAN>");
        return;
      }

      Cell c = (Cell)
        Cell.getReferenceByName(new UAN(args[0]));

      standardOutput <- print("Cell Value") @
      c <- get() @
      standardOutput <- println(token);
   }
}
```

Migration

- Obtaining a remote actor reference and migrating the actor.

```
TravelAgent a = (TravelAgent)
    TravelAgent.getReferenceByName
                ("uan://myhost/ta");

a <- migrate( "rmsp://yourhost/travel" ) @
a <- printItinerary();
```


Moving Cell Tester Example

```
module examples.cell;

behavior MovingCellTester {

    void act( String[] args ) {

     if (args.length != 3){
         standardOutput <- println("Usage:
           salsa examples.cell.MovingCellTester <UAN> <UAL1> <UAL2>");
         return;
     }

     Cell c = new Cell("Hello") at (new UAN(args[0]), new UAL(args[1]));

     standardOutput <- print( "Initial Value:" ) @
     c <- get() @ standardOutput <- println( token ) @
     c <- set("World") @
     standardOutput <- print( "New Value:" ) @
     c <- get() @ standardOutput <- println( token ) @
     c <- migrate(args[2]) @
     c <- set("New World") @
     standardOutput <- print( "New Value at New Location:" ) @
     c <- get() @ standardOutput <- println( token );
   }
}
```

Agent Migration Example

```
behavior Migrate {

   void print() {
      standardOutput<-println( "Migrate actor is here." );
   }

   void act( String[] args ) {

      if (args.length != 3) {
        standardOutput<-println("Usage: salsa migration.Migrate  <UAN> <srcUAL>
                                        <destUAL>");
        return;
      }

        UAN uan = new UAN(args[0]);
        UAL ual = new UAL(args[1]);

        Migrate  migrateActor = new Migrate() at (uan, ual);

        migrateActor<-print() @
        migrateActor<-migrate( args[2] ) @
        migrateActor<-print();
   }
}
```


Migration Example

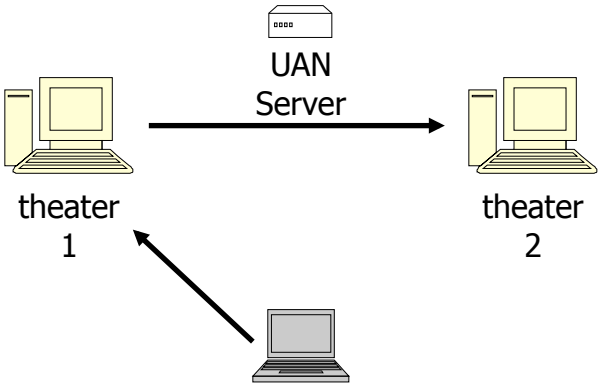
- The program must be given *valid* universal actor name and locators.
  - Appropriate name services and theaters must be running.
- After remotely creating the actor. It sends the `print` message to itself before migrating to the second theater and sending the message again.

Compilation and Execution

```
$ java salsac.SalsaCompiler Migrate.salsa
SALSA Compiler Version 1.0:  Reading from file Migrate.salsa . . .
SALSA Compiler Version 1.0:  SALSA program parsed successfully.
SALSA Compiler Version 1.0:  SALSA program compiled successfully.
$ javac Migrate.java
$ java Migrate
$ Usage: java Migrate <uan> <ual> <ual>
```

- Compile Migrate.salsa file into Migrate.java.
- Compile Migrate.java file into Migrate.class.
- Execute Name Server
- Execute Theater 1 and Theater 2 Environments
- Execute Migrate in any computer

Migration Example



The actor will print "Migrate actor is here." at theater 1 then at theater 2.

World Migrating Agent Example

Host	Location	OS/JVM	Processor
yangtze.cs.uiuc.edu	Urbana IL, USA	Solaris 2.5.1 JDK 1.1.6	Ultra 2
vulcain.ecoledoc.lip6.fr	Paris, France	Linux 2.2.5 JDK 1.2pre2	Pentium II 350Mhz
solar.isr.co.jp	Tokyo, Japan	Solaris 2.6 JDK 1.1.6	Sparc 20

Local actor creation	386*us*
Local message sending LAN message sending WAN message sending	148 *us* 30-60 ms 2-3 s
LAN minimal actor migration LAN 100Kb actor migration WAN minimal actor migration WAN 100Kb actor migration	150-160 ms 240-250 ms 3-7 s 25-30 s

Address Book Service

```
module examples.addressbook;

behavior AddressBook implements ActorService {
   Hashtable name2email;
   AddressBook() {
        name2email = new HashTable();
   }
   String getName(String email) { … }
   String getEmail(String name) { … }
   boolean addUser(String name, String email) { … }

   void act( String[] args ) {
      if (args.length != 0){
         standardOutput<-println("Usage: salsa -Duan=<uan> -Dual=<ual>
                                  examples.addressbook.AddressBook");
      }
   }
}
```

Address Book Add User Example

```
module examples.addressbook;

behavior AddUser {
   void act( String[] args ) {
      if (args.length != 3){
         standardOutput<-println("Usage: salsa
           examples.addressbook.AddUser <BookUAN> <Name> <Email>");
         return;
       }
       AddressBook book = (AddressBook)
         AddressBook.getReferenceByName(new UAN(args[0]));
       book<-addUser(args(1), args(2));
   }
}
```


Address Book Get Email Example

```
module examples.addressbook;

behavior GetEmail {
    void act( String[] args ) {
      if (args.length != 2){
          standardOutput <- println("Usage: salsa
            examples.addressbook.GetEmail <BookUAN> <Name>");
          return;
       }
       getEmail(args(0),args(1));
    }

    void getEmail(String uan, String name){
       AddressBook book = (AddressBook)
          AddressBook.getReferenceByName(uan);
       standardOutput <- print(name + "'s email: ") @
       book <- getEmail(name) @
       standardOutput <- println(token);
    }
}
```

Address Book Migrate Example

```
module examples.addressbook;

behavior MigrateBook {
   void act( String[] args ) {
      if (args.length != 2){
         standardOutput<-println("Usage: salsa
           examples.addressbook.Migrate <BookUAN> <NewUAL>");
         return;
      }
      AddressBook book = (AddressBook)
        AddressBook.getReferenceByName(new UAN(args[0]));
      book<-migrate(args(1));
   }
}
```


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 Van Roy and Haridi's book, Section 7.8.3 (page 558).

Exercises

4. How would you implement the join continuation linguistic abstraction considering different potential distributions of its participating actors?

5. Download and execute the `Agent.salsa` example.

6. Modify the lock example in the SALSA distribution to include a wait/ notify protocol, as opposed to "busy-waiting" (or rather "busy-asking").

7. Van Roy and Haridi's Book Exercise 11.11.3 (pg 746). Implement the example using SALSA/WWC.