Distributed (Systems) Programming

Universal Actors, SALSA, World-Wide Computer

Carlos Varela
Rennselaer Polytechnic Institute

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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.

Overview of programming distributed systems

- It is harder than concurrent programming!
- Yet unavoidable in today's information-oriented society, e.g.:
  - Internet
  - Web services
  - Grid 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.

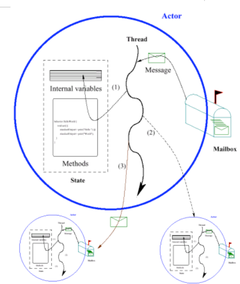
Actors/SALSA Revisited

- 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 Intriguing Technology Track,* 36(12), pp 20-34.



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:

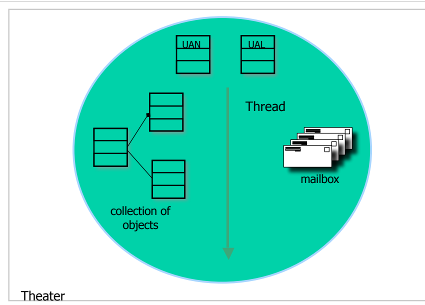
uan://wwc.cs.rpi.edu/cvarela/calendar

Name server address and port. | Actor name.

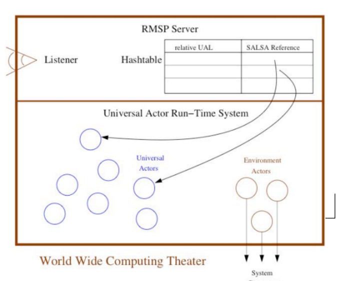
Universal Actors

- 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:

rmsp://wwc.cs.rpi.edu/calendarInstance10

Theater address and port. | Actor location.

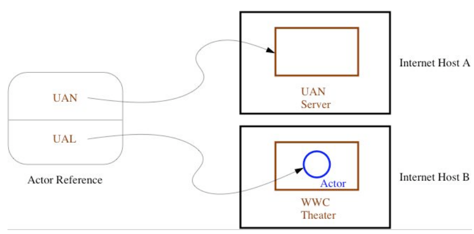
Environmental Actors

- Theaters provide access to *environmental actors*.
- Environmental 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

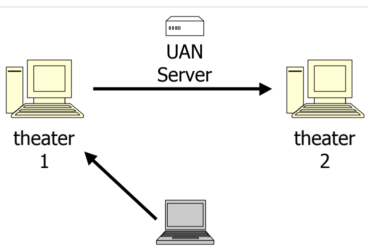
- The program must be given *valid* universal actor name and locators.
  - Appropriate name services and theaters must be running.
- After remotely creating the actor. It sends the `print` message to itself before migrating to the second theater and sending the message again.

Compilation and Execution

```
$ java SalsaCompiler demo/Migrate.salsa
SALSA Compiler Version 1.0:  Reading from file demo/Migrate.salsa . .
.
SALSA Compiler Version 1.0:  SALSA program parsed successfully.
SALSA Compiler Version 1.0:  SALSA program compiled successfully.
$ javac demo/Migrate.java
$ java demo.Migrate
$ Usage: java migration.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);
    }
}
```

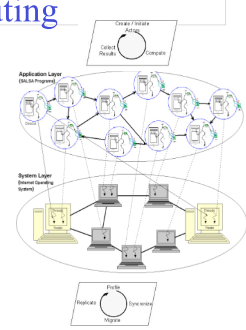

Address Book Migrate Example

```
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));
    }
}
```


Middleware for Autonomous Computing

- Middleware
  - A software layer between distributed applications and operating systems.
  - Alleviates application programmers from directly dealing with distribution issues
    - Heterogeneous hardware/O.S.s
    - Load balancing
    - Fault-tolerance
    - Security
    - Quality of service
- Internet Operating System (IOS)
  - A decentralized framework for adaptive, scalable execution
  - Modular architecture to evaluate different distribution and reconfiguration strategies



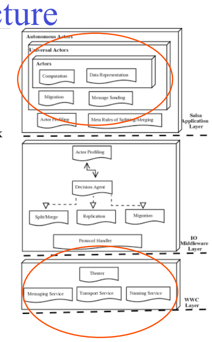
K. El Maghraoui, T. Desell, B. Szymanski, and C. Varela, "The Internet Operating System: Middleware for Adaptive Distributed Computing", ***International Journal of High Performance Computing and Applications***, to appear 2006.

K. El Maghraoui, T. Desell, B. Szymanski, J. Teresco and C. Varela, "Towards a Middleware Framework for Dynamically Reconfigurable Scientific Computing", ***Grid Computing and New Frontiers of High Performance Processing***, Elsevier 2005.

T. Desell, K. El Maghraoui, and C. Varela, "*Load Balancing of Autonomous Actors over Dynamic Networks*", HICSS-37 Software Technology Track, Hawaii, January 2004. 10pp.

World-Wide Computer Architecture

- SALSA application layer
  - Programming language constructs for actor communication, migration, and coordination.
- IOS middleware layer
  - A Resource Profiling Component
    - Captures information about actor and network topologies and available resources
  - A Decision Component
    - Takes migration, split/merge, or replication decisions based on profiled information
  - A Protocol Component
    - Performs communication between nodes in the middleware system
- WWC run-time layer
  - Theaters provide runtime support for actor execution and access to local resources
  - Pluggable transport, naming, and messaging services



Actor Garbage Collection

- Implemented since SALSA 1.0 using *pseudo-root* approach.
- Includes distributed cyclic garbage collection.
- For more details, please see:

Wei-Jen Wang and Carlos A. Varela. Distributed Garbage Collection for Mobile Actor Systems: The Pseudo Root Approach. In *Proceedings of the First International Conference on Grid and Pervasive Computing (GPC 2006),* Taichung, Taiwan, May 2006. Springer-Verlag LNCS.

Wei-Jen Wang and Carlos A. Varela. A Non-blocking Snapshot Algorithm for Distributed Garbage Collection of Mobile Active Objects. *Technical report 06-15, Dept. of Computer Science*, R.P.I., October 2006. Note: Submitted to IEEE TPDS.

Distributed Systems Visualization

- Generic online Java-based distributed systems visualization tool
- Uses a declarative Entity Specification Language (ESL)
- Instruments byte-code to send events to visualization layer.
- For more details, please see:

T. Desell, H. Iyer, A. Stephens, and C. Varela. OverView: A Framework for Generic Online Visualization of Distributed Systems. In *Proceedings of the European Joint Conferences on Theory and Practice of Software (ETAPS 2004), eclipse Technology eXchange (eTX) Workshop*, Barcelona, Spain, March 2004.

Exercises

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

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

68. *Modify the lock example to include a wait/notify protocol, as opposed to “busy-waiting” (or rather “busy-asking”).

69. *VRH Exercise 11.11.3 (pg 746). Implement the example using SALSA/WWC.