# Distributed systems abstractions (PDCS 9, CPE 6*)

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* Concurrent Programming in Erlang, by J. Armstrong, R. Virding, C. Wikström, M. Williams

# Overview of programming distributed systems

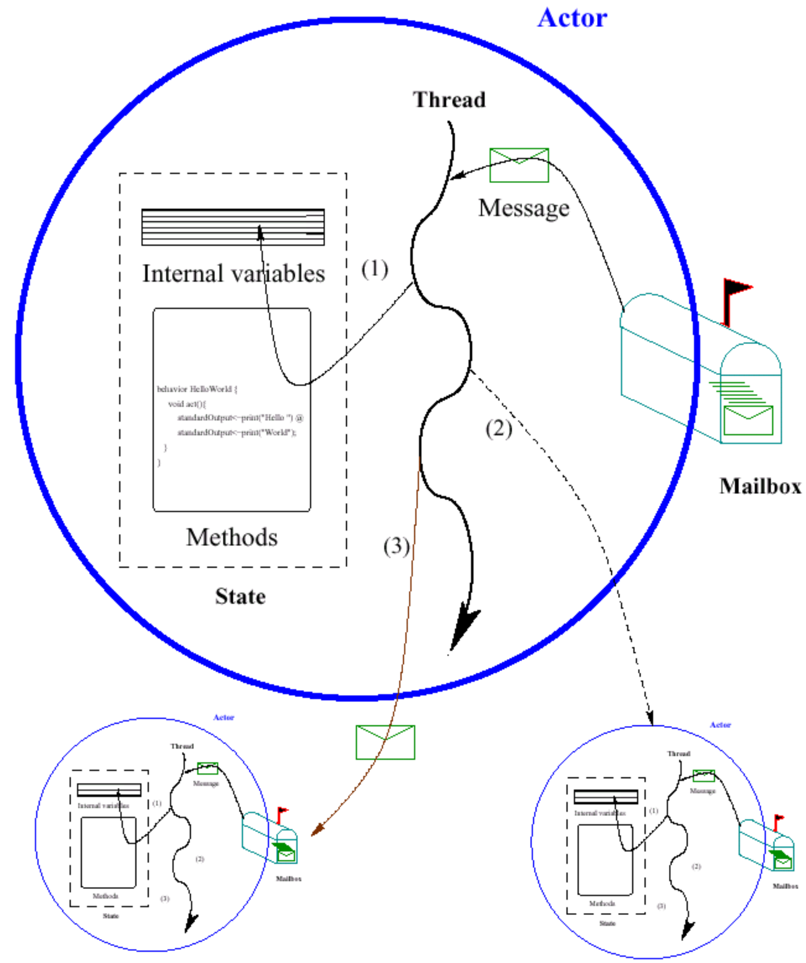
- It is harder than concurrent programming!
- Yet unavoidable in today's information-oriented society, e.g.:
  - Internet of Things, mobile devices
  - Web services
  - Cloud computing
- Communicating processes with independent address spaces
- Limited network performance
  - Orders of magnitude difference between WAN, LAN, and intra-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.

# SALSA Revisited

- 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.

- Advantages for distributed computing
  - Actors encapsulate state and concurrency:
    - Actors can run in different machines.
    - Actors can change location dynamically.
  - Communication is asynchronous:
    - Fits real world distributed systems.
  - Actors can fail independently.



# World-Wide Computer (WWC)

- Distributed 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, garbage collection.

# Universal Actor Names (UAN)

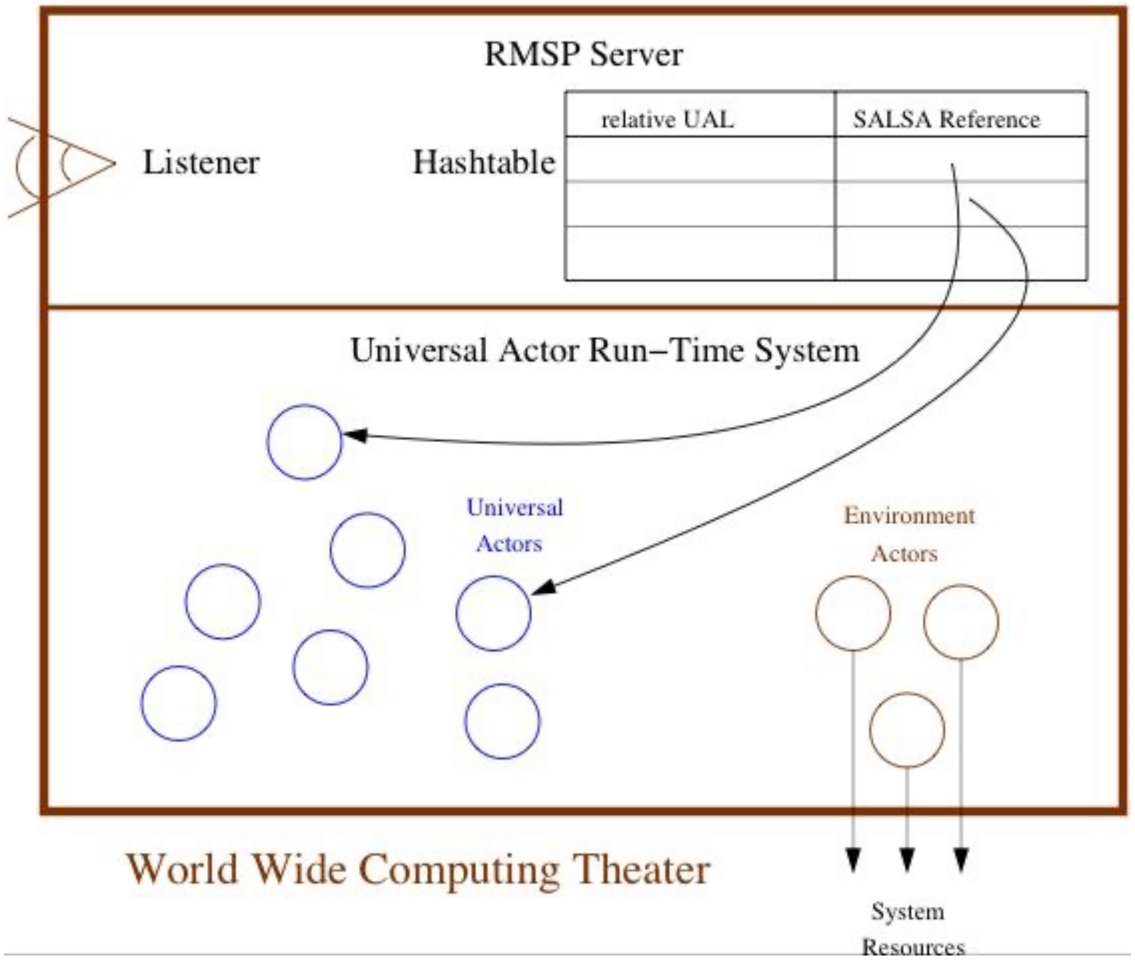
- Consist of *human readable* names.
- Provide location transparency to actors.
- Name to locator mapping updated as actors migrate.
- UAN servers provide mapping between names and locators.
  - Example Universal Actor Name:

```
uan://wwc.cs.rpi.edu:3030/cvarela/calendar
```

Name server address and (optional) port. — wwc.cs.rpi.edu:3030

Unique relative actor name. — /cvarela/calendar

# WWC Theaters



# Universal Actor Locators (UAL)

- Theaters provide an execution environment for universal actors.
- Provide a layer beneath actors for message passing and migration.
- When an actor migrates, its UAN remains the same, while its UAL changes to refer to the new theater.
- Example Universal Actor Locator:

```
rmsp://wwc.cs.rpi.edu:4040
```

Theater's IP address and (optional) port.

# SALSA Language Support for Worldwide Computing

- SALSA provides linguistic abstractions for:
  - Universal naming (UAN & UAL).
  - Remote actor creation.
  - Location-transparent 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);
```

- To create an actor with a specified UAN at current location:

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

# Message Sending

```
TravelAgent a = new TravelAgent();

a <- book( flight );
```

Message sending syntax is the same (<-), independently of actor's location.

# 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 dcell;

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;
    }
}
```

**`implements ActorService`** signals that actors with this behavior are not to be garbage collected.

# Reference Cell Tester

```
module dcell;

behavior CellTester {

    void act( String[] args ) {

      if (args.length != 2){
        standardError <- println(
              "Usage: salsa dcell.CellTester <UAN> <UAL>");
        return;
     }

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

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

# Reference Cell Client Example

```
module dcell;

behavior GetCellValue {

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

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

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

# Address Book Service

```
module addressbook;
import java.util.*

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>
                                        addressbook.AddressBook");
       }
    }
}
```

# Address Book Add User Example

```
module addressbook;

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

# Address Book Get Email Example

```
module addressbook;

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

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

# Erlang Language Support for Distributed Computing

- Erlang provides linguistic abstractions for:
  - Registered processes (actors).
  - Remote process (actor) creation.
  - Remote message sending.
  - Process (actor) groups.
  - Error detection.
- Erlang-compiled code closely tied to Erlang *node* run-time platform.

# Erlang Nodes

- To return our own node name:

```
node()
```

- To return a list of other known node names:

```
nodes()
```

- To monitor a node:

```
monitor_node(Node, Flag)
```

If `flag` is true, monitoring starts. If false, monitoring stops. When a monitored node fails, `{nodedown, Node}` is sent to monitoring process.

# Actor Creation

- To create an actor locally

**travel** is the module name,
**agent** is the function name,
**Agent** is the actor name.

```
Agent = spawn(travel, agent, []);
```

- To create an actor in a specified remote node:

```
Agent = spawn(host, travel, agent, []);
```

**host** is the node name.

# Actor Registration

**ta** is the registered name (an atom),
**Agent** is the actor name (PID).

- To register an actor:

```
register(ta, Agent)
```

- To return the actor identified with a registered name:

```
whereis(ta)
```

- To remove the association between an atom and an actor:

```
unregister(ta)
```

# Message Sending

```
Agent = spawn(travel, agent, []),
        register(ta, Agent)

        Agent ! {book, Flight}
        ta ! {book, Flight}
```

Message sending syntax is the same (`!`) with actor name (`Agent`) or registered name (`ta`).

# Remote Message Sending

- To send a message to a remote registered actor:

```
{ta, host} ! {book, Flight}
```

# Reference Cell Service Example

```
-module(dcell).
-export([cell/1,start/1]).

cell(Content) ->
  receive
    {set, NewContent} -> cell(NewContent);
    {get, Customer}   -> Customer ! Content,
                         cell(Content)
  end.

start(Content) ->
  register(dcell, spawn(dcell, cell, [Content]))
```

# Reference Cell Tester

```
-module(dcellTester).
-export([main/0]).

main() -> dcell:start(0),
          dcell!{get, self()},
          receive
             Value ->
                io:format(”Initial Value:~w~n”,[Value])
          end.
```

# Reference Cell Client Example

```
-module(dcellClient).
-export([getCellValue/1]).

getCellValue(Node) ->
          {dcell, Node}!{get, self()},
          receive
             Value ->
                io:format(”Initial Value:~w~n”,[Value])
          end.
```

# Address Book Service

```
-module(addressbook).
-export([start/0,addressbook/1]).

start() ->
    register(addressbook, spawn(addressbook, addressbook, [[]])).

addressbook(Data) ->
  receive
    {From, {addUser, Name, Email}} ->
       From ! {addressbook, ok},
       addressbook(add(Name, Email, Data));
    {From, {getName, Email}} ->
       From ! {addressbook, getname(Email, Data)},
       addressbook(Data);
    {From, {getEmail, Name}} ->
       From ! {addressbook, getemail(Name, Data)},
       addressbook(Data)
  end.

add(Name, Email, Data) -> …
getname(Email, Data) -> …
getemail(Name, Data) -> …
```

# Address Book Client Example

```
-module(addressbook_client).
-export([getEmail/1,getName/1,addUser/2]).

addressbook_server() -> 'addressbook@127.0.0.1'.

getEmail(Name) -> call_addressbook({getEmail, Name}).
getName(Email) -> call_addressbook({getName, Email}).
addUser(Name, Email) -> call_addressbook({addUser, Name, Email}).

call_addressbook(Msg) ->
    AddressBookServer = addressbook_server(),
    monitor_node(AddressBookServer, true),
    {addressbook, AddressBookServer} ! {self(), Msg},
    receive
       {addressbook, Reply} ->
           monitor_node(AddressBookServer, false),
           Reply;
       {nodedown, AddressBookServer} ->
           no
    end.
```

# Exercises

51. How would you implement the join block linguistic abstraction considering different potential distributions of its participating actors?
52. CTM Exercise 11.11.3 (page 746). Implement the example using SALSA/WWC and Erlang.
53. PDCS Exercise 9.6.3 (page 203).
54. PDCS Exercise 9.6.9 (page 204).
55. PDCS Exercise 9.6.12 (page 204).
56. Write the same distributed programs in Erlang.