

Mobility, garbage collection, load
balancing, visualization (SALSA)
Fault-tolerance, hot code loading (Erlang)
(PDCS 9; CPE 7*)

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October 22, 2019

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

Advanced Features of Actor Languages

- SALSA and Erlang support the basic primitives of the actor model:
 - Actors can create new actors.
 - Message passing is asynchronous.
 - State is encapsulated.
 - Run-time ensures fairness.
- SALSA also introduces advanced coordination abstractions: tokens, join blocks, and first-class continuations; SALSA supports distributed systems development including actor mobility and garbage collection. Research projects have also investigated load balancing, malleability (IOS), scalability (COS), and visualization (OverView).
- Erlang introduces a selective receive abstraction to enforce different orders of message delivery, including a timeout mechanism to bypass blocking behavior of `receive` primitive. Erlang also provides error handling abstractions at the language level, and dynamic (hot) code loading capabilities.

Universal Actor Names (UAN)

- Consists of *human readable* names.
- Provides 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://wvc.cs.rpi.edu:3030/cvarela/calendar`

Name server
address and
(optional) port.

Unique
relative
actor name.

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.

Migration

- Obtaining a remote actor reference and migrating the actor.

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

a <- migrate (“yourhost:yourport” ) @
a <- printItinerary();
```

Agent Migration Example

```
module migrate;

behavior Migrate {

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

    void act( String[] args ) {

        if (args.length != 3) {
            standardError<-println("Usage: salsa migrate.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

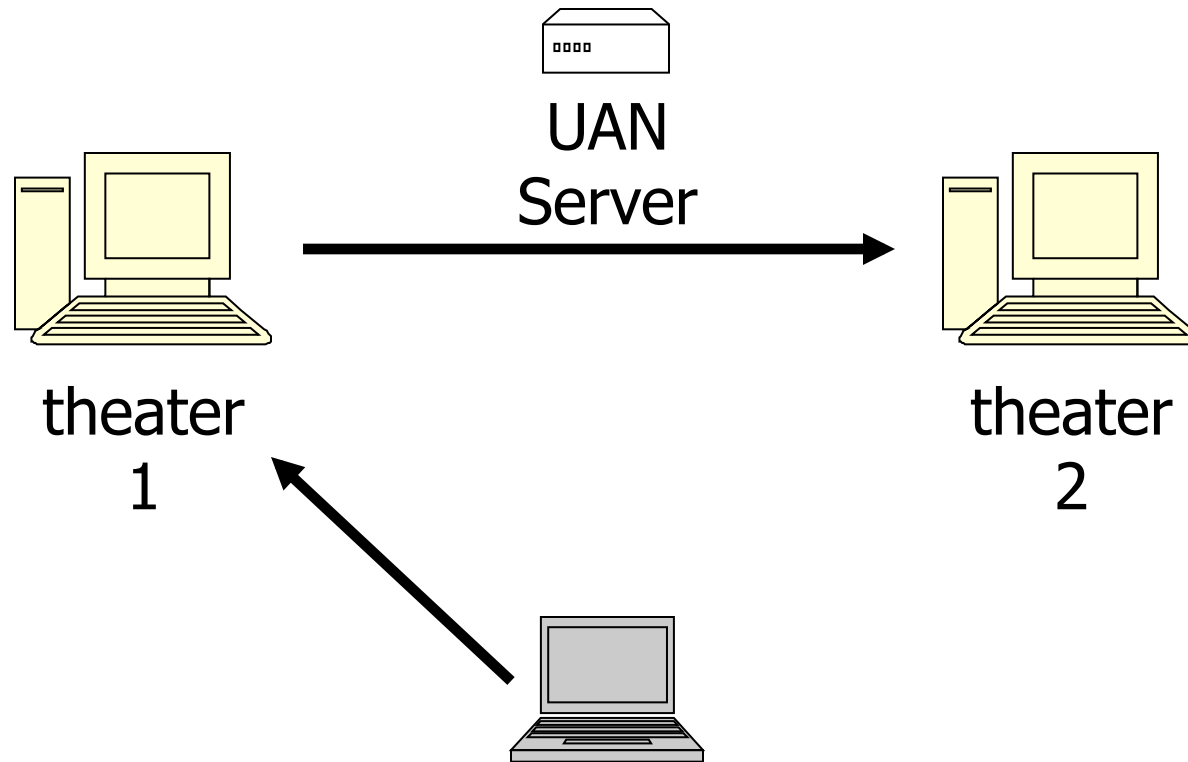
- The program must be given *valid* universal actor name and locators.
 - Appropriate name server and theaters must be running.
 - Theater must be run from directory with access to the code for the migrating actor's behavior.
- After remotely creating the actor. It sends the `print` message to itself before migrating to the second theater and sending the message again.

Compilation and Execution

```
$ salsac migrate/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.
$ salsa migrate.Migrate
Usage: salsa migrate.Migrate <UAN> <srcUAL> <destUAL>
```

1. Compile `Migrate.salsa` file into `Migrate.java`, and then bytecode (`.class` files.)
2. Execute Name Server
3. Execute Theater 1 and Theater 2 (with access to migrate directory)
4. Execute Migrate in any computer with Internet access

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

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.

Moving Cell Tester Example

```
module dcell;

behavior MovingCellTester {

    void act( String[] args ) {

        if (args.length != 3){
            standardError <- println("Usage:
                salsa dcell.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 );
    }
}
```

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 Migrate Example

```
module addressbook;

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

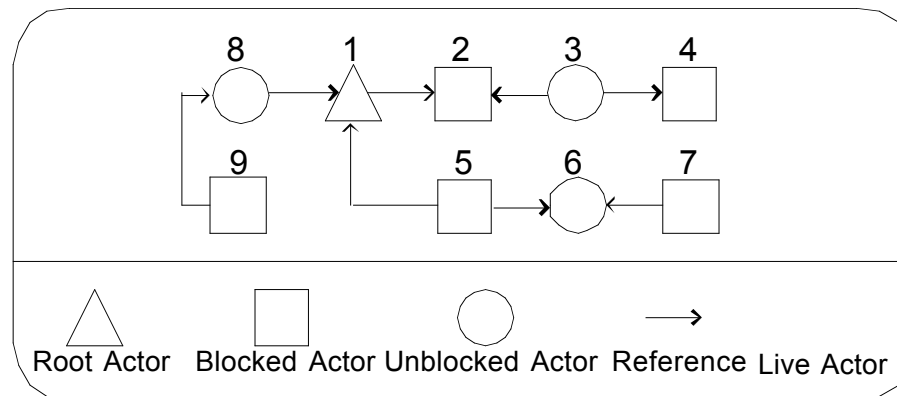
Actor Garbage Collection

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

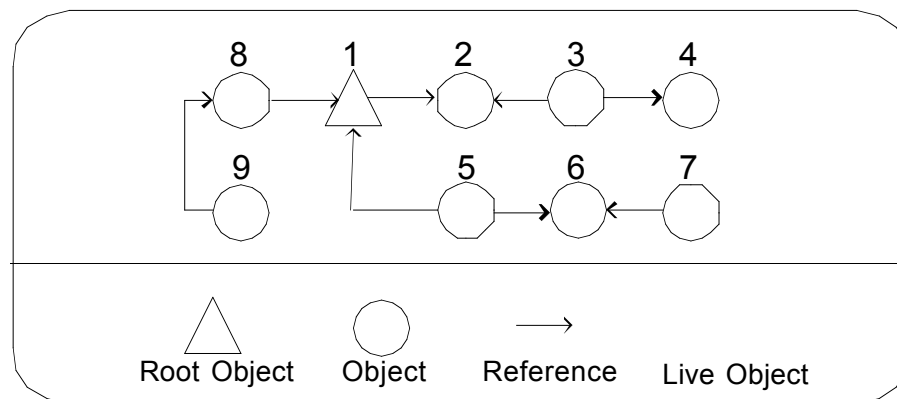
Wei-Jen Wang and Carlos A. Varela. Distributed Garbage Collection for Mobile Actor Systems: The Pseudo Root Approach. In *Proceedings of the First International Conference on Grid and Pervasive Computing (GPC 2006)*, Taichung, Taiwan, May 2006. Springer-Verlag LNCS.

[Wei-Jen Wang](#), [Carlos Varela](#), [Fu-Hau Hsu](#), and [Cheng-Hsien Tang](#). Actor Garbage Collection Using Vertex-Preserving Actor-to-Object Graph Transformations. In *Advances in Grid and Pervasive Computing*, volume 6104 of *Lecture Notes in Computer Science*, Bologna, pages 244-255, May 2010. Springer Berlin / Heidelberg.

Challenge 1: Actor GC vs. Object GC



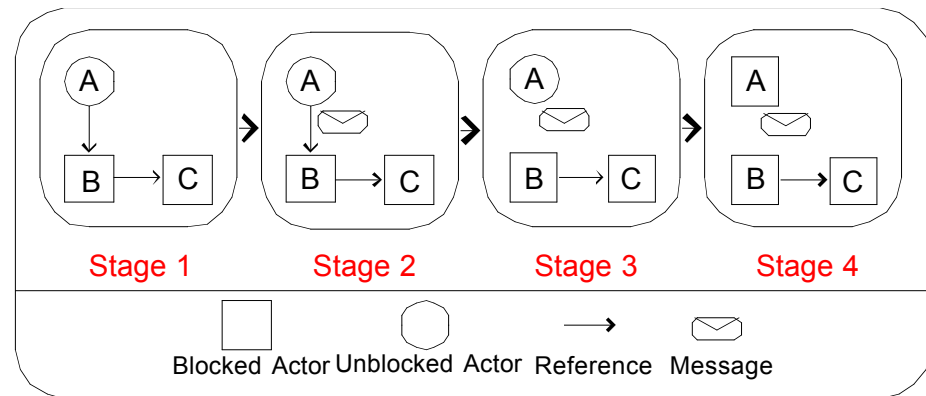
Actor Reference Graph



Passive Object Reference Graph

Challenge 2: Non-blocking communication

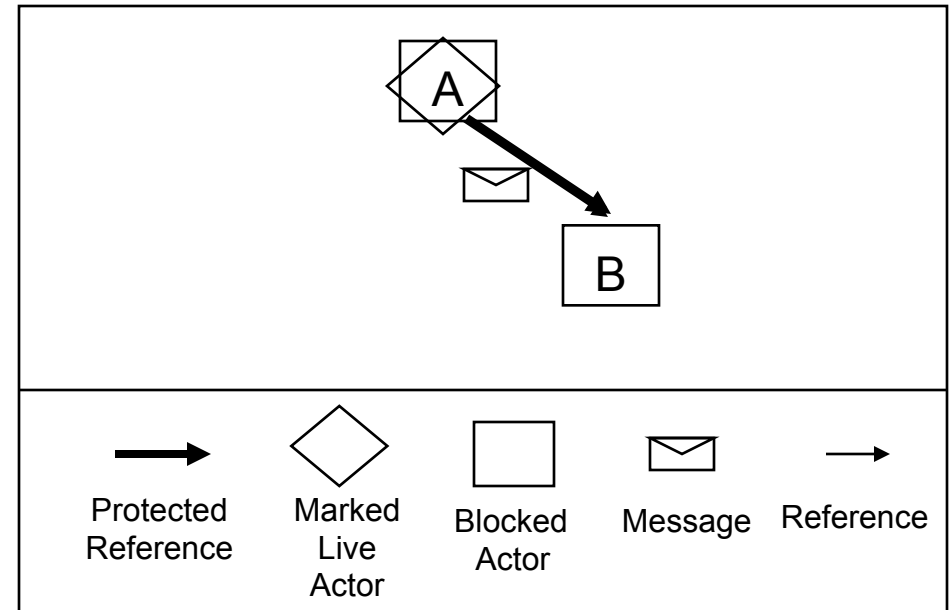
- Following references to mark live actors is not safe!



An example of mutation and asynchronous delivery of message

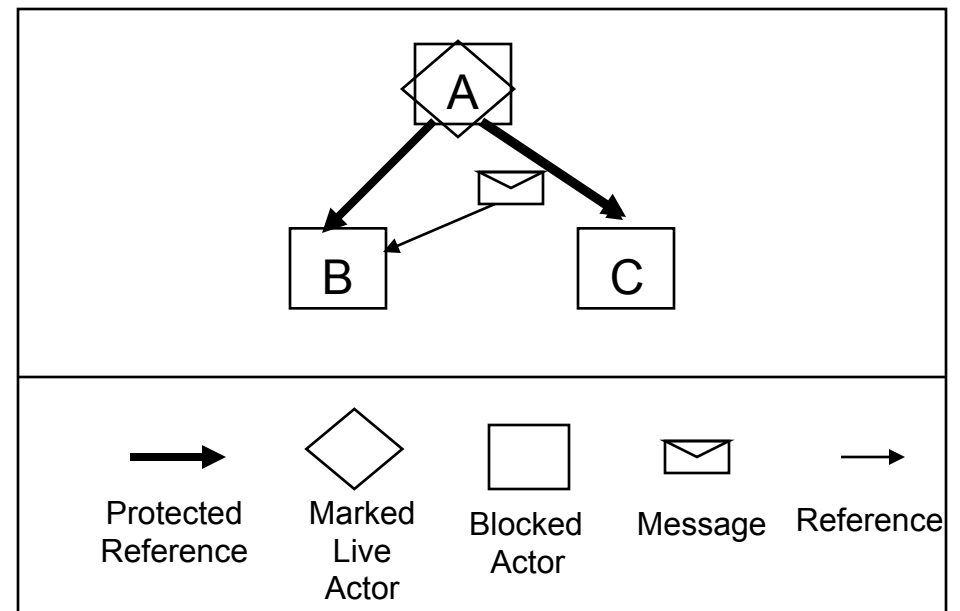
Challenge 2: Non-blocking communication

- Following references to mark live actors is not safe!
- What can we do?
 - We can *protect the reference from deletion* and *mark the sender live* until the sender knows the message has arrived



Challenge 2: Non-blocking communication (continued)

- How can we guarantee the safety of an actor referenced by a message?
- The solution is to *protect the reference from deletion* and *mark the sender live* until the sender knows the message has arrived



Challenge 3: Distribution and Mobility

- What if an actor is remotely referenced?
 - We can *maintain an inverse reference list* (only visible to the garbage collector) to indicate whether an actor is referenced.
 - Three operations change inverse references: *actor creation*, *reference passing*, and *reference deletion*.
 - The inverse reference registration must be based on *non-blocking* and *non-First-In-First-Out* communication!

The Pseudo Root Approach

- Pseudo roots:
 - Treat unblocked actors, migrating actors, and roots as pseudo roots.
 - Map *in-transit messages and references* into *protected references* and *pseudo roots*
 - Use inverse reference list (only visible to garbage collectors) to identify remotely referenced actors
- Actors which are not reachable from any pseudo root are garbage.

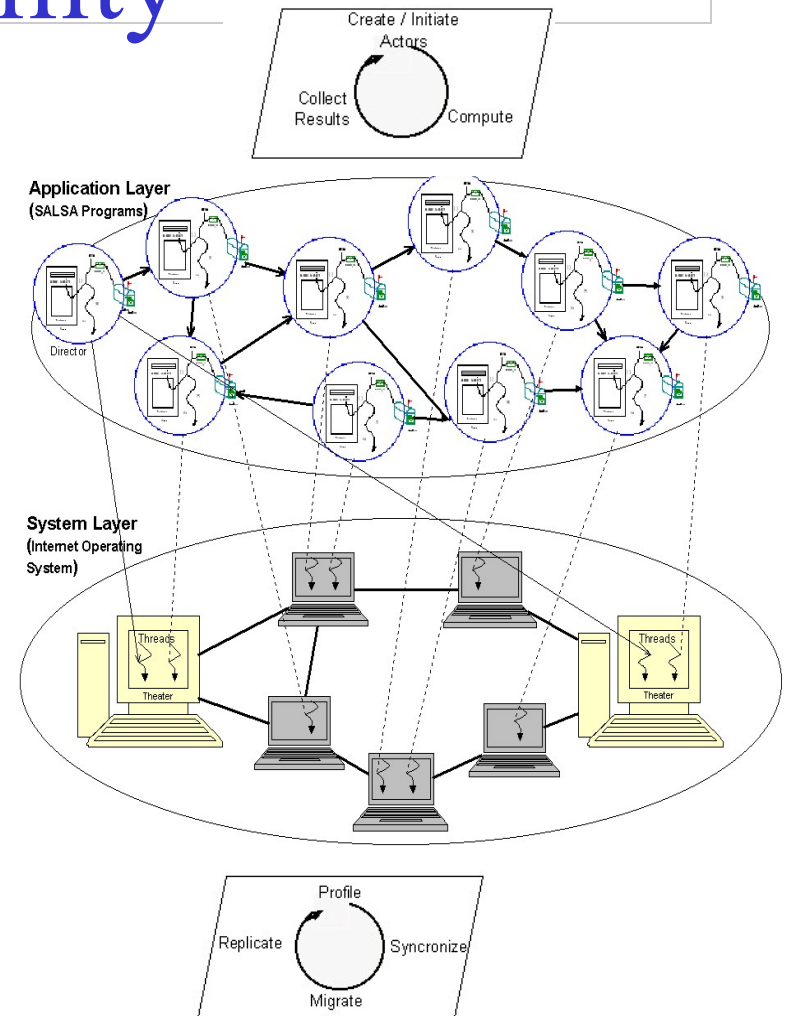
IOS: Load Balancing and Malleability

- 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

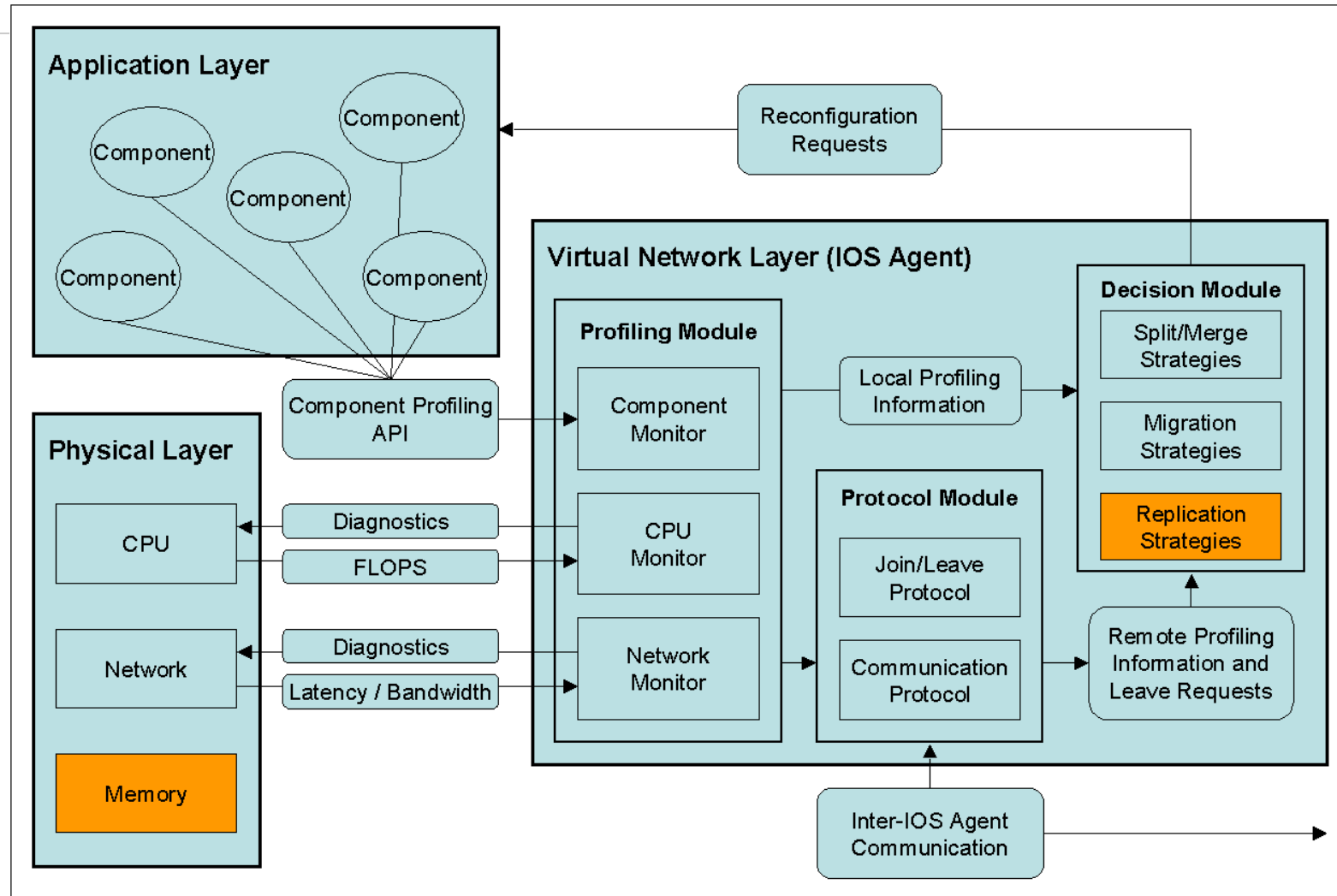
K. El Maghraoui, T. Desell, B. Szymanski, and C. Varela, "The Internet Operating System: Middleware for Adaptive Distributed Computing", *International Journal of High Performance Computing and Applications*, 2006.

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.



Middleware Architecture



IOS Architecture

- 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 with other agents in virtual network (e.g., peer-to-peer, cluster-to-cluster, centralized.)

A General Model for Weighted Resource-Sensitive Work-Stealing (WRS)

- Given:

A set of resources, $R = \{r_0 \dots r_n\}$

A set of actors, $A = \{a_0 \dots a_n\}$

ω is a weight, based on importance of the resource r to the performance of a set of actors A

$$0 \leq \omega(r,A) \leq 1$$

$$\sum^{\text{all } r} \omega(r,A) = 1$$

$\alpha(r,f)$ is the amount of resource r available at foreign node f

$v(r,l,A)$ is the amount of resource r used by actors A at local node l

$M(A,l,f)$ is the estimated cost of migration of actors A from l to f

$L(A)$ is the average life expectancy of the set of actors A

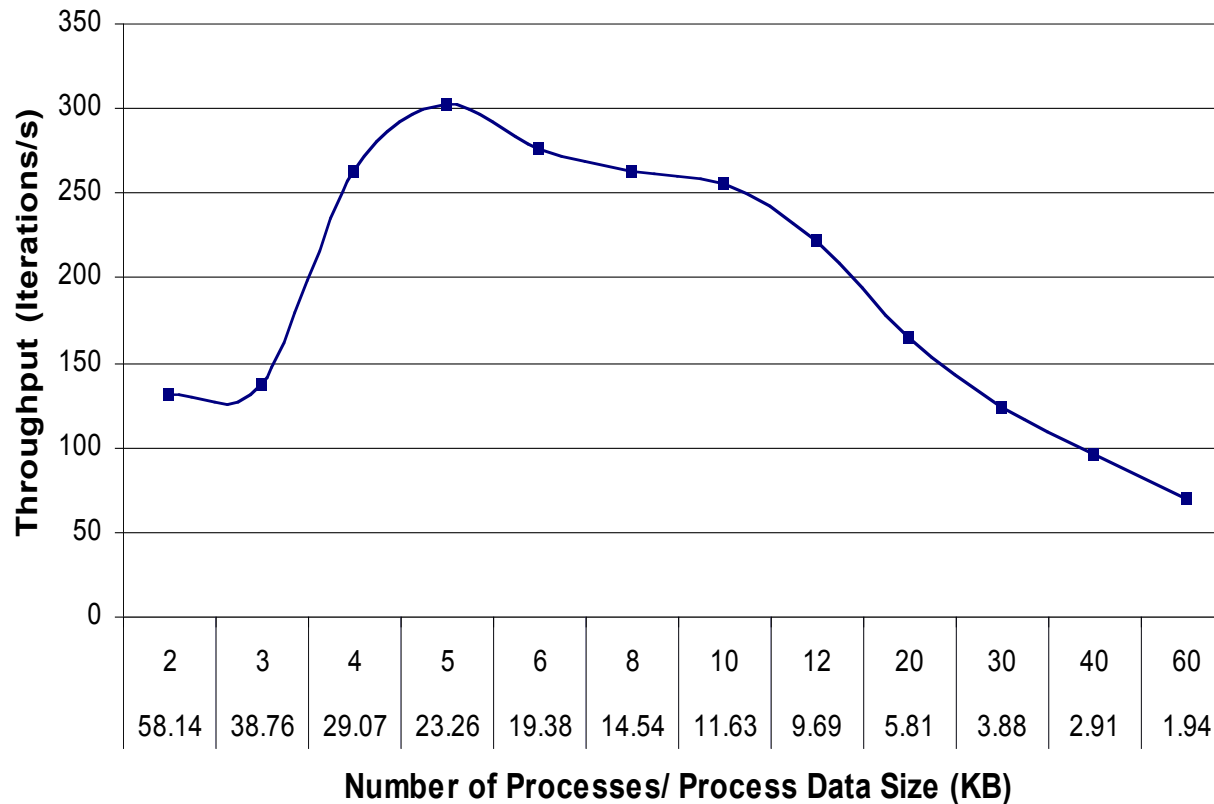
- The predicted increase in overall performance Γ gained by migrating A from l to f , where $\Gamma \leq 1$:

$$\Delta(r,l,f,A) = (\alpha(r,f) - v(r,l,A)) / (\alpha(r,f) + v(r,l,A))$$

$$\Gamma = \sum^{\text{all } r} (\omega(r,A) * \Delta(r,l,f,A)) - M(A,l,f)/(10+\log L(A))$$

- When work requested by f , migrate actor(s) A with greatest predicted increase in overall performance, if positive.

Impact of Process/Actor Granularity



Experiments on a dual-processor node (SUN Blade 1000)

Component Malleability

- New type of reconfiguration:
 - Applications can dynamically change component granularity
- Malleability can provide many benefits for HPC applications:
 - Can more adequately reconfigure applications in response to a dynamically changing environment:
 - Can scale application in response to dynamically joining resources to improve performance.
 - Can provide soft fault-tolerance in response to dynamically leaving resources.
 - Can be used to find the ideal granularity for different architectures.
 - Easier programming of concurrent applications, as parallelism can be provided transparently.

Component Malleability

- Modifying application component granularity dynamically (at runtime) to improve scalability and performance.
- SALSA-based malleable actor implementation.
- MPI-based malleable process implementation.
- IOS decision module to trigger split and merge reconfiguration.
- For more details, please see:

El Maghraoui, Desell, Szymanski and Varela, “Dynamic Malleability in MPI Applications”, *CCGrid 2007*, Rio de Janeiro, Brazil, May 2007, **nominated for Best Paper Award**.

Distributed Systems Visualization

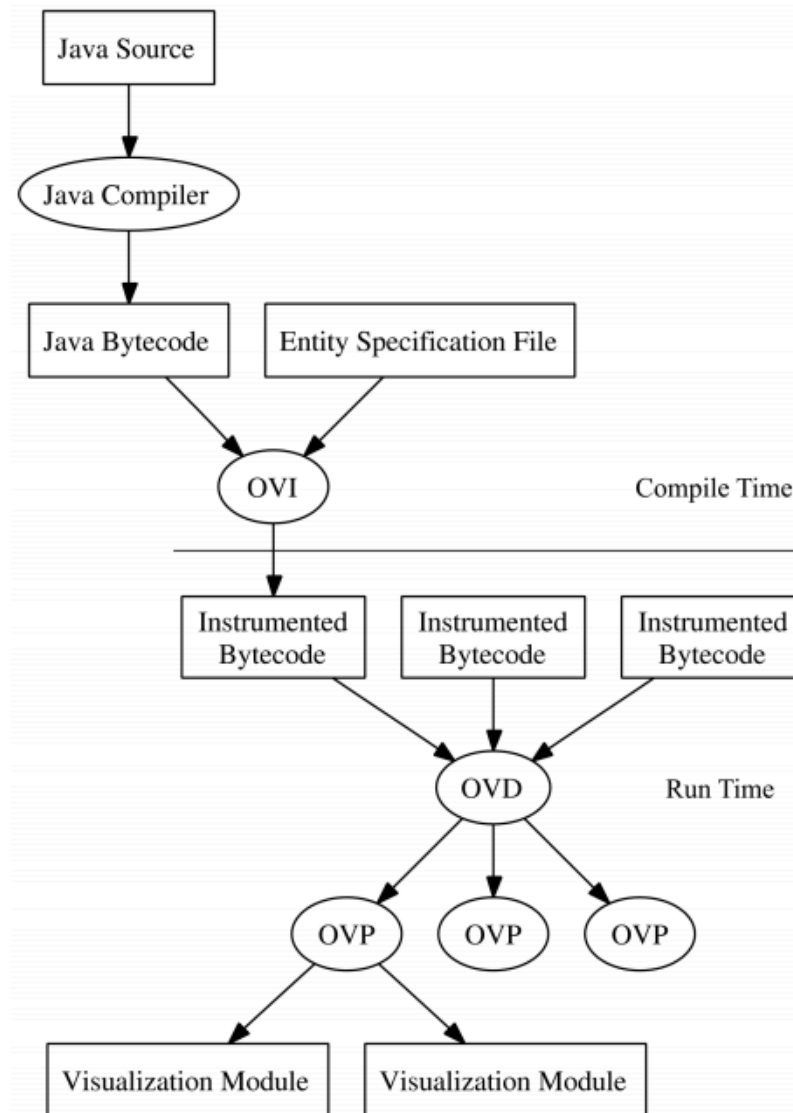
- Generic online Java-based distributed systems visualization tool
- Uses a declarative Entity Specification Language (ESL)
- Instruments byte-code to send events to visualization layer.
- For more details, please see:

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.

Gustavo A. Guevara S., Travis Desell, Jason Laporte, and Carlos A. Varela. Modular Visualization of Distributed Systems. *CLEI Electronic Journal*, 14:1-17, April 2011.

Note: **Best papers from CLEI 2010.**

Overview Architecture



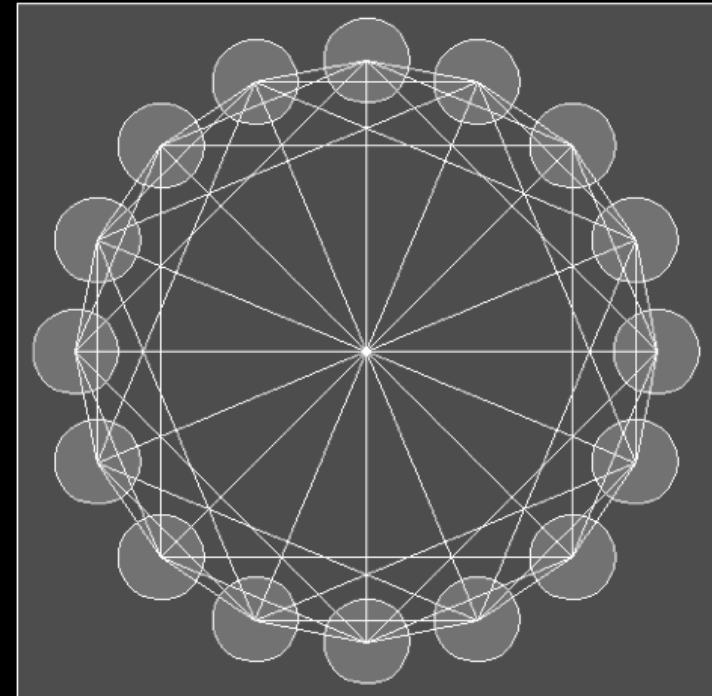
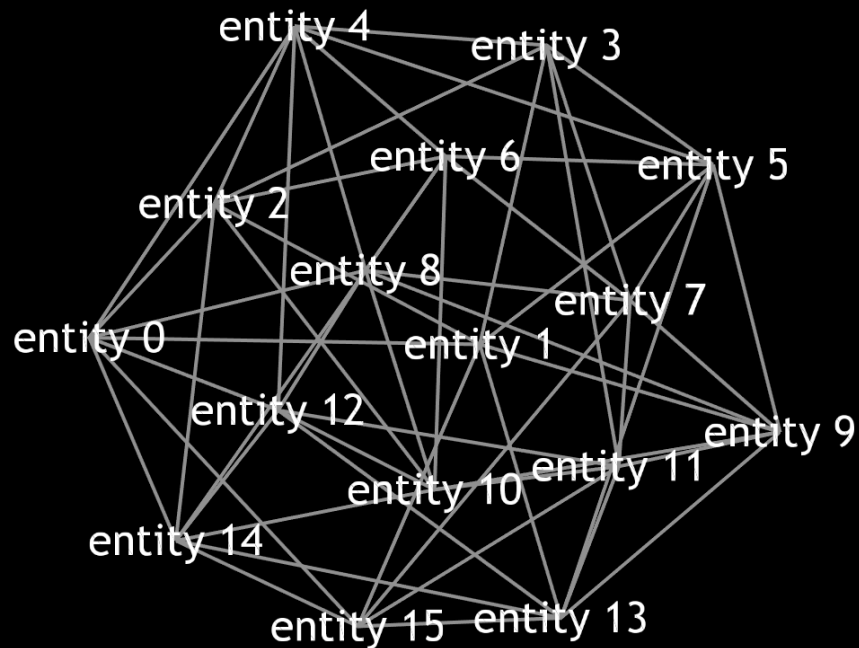
Example Specifications for SALSA

```
entity UniversalActor is salsa.language.UniversalActor$State {
  when start putMessageInMailbox(salsa.language.Message message)
    -> communication(message.getSource().getId(),
                     message.getTarget().getId());
  when finish finalize()
    -> deletion(this.getId());
}
```

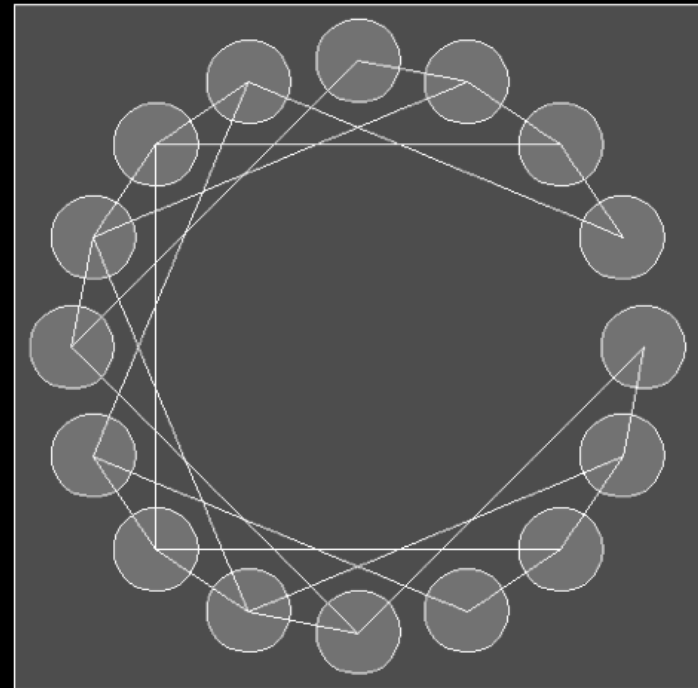
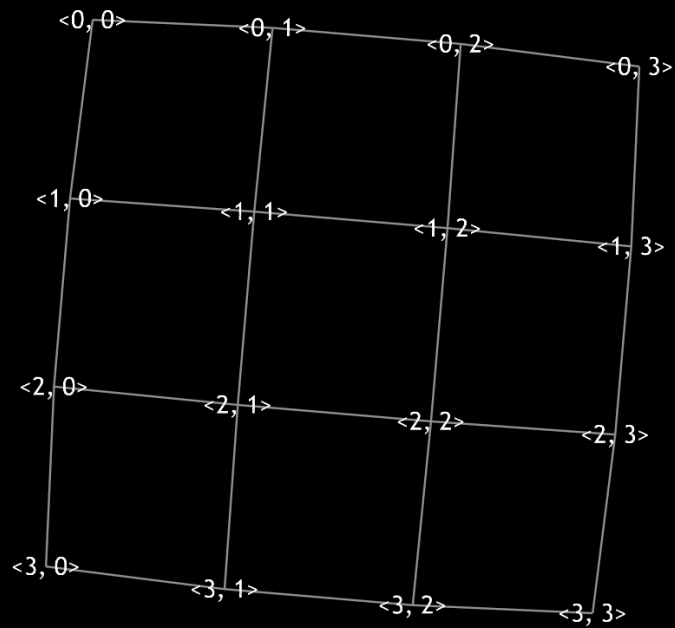
```
entity WWCSysyem is wwc.messaging.WWCSysyem$State {
  when start createActor(salsa.naming.UAN uan,
                        salsa.naming.UAL ual,
                        java.lang.String className)
    -> creation(uan.getId(), ual.getHostAndPort());

  when start addActor(salsa.language.Actor actor)
    -> migration(actor.getUAN().getId(),
                 actor.getUAL().getHostAndPort());
}
```

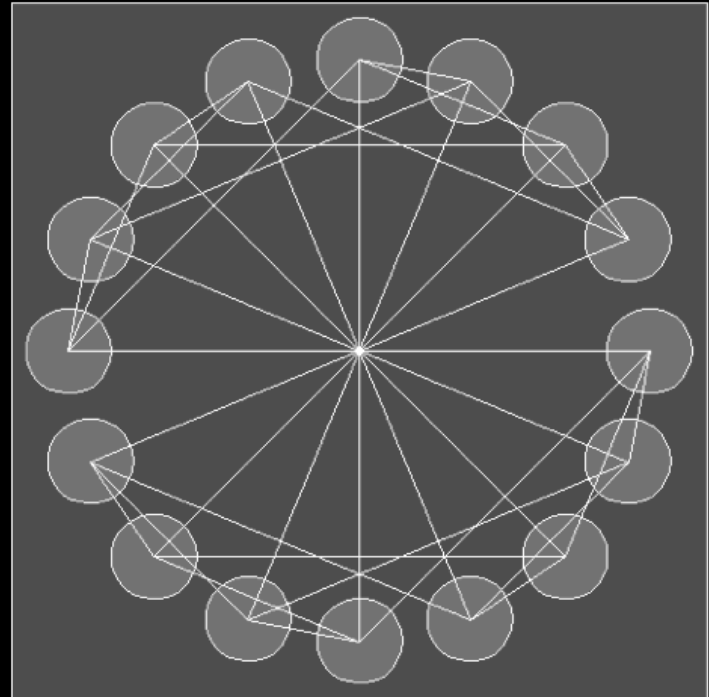
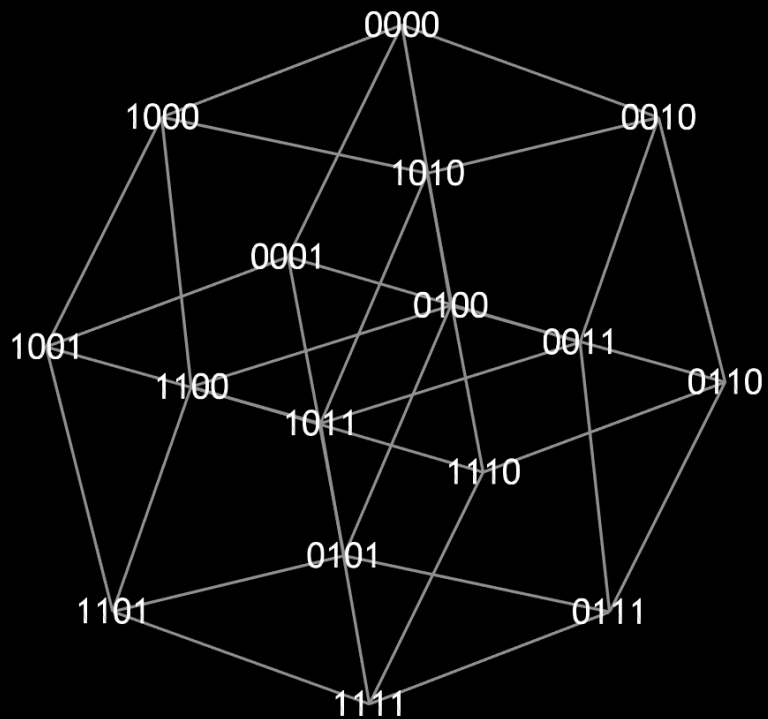
Chord application topology



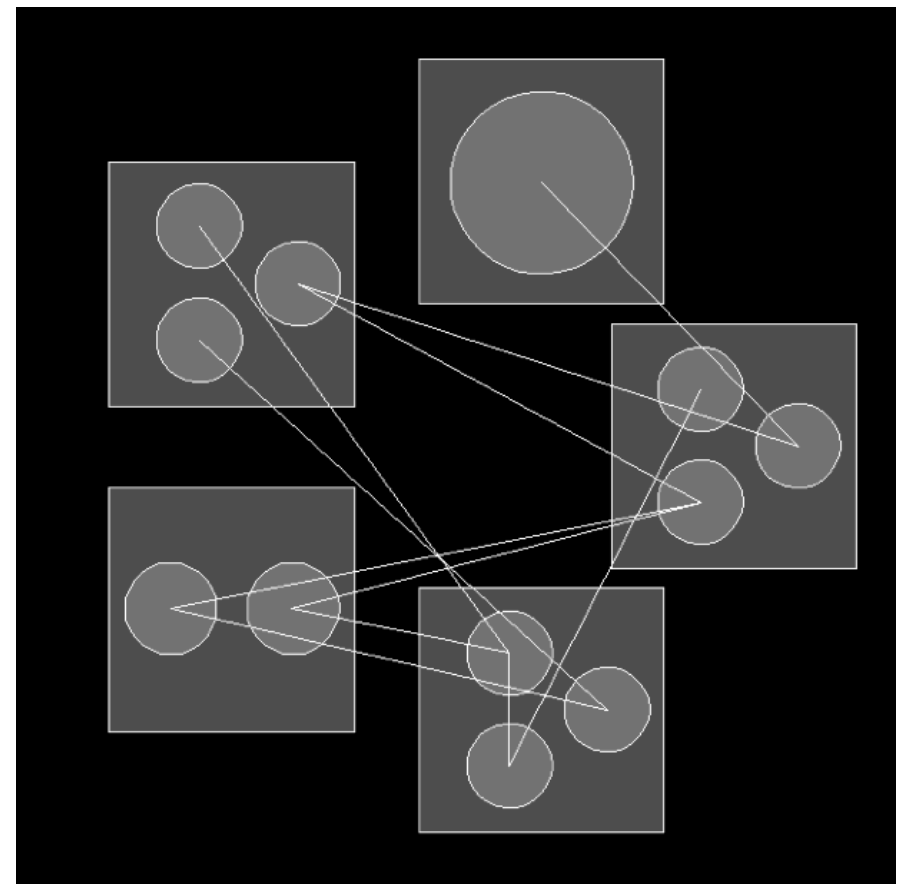
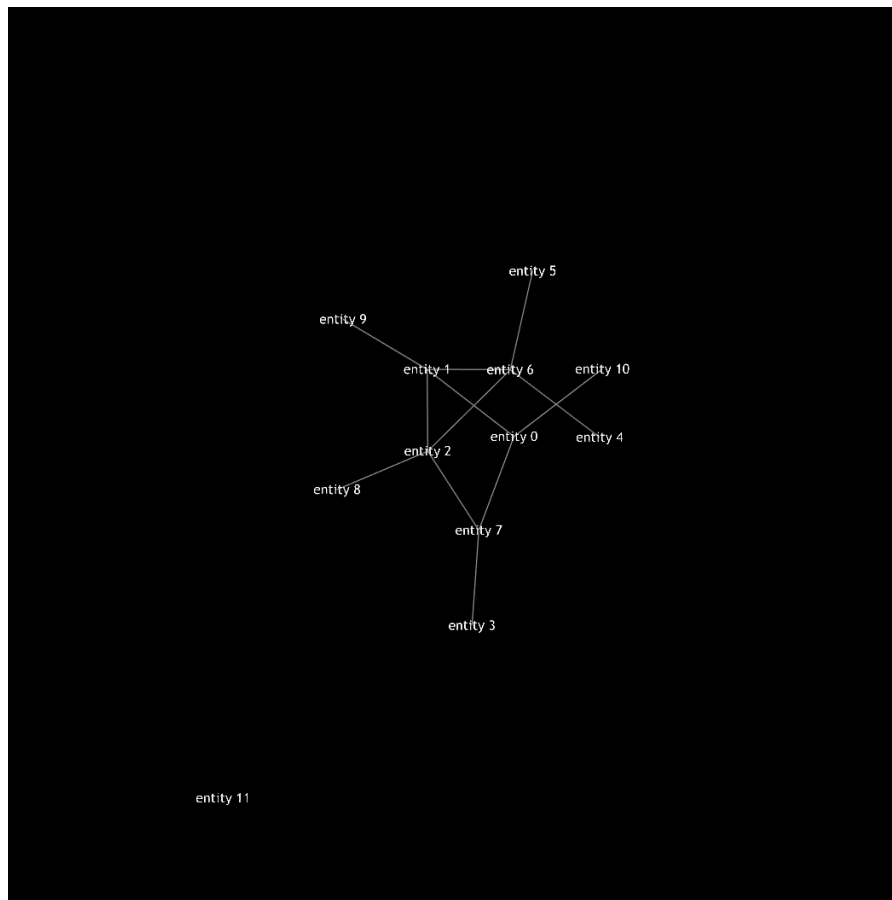
2D-Mesh application topology



Hypercube application topology



Visualizing distribution and mobility



Open Source Code

- Consider to contribute!
- Visit our web pages for more info:
 - SALSA: <http://wcl.cs.rpi.edu/salsa/>
 - IOS: <http://wcl.cs.rpi.edu/ios/>
 - OverView: <http://wcl.cs.rpi.edu/overview/>
 - COS: <http://wcl.cs.rpi.edu/cos/>
 - PILOTS: <http://wcl.cs.rpi.edu/pilots/>
 - MilkyWay@Home: <http://milkyway.cs.rpi.edu/>

Erlang Language Support for Fault-Tolerant Computing

- Erlang provides linguistic abstractions for:
 - Error detection.
 - Catch/throw exception handling.
 - Normal/abnormal process termination.
 - Node monitoring and exit signals.
 - Process (actor) groups.
 - Dynamic (hot) code loading.

Exception Handling

- To protect sequential code from errors:

```
catch Expression
```

If failure does not occur in **Expression** evaluation, **catch Expression** returns the value of the expression.

- To enable non-local return from a function:

```
throw({ab_exception, user_exists})
```

Address Book Example

```
-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));
        ...
    end.

add(Name, Email, Data) ->
    case getemail(Name, Data) of
        undefined ->
            [{Name,Email}|Data];
        _ -> % if Name already exists, add is ignored.
            Data
    end.

getemail(Name, Data) -> ...
```

Address Book Example with Exception

```
addressbook(Data) ->
  receive
    {From, {addUser, Name, Email}} ->
      case catch add(Name, Email, Data) of
        {ab_exception, user_exists} ->
          From ! {addressbook, no},
          addressbook(Data);
        NewData->
          From ! {addressbook, ok},
          addressbook(NewData)
      end;
    ...
  end.

add(Name, Email, Data) ->
  case getemail(Name, Data) of
    undefined ->
      [{Name,Email}|Data];
    _ -> % if Name already exists, exception is thrown.
      throw({ab_exception,user_exists})
  end.
```


Normal/abnormal termination

- To terminate an actor, you may simply return from the function the actor executes (without using tail-form recursion). This is equivalent to calling:

```
exit(normal) .
```

- Abnormal termination of a function, can be programmed:

```
exit({ab_error, no_msg_handler})
```

equivalent to:

```
throw({'EXIT', {ab_error, no_msg_handler}})
```

- Or it can happen as a run-time error, where the Erlang run-time sends a signal equivalent to:

```
exit(badarg) % Wrong argument type
```

```
exit(function_clause) % No pattern match
```

Address Book Example with Exception and Error Handling

```
addressbook(Data) ->
  receive
    {From, {addUser, Name, Email}} ->
      case catch add(Name, Email, Data) of
        {ab_exception, user_exists} ->
          From ! {addressbook, no},
          addressbook(Data);
        {ab_error, What} -> ... % programmer-generated error (exit)
        {'EXIT', What} -> ... % run-time-generated error
      NewData->
        From ! {addressbook, ok},
        addressbook(NewData)
      end;
    ...
  end.
```

Node monitoring

- 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.

Address Book Client Example with Node Monitoring

```
-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.
```

Process (Actor) Groups

- To create an actor in a specified remote node:

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

- To create an actor in a specified remote node and create a link to the actor:

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

An 'EXIT' signal will be sent to the originating actor if the host node does not exist.

Group Failure

- Default error handling for linked processes is as follows:
 - Normal exit signal is ignored.
 - Abnormal exit (either programmatic or system-generated):
 - Bypass all messages to the receiving process.
 - Kill the receiving process.
 - Propagate same error signal to links of killed process.
- All linked processes will get killed if a participating process exits abnormally.

Dynamic code loading

- To update (module) code while running it:

```
-module (m) .  
-export ([loop/0]) .  
  
loop () ->  
    receive  
        code_switch ->  
            m:loop ();  
        Msg -> ...  
        loop ()  
    end.
```

code_switch message dynamically loads the new module code. Notice the difference between m:loop() and loop().

Exercises

57. Download and execute the `Migrate.salsa` example.
58. Download `OverView` and visualize a Fibonacci computation in SALSA. Observe garbage collection behavior.
59. Download social networking example (PDCS Chapter 11) in SALSA and execute it in a distributed setting.
60. PDCS Exercise 11.8.2 (page 257).
61. Create a ring of linked actors in Erlang.
 - a. Cause one of the actors to terminate abnormally and observe default group failure behavior.
 - b. Modify default error behavior so that upon an actor failure, the actor ring reconnects.
62. Modify the cell example, so that a new “`get_and_set`” operation is supported. Dynamically (as cell code is running) upgrade the cell module code to use your new version.