Concurrent and Distributed Programming Patterns in SALSA

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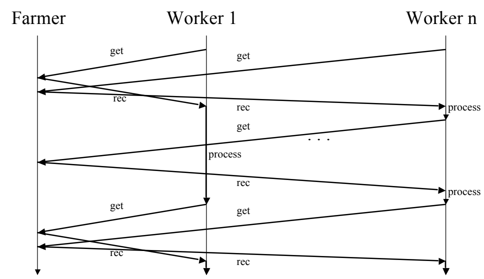
Overview

- Programming techniques and patterns
  - farmer-worker computations,
  - iterative computations,
  - peer-to-peer agent networks,
  - soft real-time: priorities, delays
  - causal connections: named tokens, waitfor property
- Distributed runtime architecture (World-Wide Computer)
  - architecture and implementation
  - distributed garbage collection
- Autonomic computing (Internet Operating System)
  - architecture and implementation
  - autonomous migration
  - split and merge
- Distributed systems visualization (OverView)

Farmer Worker Computations

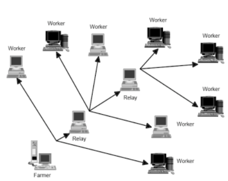
- Most common "Massively Parallel" type of computation
- Workers repeatedly request tasks or jobs from farmer and process them

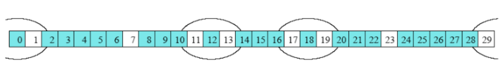
Farmer Worker Computations



Twin Primes & Brun's Constant

- **Investigators:**
  P. H. Fry, J. Nesheiwat, B. Szymanski (RPI CS)
- **Problem Statement:**
  Are there infinitely many twin primes?
  Calculating Brun's Constant (sum of inverse of all twin primes) to highest accuracy.
- **Application Information (Twin Primes):**
  Massively Parallel
  Farmer/Worker
  Non-Iterative

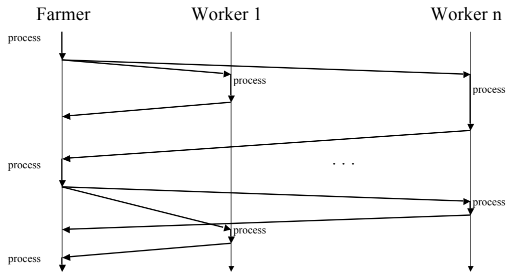




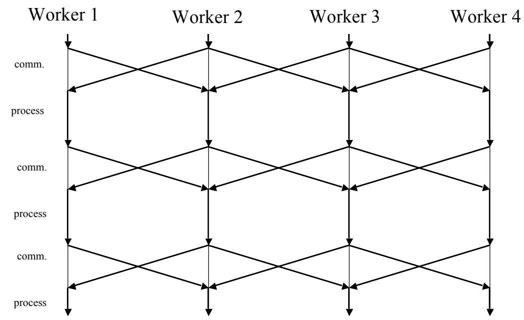
Iterative Computations

- Common pattern for partial differential equations, scientific computing and distributed simulation
- Workers connected to neighbors
- Data location dependent
- Workers process an iteration with results from neighbors, then send results to neighbors
- Performance bounded by slowest worker

Iterative Farmer/Worker

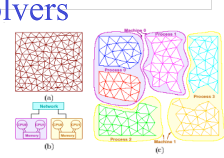


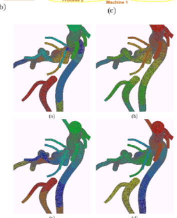
Iterative P2P



Adaptive Partial Differential Equation Solvers

- Investigators:
  - **J. Flaherty, M. Shephard B. Szymanski, C. Varela (RPI)**
  - **J. Teresco (Williams), E. Deelman (ISI-UCI)**
- Problem Statement:
  - **How to dynamically adapt solutions to PDEs to account for underlying computing infrastructure?**
- Applications/Implications:
  - **Materials fabrication, biomechanics, fluid dynamics, aeronautical design, ecology.**
- Approach:
  - **Partition problem and dynamically map into computing infrastructure and balance load.**
  - **Low communication overhead over low-latency connections.**
- Software:
  - **Rensselaer Partition Model (RPM)**
  - **Algorithm Oriented Mesh Database (AOMD).**
  - **Dynamic Resource Utilization Model) (DRUM)**
- Application Information (Heat):
  - **Tightly coupled**
  - **Iterative**

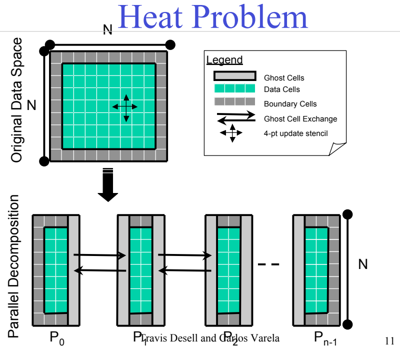




Case Study: Heat Diffusion Problem

- A problem that models heat transfer in a solid
- A two-dimensional mesh is used to represent the problem data space
- An Iterative Application
- Highly synchronized

Parallel Decomposition of the Heat Problem



Peer-to-Peer Computations

Peer-to-peer systems (1)

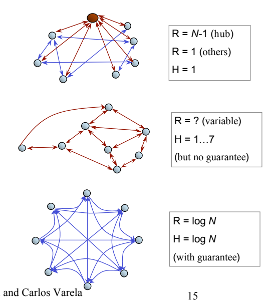
- Network transparency works well for a small number of nodes; what do we do when the number of nodes becomes very large?
  - This is what is happening now
- We need a scalable way to handle large numbers of nodes
- Peer-to-peer systems provide one solution
  - A distributed system that connects resources located at the edges of the Internet
  - Resources: storage, computation power, information, etc.
  - Peer software: all nodes are functionally equivalent
- Dynamic
  - Peers join and leave frequently
  - Failures are unavoidable

Peer-to-peer systems (2)

- Unstructured systems
  - Napster (first generation): still had centralized directory
  - Gnutella, Kazaa, … (second generation): neighbor graph, fully decentralized but no guarantees, often uses superpeer structure
- Structured overlay networks (third generation)
  - Using non-random topologies
  - Strong guarantees on routing and message delivery
  - Testing on realistically harsh environments (e.g., PlanetLab)
  - DHT (Distributed Hash Table) provides lookup functionality
  - Many examples: Chord, CAN, Pastry, Tapestry, P-Grid, DKS, Viceroy, Tango, Koorde, etc.

Examples of P2P networks

- Hybrid (client/server)
  - Napster
- Unstructured P2P
  - Gnutella
- Structured P2P
  - Exponential network
  - DHT (Distributed Hash Table), e.g., Chord



Properties of structured overlay networks

- Scalable
  - Works for any number of nodes
- Self organizing
  - Routing tables updated with node joins/leaves
  - Routing tables updated with node failures
- Provides guarantees
  - If operated inside of failure model, then communication is guaranteed with an upper bound on number of hops
  - Broadcast can be done with a minimum number of messages
- Provides basic services
  - Name-based communication (point-to-point and group)
  - DHT (Distributed Hash Table): efficient storage and retrieval of (key,value) pairs

Self organization

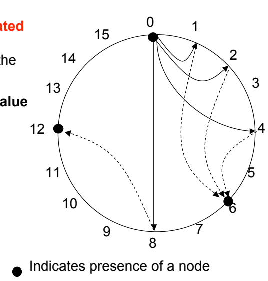
- Maintaining the routing tables
  - Correction-on-use (lazy approach)
  - Periodic correction (eager approach)
  - Guided by assumptions on traffic
- Cost
  - Depends on structure
  - A typical algorithm, DKS (distributed k-ary search), achieves logarithmic cost for reconfiguration and for key resolution (lookup)
- Example of lookup for Chord, the first well-known structured overlay network

Chord: lookup illustrated

Given a key, find the value associated to the key
(here, the value is the IP address of the node that stores the key)

Assume node 0 searches for the value associated to key K with virtual identifier 7

Interval	node to be contacted
[0,1)	0
[1,2)	6
[2,4)	6
[4,8)	6
[8,0)	12



Soft Real-Time

Message Properties

- SALSA provides message properties to control message sending behavior:
  - delay
    - To delay sending a message to an actor for a given time
  - waitfor
    - To delay sending a message to an actor until a token is available

Delayed Message Sending

- To (asynchronously) send a message after a given delay in milliseconds:

```
a <- book(flight):delay(1000);
```

Message is sent after one second has passed.

Causal Connections

Synchronized Message Sending

- To (asynchronously) send a message after another message has been processed:

```
token fundsOk = bank <- checkBalance();
…
a <- book(flight):waitfor(fundsOk);
```

Message is sent after token has been produced.

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()`.

Named Tokens (Multicast)

- Named tokens enable multicast:
  - Example:

```
token t1 = a1 <- m1();

for (int i = 0; i < a.length; i++) a[i] <- m( t1 );
```

Sends the result of m1 to each actor in array a.

Named Tokens (Loops)

- **Named tokens allow for synchronized loops:**

– Example 1:

```
token t1 = initial;
for (int i = 0; i < n; i++) {
t1 = a <- m( t1 );
}
```

Sends m to a n times, passing the result of the previous m as an argument.

– Example 2 (using waitfor):

```
token t1 = null;
for (int i = 0; i < a.length; i++) {
t1 = a[i] <- m( i ) : waitfor( t1 );
}
```

Sends m(i) to actor a[i], message m(i) will wait for m(i-1) to be processed.

Join Blocks

- **Join blocks allow for synchronization over multiple messages**
- **Join blocks return an array of objects (Object[]), containing the results of each message sent within the join block. The results are in the same order as how the messages they were generated by were sent.**
  - Example:

```
token t1 = a1 <- m1();
join {
    for (int i = 0; i < a.length; i++) {
        a[i] <- m( t1 );
    }
} @ process( token );
```

Sends the message m with the result of m1 to each actor in array a. After all the messages m have been processed, their results are sent as the arguments to process.

Current Continuations

- **Current Continuations allow for first class access to a messages continuation**
- **Current Continuations enable recursion**

– Example:

```
int fibonacci(int n) {
if (n == 0) return 0;
else if (n == 1 || n == 2) return 1;
else {
token a = fibonacci(n - 1);
token b = fibonacci(n - 2);
add(a, b) @ currentContinuation;
}
}
```

Finds the nth fibonacci number. The result of add(a, b) is sent as the return value of fibonacci to the next message in the continuation.

Current Continuations (Loops)

- **Current Continuations can also be used to perform recursive loops:**

– Example:

```
void loop(int n) {
if (n == 0) {
m(n) @
currentContinuation;
} else {
loop(n – 1) @
m(n) @
currentContinuation;
}
}
```

Sends the messages m(0), m(1), m(2) ...m(n). m(i) is always processed after m(i-1).

Current Continuations (Delegation)

- **Current Continuations can also be used to delegate tasks to other actors:**

– Example:

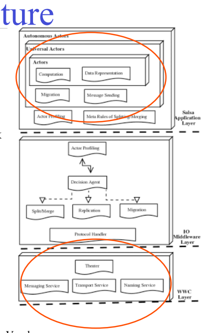
```
String getAnswer(Object question) {
if (question instanceof Question1) {
knowsQ1 <- getAnswer(question) @
currentContinuation;
} else if (question instanceof Question2) {
knowsQ2 <- getAnswer(question) @
currentContinuation;
} else return "don't know!";
}
```

If the question is Question1 this will get the answer from actor knowsQ1 and pass this result as it's token, if the question is Question2 this will get the answer from actor knowsQ2 and pass that result as it's token, otherwise it will return "don't know!".

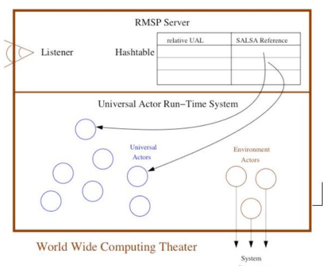
Distributed run-time (WWC)

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



WWC Theaters



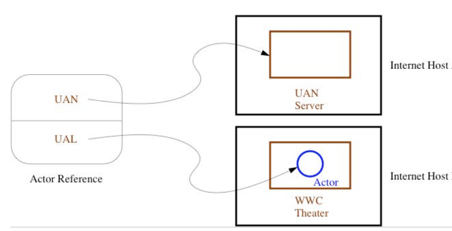
Scheduling

- The choice of which actor gets to execute next and for how long is done by a part of the system called the *scheduler*
- An actor is *non-blocked* if it is processing a message or if its mailbox is not empty, otherwise the actor is *blocked*
- A scheduler is fair if it does not starve a non-blocked actor, i.e. all non-blocked actors eventually execute
- Fair scheduling makes it easier to reason about programs and program composition
  - Otherwise some correct program (in isolation) may never get processing time when composed with other programs

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 location (host:port) changes but its name (UAN) does not.

Universal Actor Naming Protocol



Universal Actor Naming Protocol

- UANP includes messages for:
  - Binding actors to UAN, host:port 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 host:port and unique ID 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.

Naming Service Requirements

- Efficient name resolution/updates
- Fault tolerance
- Scalability
- Security
- Names should be:
  - Globally unique
  - Persistent
  - Human readable

Fault-Tolerant Home-Based Naming Service (FHNS)

- Each agent has a *home base* that keeps track of agent's location.
- Home base can be specified by agent or assigned by the naming service.
- Two types of URI-based names:
  - Location-dependent names (host:port and unique identifier)
  - Location-independent names (URN)

Naming Service API

Function	Description
put(name, location)	Binds a name to an initial location.
get(name)	Returns the location for the given name.
update(name,location)	Updates the location for the given name.
delete(name)	Remove the location for the given name.

Home Bases, Agents and Identifiers

Home Base Name	Identifier
rome:3030	7
hongkong:4040	0
newyork:5050	5

Agent Name	Identifier
fhns://rome:3030/Migrant	6
fhns://hongkong:4040/Tumbleweed	0
fhns:drifters:Gypsy	4
fhns:drifters:Nomad	2

Virtual Ring of Home Bases

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Home Base Theater Components

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Home Base Failures

- Failing home bases sequentially from 8 to 1 ensures that naming service is still available.
- Lookup is logarithmic on number of home bases.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Name Resolution Efficiency

- Logarithmic growth in number of messages to service a naming request.
- a: Theoretical results
- b: Practical results

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Network latency and Request Processing Times

- While number of messages increases logarithmically, request processing times increase linearly with number of hops for location-independent names.
- Location-dependent names take a constant lookup time.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Load Balancing

- Given K identifiers and H home bases, ideally each home base hosts K/H identifiers.
- Two nodes with similar hash values creates imbalance.
- a: Identifier Coverage
- b: Agent Name Coverage

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Load Balancing with Virtual Nodes

- a: Namespace coverage among 4 home bases.
- b: 4 home bases with 8 virtual nodes
- c: Namespace coverage with virtual nodes

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

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.

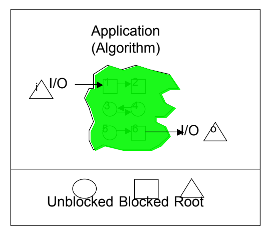
Wei-Jen Wang and Carlos A. Varela. A Non-blocking Snapshot Algorithm for Distributed Garbage Collection of Mobile Active Objects. *Technical report 06-15, Dept. of Computer Science*, R.P.I., October 2006. Note: Submitted to IEEE TPDS.

Motivation

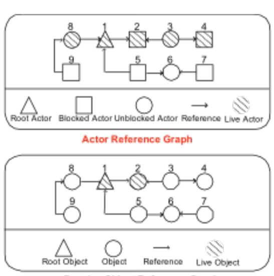
- Actors are reactive concurrent mobile entities.
- Garbage collection is needed for high level programming.
- Why do we need a new algorithm for actor garbage collection?
  - Existing algorithms rely on First-In-First-Out Communication or blocking communication
  - The new concept of mobile actors
- The need for automatic actor garbage collection in the SALSA programming language

Actor Garbage Definition

- Terminology:
  - ***Blocked:*** an idle actor with an empty message box
  - ***Unblocked:*** it is not blocked
  - ***Root****:* A root actor is defined as *being always live* (useful).
- The definition of actor garbage relates to meaningful computations
  - An application must be able to produce computing results!

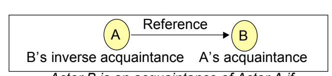


Challenge 1: Actor GC vs. Object GC



Operational Definition of Live Actors

- The new definition relies on "potentially live":
  - Every unblocked actor is potentially live.
  - Every acquaintance of a potentially live actor is potentially live
- The new definition of live actors:
  - A root actor is live.
  - Every acquaintance of a live actor is live.
  - Every potentially live, inverse acquaintance of a live actor is live.



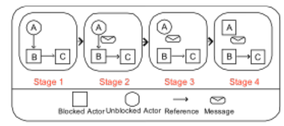
Actor B is an acquaintance of Actor A if Actor A has a reference pointing to Actor B.

Assumption of Resource (Root) Access

- We assume every actor has persistent references to some root
  - It is realistic in any kind of programming language!
- The resource access assumption leads to the ***live unblocked actor principle***!
  - It makes ***every potentially live actor*** live!

Challenge 2: Non-blocking communication

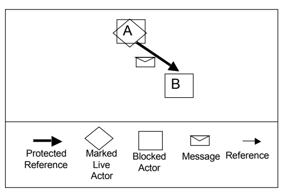
- Following references to mark live actors is not safe!



An example of mutation and asynchronous delivery of message

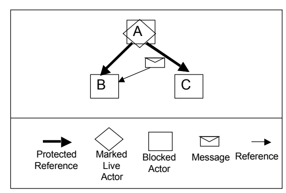
Challenge 2: Non-blocking communication

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



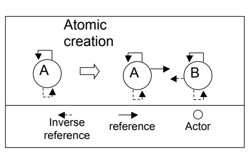
Challenge 2: Non-blocking communication (continued)

- 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.
  - The inverse reference registration must be based on ***non-blocking*** and ***non-First-In-First-Out*** communication!
  - Three operations change inverse references: ***actor creation***, ***reference passing***, and ***reference deletion***.



Actor Creation

Challenge 3: Distribution and Mobility (continued)

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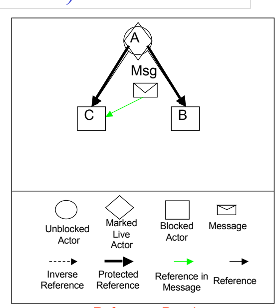

Reference Passing

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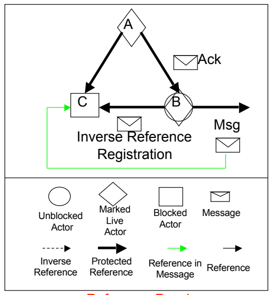

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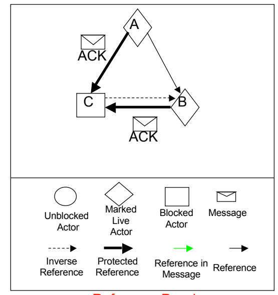

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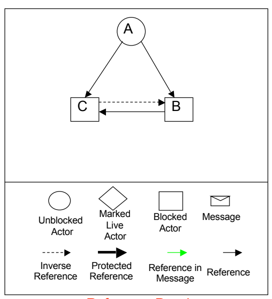

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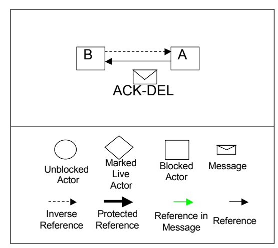
  - The inverse reference registration must be based on ***non-blocking*** and ***non-First-In-First-Out*** communication!
  - Three operations are involved: ***actor creation***, ***reference passing***, and ***reference deletion***.



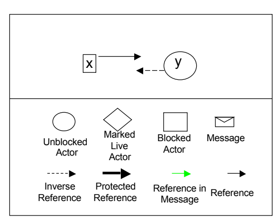
Reference Deletion

The Concept of 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.

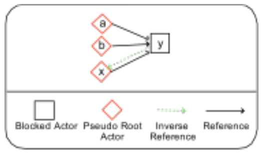
Property of the Pseudo Root Approach (1)

- Lemma 1. Precise inverse references to non-pseudo-root actors.
  - Let x ≠ y. If Actor y is referenced by a non-pseudo-root actor x, actor y must have an inverse reference to Actor x.



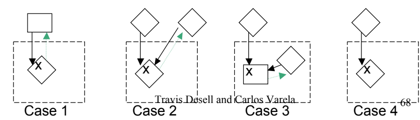
Property of the Pseudo Root Approach (2)

- Lemma 2. Safe imprecise inverse references to pseudo root actors.
  - If an actor is referenced by several pseudo roots, either 1) it has at least one inverse reference to one of the pseudo roots, or 2) it is a pseudo root.



Property of the Pseudo Root Approach (3)

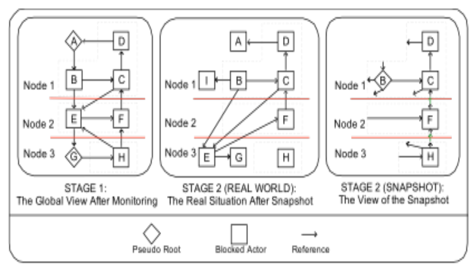
- Theorem 1. One-step back tracing safety.
  - Let Actor x be remotely referenced. Actor x can be identified live by one-step back tracing through its registered inverse references, or it is transitively reachable from a local pseudo root.



Challenge 3: Distribution and Mobility (continued)

- How to collect global mutually referenced garbage (cycles)?
- Our solution is to use a snapshot based algorithm

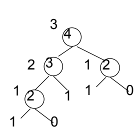
Example of the Snapshot Algorithm



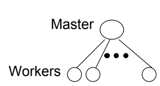
An Example of the Distributed Partial Approximation Snapshot Algorithm

Experiments

- We use three kinds of applications to evaluate our algorithm
  - The Fibonacci Number (tree structure computing)
  - The N-Queens Number Problem (Master-Worker)
  - Matrix Multiplication (Master-Worker with heavy communication)

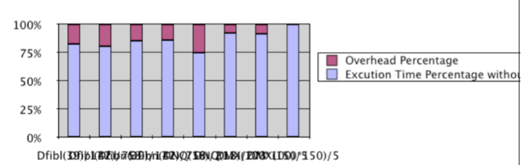


The Fibonacci Number



The N-Queens Number Problem & Matrix Multiplication

Results



Mechanism	Application(Argument)/Number of Actors							
	Dfibl(39) /177	DFibl(42) /753	Dfibn(39) /177	DFibn(42) /753	DNQ(16) /211	DNQ(18) /273	DMX(100^2) /5	DMX(150^2) /5
No GC (real)	1.722	3.974	3.216	8.527	13.120	426.151	6.165	39.011
GC (real)	2.091	4.957	3.761	9.940	17.531	461.757	6.715	38.955
GC Overhead (REALOI)	21%	25%	17%	17%	34%	8%	9%	0%

Autonomic Computing (IOS)

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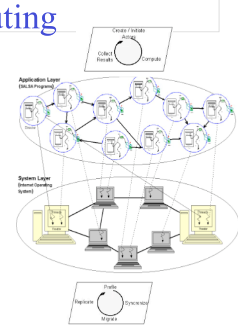
Middleware for Autonomous Computing

- 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.

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Middleware Implementation - IOS

- Leveraged IOS (The Internet Operating System):
  - **Generic middleware for distributed application reconfiguration.**
  - **Works with multiple programming paradigms (MPI, SALSA)**

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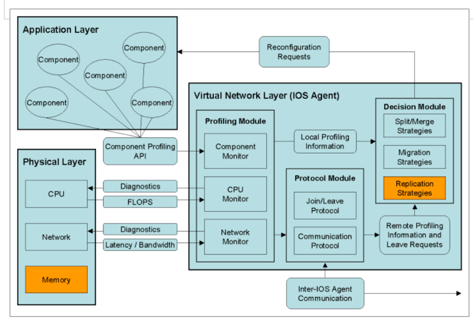
Middleware Architecture



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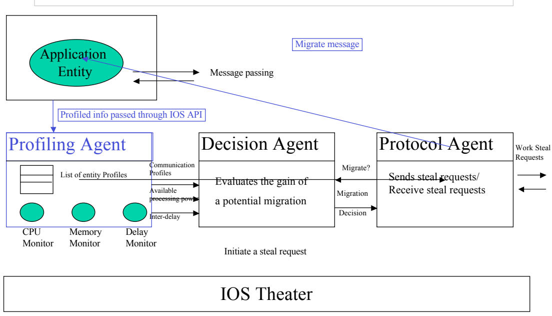
A Generic Architecture



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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.)

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IOS API

- The following methods notifiy the profiling agent of actors entering and exiting the theater due to migration and binding:
  - **public void addProfile(UAN uan);**
  - **public void removeProfile(UAN uan);**
  - **Public void migrateProfile(UAN uan, UAL target)**
- The profiling agent updates its actor profiles based on message sending with these methods
  - **public void msgSend(UAN uan, Msg_INFO msgInfo);**
- The profiling agent updates its actor profiles based on message reception with this method
  - **public void msgReceive(UAN uan, targetUAL, Msg_INFO msgInfo);**
- The following methods notify the profiling agent of the start of a message being processed and the end of a message being processed, with a UAN or UAL to identify the sending actor
  - **public void beginProcessing(UAN uan, Msg_INFO msgInfo);**
  - **public void endProcessing(UAN uan, Msg_INFO msgInfo);**

Resource Sensitive Model

- Decision components use a resource sensitive model to decide based on the profiled applications how to balance the resources' consumption
- Reconfiguration decisions
  - Where to migrate
  - When to migrate
  - How many entities to migrate

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

- Given:
  A set of resources, $R = \{r_0 \ldots r_n\}$
  A set of actors, $A = \{a_0 \ldots a_n\}$
  ω is a weight, based on importance of the resource r to the performance of a set of actors A

  $0 \leq \omega(r,A) \leq 1$
  $\Sigma^{\text{all } r}\ \omega(r,A) = 1$

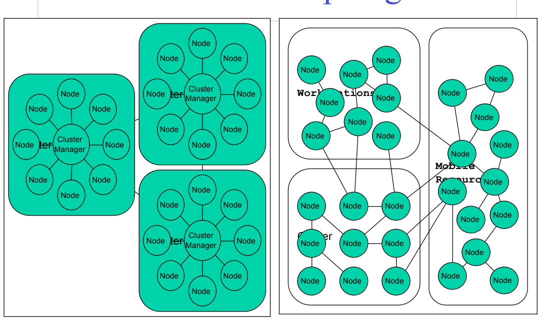
  $\alpha(r,f)$ is the amount of resource r available at foreign node f
  $\upsilon(r,l,A)$ is the amount of resource r used by actors A at local node l
  $M(A,l,f)$ is the estimated cost of migration of actors A from l to f
  $L(A)$ is the average life expectancy of the set of actors A
- The predicted increase in overall performance Γ gained by migrating A from l to f, where $\Gamma \leq 1$:

  $\Delta(r,l,f,A) = (\alpha(r,f) - \upsilon(r,l,A)) / (\alpha(r,f) + \upsilon(r,l,A))$
  $\Gamma = \Sigma^{\text{all } r}\ (\omega(r,A) * \Delta(r,l,f,A)) - M(A,l,f)/(10+\log L(A))$
- When work requested by f, migrate actor(s) A with greatest predicted increase in overall performance, if positive.

Virtual Topologies of IOS Agents

- Agents organize themselves in various network-sensitive virtual topologies to sense the underlying physical environments
- Peer-to-peer topology : agents form a p2p network to exchange profiled information.
- Cluster-to-cluster topology: agents organize themselves in groups of clusters. Cluster managers form a p2p network.

C2C vs. P2P topologies

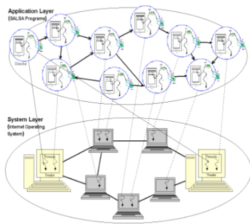


IOS Load Balancing Strategies

- IOS modular architecture enables using different load balancing and profiling strategies, *e.g.:*
  - Round-robin (RR)
  - Random work-stealing (RS)
  - Application topology-sensitive work-stealing (ATS)
  - Network topology-sensitive work-stealing (NTS)

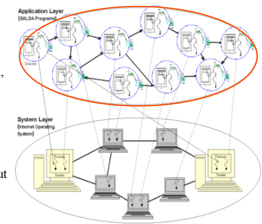
Random Stealing (RS)

- Based on Cilk's random work stealing
- Lightly-loaded nodes periodically send work steal packets to randomly picked peer theaters
- Application entities migrate from highly loaded theaters to lightly loaded theaters
- Simple strategy: no broadcasts required
- Stable strategy: it avoids additional traffic on overloaded networks



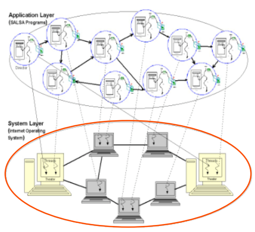
Application Topology-Sensitive Work-Stealing (ATS)

- An extension of RS to collocate components that communicate frequently
- Decision agent picks the component that will minimize inter-node communication after migration, based on
  - Location of acquaintances
  - Profiled communication history
- Tries to minimize the frequency of remote communication improving overall system throughput



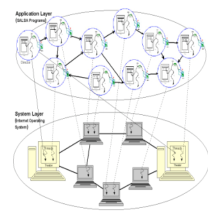
Network Topology-Sensitive Work-Stealing (NTS)

- An extension of ATS to take the network topology and performance into consideration
- Periodically profile end-to-end network performance among peer theaters
  - Latency
  - Bandwidth
- Tries to minimize the cost of remote communication improving overall system throughput
  - Tightly coupled entities stay within reasonably low latencies/ high bandwidths
  - Loosely coupled entities can flow more freely



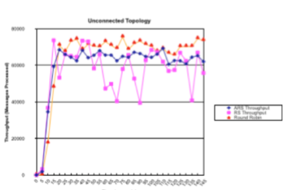
Using the IOS middleware

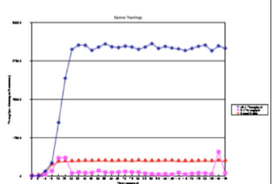
- Start IOS Peer Servers: a mechanism for peer discovery
- Start a network of IOS theaters
- Write your SALSA programs and extend all actors to autonomous actors
- Start autonomous actors in theaters
- IOS automatically reconfigures the location of actors in the network for improved performance of the application.
- IOS supports the dynamic addition and removal of theaters



Preliminary Results---Unconnected/Sparse

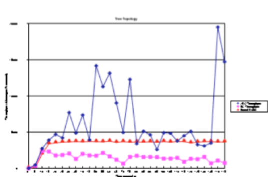
- Load balancing experiments use RR, RS and ATS
- Applications with diverse inter-actor communication topologies
  - Unconnected, sparse, tree, and hypercube actor graphs

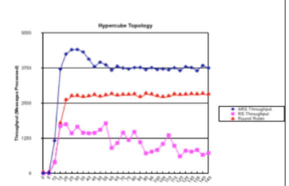




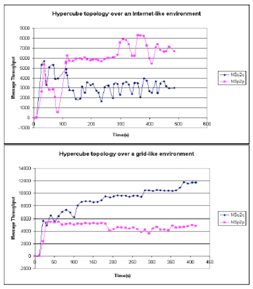
Tree and Hypercube Topology Results

- RS and ATS do not add substantial overhead to RR
- ATS performs best in all cases with some interconnectivity

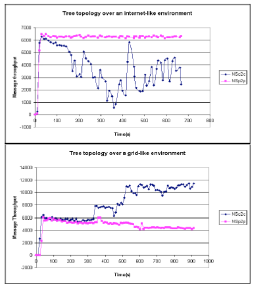




Results for applications with high communication to computation ratio

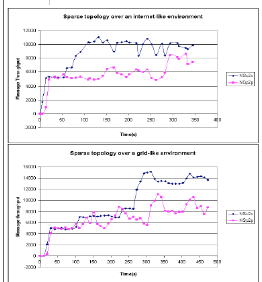


The hypercube application topology on Internet- and Grid-like environments.

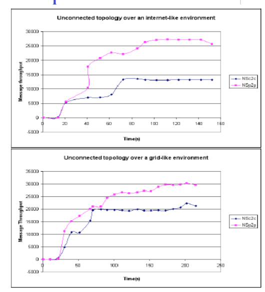


The tree application topology on Internet- and Grid-like environments.

Results for applications with low communication-to-computation ratio



The sparse application topology on Internet- and Grid-like environments.



The unconnected application topology on Internet- and Grid-like environments.

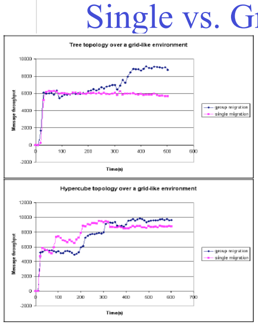
Load Balancing Strategies for Internet-like and Grid-like Environments

- Simulation results show that:
  - The peer-to-peer protocol performs better for applications with high communication-to-computation ratio in Internet-like environments
  - The cluster-to-cluster protocol performs better for applications with low communication-to-computation ratio in Grid-like environments

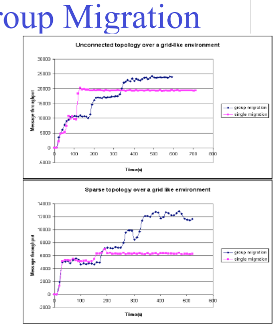
Migration Policies

- Group Migration performs better for the 4 application topologies.
- Single Migration has a more stable behavior of the application's topology throughput
- Future Work: Evaluation of migration policies for different sizes of actors.

Single vs. Group Migration



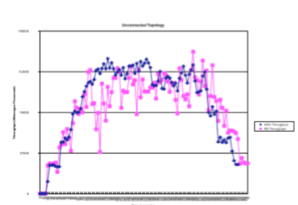
Single vs. group migration for the tree and hypercube application topologies.



Single vs. group migration for the unconnected and sparse application topologies.

Dynamic Networks

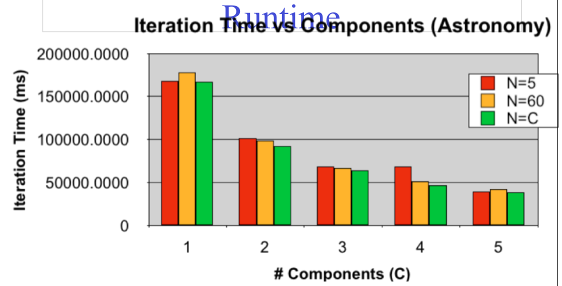
- Theaters were added and removed dynamically to test scalability.
- During the 1st half of the experiment, every 30 seconds, a theater was added.
- During the 2nd half, every 30 seconds, a theater was removed
- Throughput improves as the number of theaters grows.



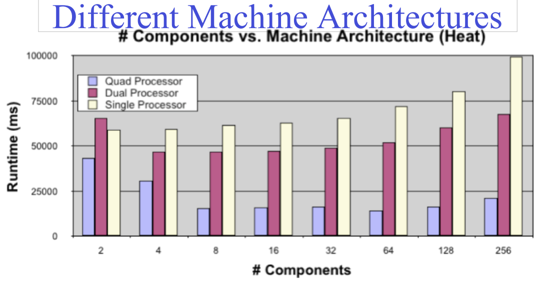
Component Malleability

- 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.

Impact of Granularity on Runtime



Impact of Granularity on Different Machine Architectures



Methodology

- How to accomplish dynamic granularity?
  - Programmers define how to *split* and *merge* components.
  - Middleware determines which components to split or merge, and when to perform split and merge.

Types of Malleability

- How can split and merge be done?
  - Split 1:2, Merge 2:1
  - Split 1:N, Merge N:1
  - Split N:M, Merge M:N
  - Split N:N+1, Merge N+1:N

Implementing Split/Merge

- Leveraged the SALSA programming language.
  - Actor oriented programming model
  - Compiled to Java
- Added language level support for malleable actors.
- Generic strategy used to split and merge actors:
  - Performed Atomically
  - Allows Concurrency
  - User specifies via API:
    - communication redirection
    - data redistribution

Example – Twin Primes Farmer

```
behavior TPFarmer {
  NumberSegmentGenerator nsg = new NumberSegmentGenerator();
  void act(String[] args) {
    numberWorkers = args[0];
    for (int i = 0; i < numberWorkers; i++) new TPWorker(this);
  }
  void requestWork(TPWorker t) {
    if (nsg.hasMoreSegments())
      t<-findPrimes(nsg.getNextSegment());
  }
  void receivePrimes(Segment s) {
    s.saveToDisk();
  }
}
```


Example - Twin Primes Worker

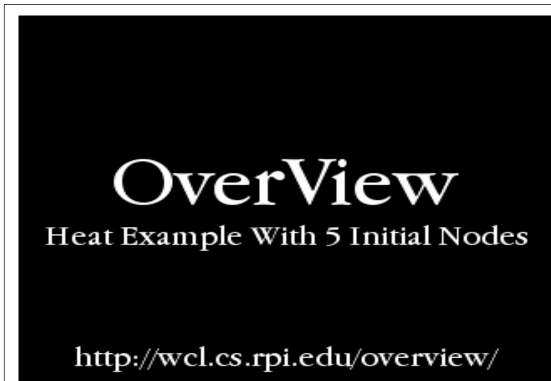
```
behavior TPWorker extends
    MalleableActor {
  TPFarmer farmer;
  TPWorker(TPFarmer farmer) {
    this.farmer = farmer;
    farmer<-requestWork(this);
  }
  void findPrimes(Segment s) {
    s.findPrimes();
    farmer<-receivePrimes(s) @
    farmer<-requestWork(this);
  }
  boolean canSplitOrMerge() {
    return true;
  }
  MalleableActor createNewActor() {
    return new TPWorker(farmer);
  }
  void handleMergeMsg(Msg m) {
    if (m.name() == "findPrimes") {
      this.process(message);
    }
  }
}
```


Distributed Systems Visualization (OverView)

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:

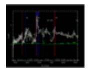
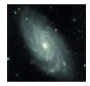
T. Desell, H. Iyer, A. Stephens, and C. Varela. OverView: A Framework for Generic Online Visualization of Distributed Systems. In *Proceedings of the European Joint Conferences on Theory and Practice of Software (ETAPS 2004), eclipse Technology eXchange (eTX) Workshop*, Barcelona, Spain, March 2004.

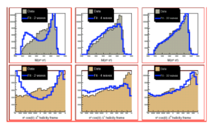


AstroInformatics and PhysInformatics Application Examples

Milky Way Origin and Structure Particle Physics

- Investigators:
  - H. Newberg (RPI Astronomy), J. Teresco (Williams)
  - M. Magdon-Ismail, B. Szymanski, C. Varela(RPI CS)
  - J. Cummings, J. Napolitano (RPI Physics)
- Problem Statement:
  - How to analyze data from 10,000 square degrees of the north galactic cap collected in five optical filters over five years by the Sloan Digital Sky Survey?
  - Do "missing baryons" exist? Sub-atomic particles that have not been observed.
- Applications/Implications:
  - Astrophysics: origins and evolution of our galaxy.
  - Physics: particle physics, search for missing baryons.
- Approach:
  - To use photometric and spectroscopic data to separate and describe components the Milky Way
  - Maximum Likelihood Analysis
- Application Information (Astronomy/Physics):
  - Farmer/Worker Model
  - Iterative
  - Loosely Coupled

Analysis of Particle Physics

- Facts:
  - Short lived particles (≈10 s) are not measurable
  - They can only ***be inferred from*** correlations in the final state particles
- How to infer?
  - ***Partial Wave Analysis (PWA)*** to describe the properties of the particles
  - ***Maximum Likelihood Evaluation (MLE)*** to find the most possible solution

* Adopted from http://www.physicscentral.com

Maximum Likelihood Evaluation (MLE)

- ***Maximum likelihood***: the largest product of the probabilities of observing each event given a set of fit parameters.
- In our case:

$$-\ln(\mathcal{L}) = -\sum_{i}^{n} \ln\left(\left|\psi_\alpha^p \psi_\alpha^d(\tau_i)\right|^2\right) - n\psi_\alpha^p \Psi_{\alpha\alpha'} \psi_{\alpha'}^{p*}$$

Logarithm likelihood

The ith Events

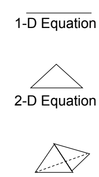
Number of events

Constant

Complex fit parameters

Simplex Algorithm

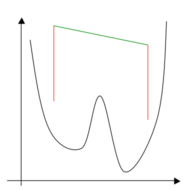
- Simplex is an algorithm to iteratively compute the maximum likelihood
  - Apply to N-dimensional problems
  - Use a simplex to fit the equation
  - Fix one point and try to find the minimal value
  - Contract the simplex if necessary
  - Improve the result iteratively
  - Need to ***guess*** the initial value



Simplex Examples

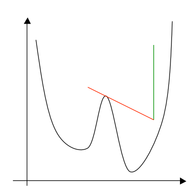
Simplex Algorithm Example

- Given an initial value, then use it to fit



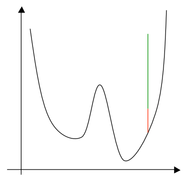
Simplex Algorithm Example

- If found the optimal value, contract the simplex and try again



Simplex Algorithm Example

- Contract to a smaller simplex and find the optimal



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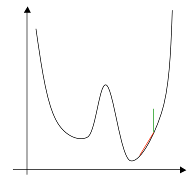
Simplex Algorithm Example

- If the gain from contracting the simplex is small enough, then stop fitting



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Final Remarks

- Thanks!
- Visit our web pages:
  - SALSA: http://wcl.cs.rpi.edu/salsa/
  - IOS: http://wcl.cs.rpi.edu/ios/
  - OverView: http://wcl.cs.rpi.edu/overview/
- Questions?

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Exercises

1. Create a Producer-Consumer pattern in SALSA and play with message delays to ensure that the consumer actor mailbox does not create a memory problem.
2. Create an autonomous iterative application and run it within IOS so that the management of actor placement is triggered by the middleware.
3. Execute the Cell example with OverView visualizing actor migration.

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