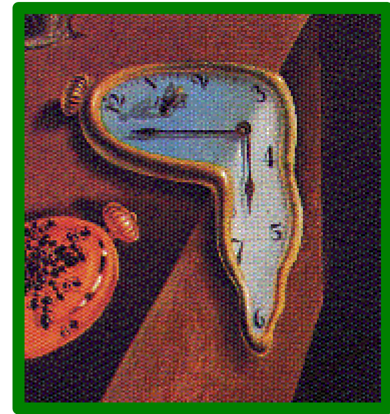
JiST:
Java in Simulation Time



Transparent Parallel and Optimistic Execution of Discrete Event Simulations (PDES) of Mobile Ad hoc Networks (MANETs)

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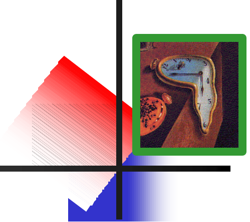
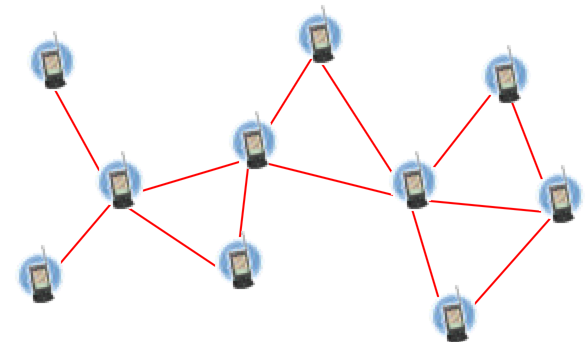
3 March 2003

http://www.cs.cornell.edu/barr/repository/jist/

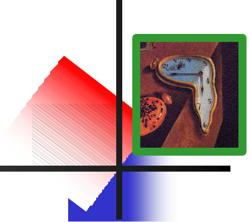
introduction



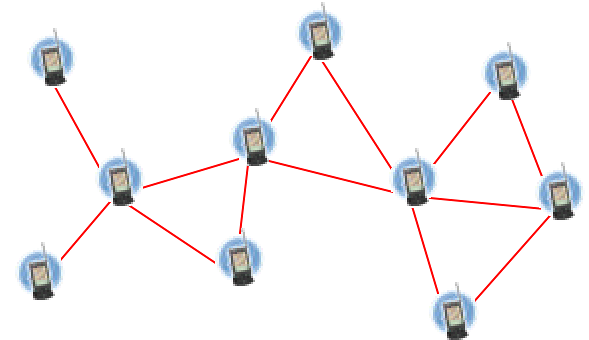
- discrete event simulations are useful
  - physics, chemistry, genomics, proteomics
  - geology, meteorology, astronomy
  - processors, networks
- basic structure
  - simulation time
  - state (partitioned)
  - events, event queue
- ad hoc network simulations
  - lack scalability, or
  - compromise detail



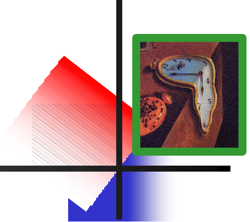
simulating ad hoc wireless networks



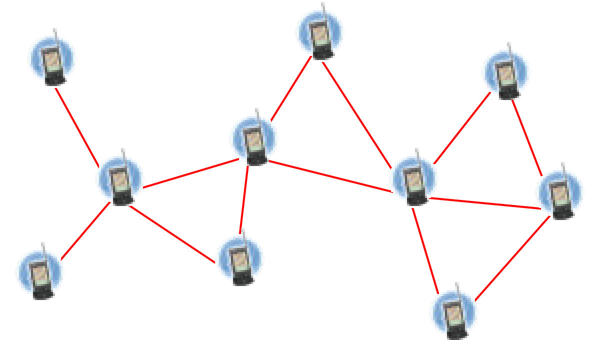
- scale
  - large number of nodes
  - expensive to own, maintain, charge...
  - distribution of control
  - aggregation of experimental data
  - node mobility
  - isolating experiment from interference
- complexity
  - simple protocols vs.
    aggregate network behavior
  - repetition



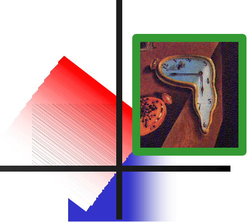
existing MANET simulators



- ns2
- PDNS
- OPNet
- GlomoSim
- custom-made

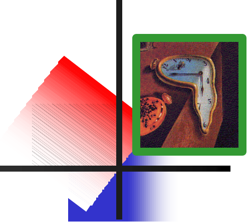


design space



- **interpreted execution**
  vs. compiled
- **general purpose language**
  vs. domain specific
- **shared nothing architecture**
  vs. shared everything

design space



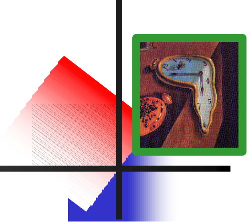
- interpreted execution

  vs. compiled

  pros:
  - runtime inspection, interrupts, debugging
  - simulation composition and configuration
  - reflection facilitates debugging

  cons:
  - rely on JIT for performance

design space



- general purpose language
  - vs. domain specific

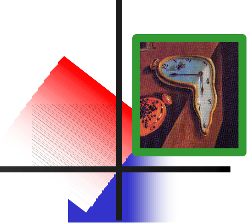
pros:

- credibility, code re-use
- general compiler advances
- familiarity, other software engineering arguments

cons:

- specific compiler optimizations

design space



- **shared nothing architecture**

  vs. shared everything

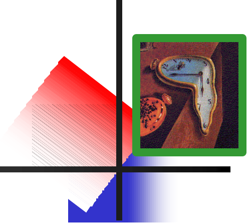
pros:

- **inexpensive (COTS)**
- **portable, simple**

cons:

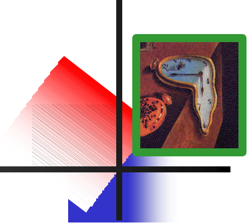
- **synchronization**
- **serialization**

existing MANET simulators



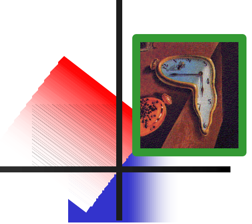
- ns2 is the gold standard
  - Tcl-based, with C++ bindings
  - used extensively within research community
  - initially developed for detailed TCP simulations
  - Monarch – modified to support ad hoc networks
  - processor and memory intensive, sequential
  - $O(n^3)$
  - max. ~ 250 nodes
- PDNS – parallel distributed ns2
  - perform event loop over Georgia Tech. RTI-KIT
  - requires fast inter-connect
  - helps with memory limits
- OPNet

existing MANET simulators



- Glomosim
  - written in Parsec, a custom C-like language
  - entities map to processes
    messages map to IPCs
  - "node aggregation"
    - imposes conservative parallelism
  - max. ~10,000 nodes
    - but on NUMA: Sun SPARCserver 1000, est. $300,000
- custom-made simulators
  - fast, specialized computation
  - lack sophisticated execution, parallelism
  - credibility

java in simulation time

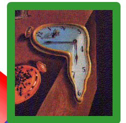


- Java-based simulation framework
- runs discrete event simulations
  - efficiently
    - in parallel
    - optimistically
  - transparently
    - simulations written in plain Java
    - compiled class files are modified at load time
- proof of concept
  - SWANS – Scalable Wireless Ad hoc Network Simulation
  - ideas not specific to Java

simulation time

- **program time**
  - progress of program independent of time
- **real time**
  - progress of program dependent on time
- **simulation time**
  - progress of time dependent on program
  - simulation event loop embedded in virtual machine
  - simulation time is advanced by the program

an example

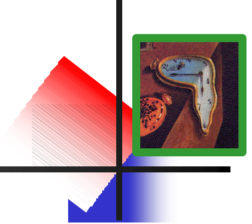


- the “hello world” of discrete event simulations

```
class MySim implements JistAPI.Entity
{
  private int data = 0;
  public void myEvent()
  {
    JistAPI.sleep(1);
    myEvent();
    System.out.println("myEvent, sim-time="+
        JistAPI.getTime()+" data="+(data++));
  }
}
```

- result: one event per time step

jist api



- **JistAPI class provides application `calls' to the JiST runtime**
- **permits standard Java compilation**

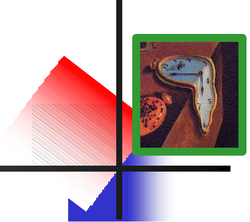
```
interface Entity              - tag object as entity

long getTime()                - return simulation time
void sleep(long t)            - advance simulation time

EntityRef THIS                - reference to this entity
EntityRef ref(Entity e)       - reference to entity
```

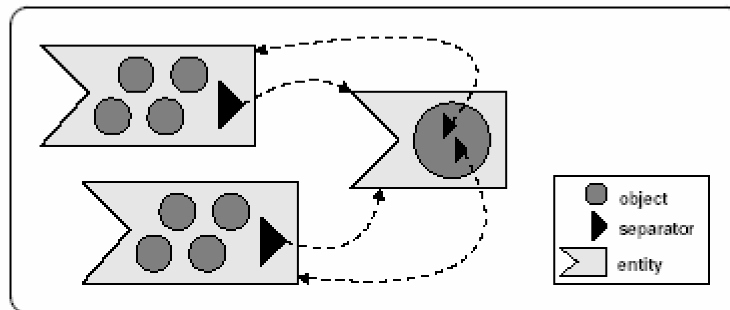
- **runs on standard Java VM**

entities and separators

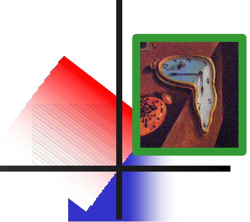


- **program state contained in objects**
- **objects partitioned into entities**
- **entities must not share state**
  - **live objects are referenced by exactly one entity**
- **therefore, each entity has its own entity time**

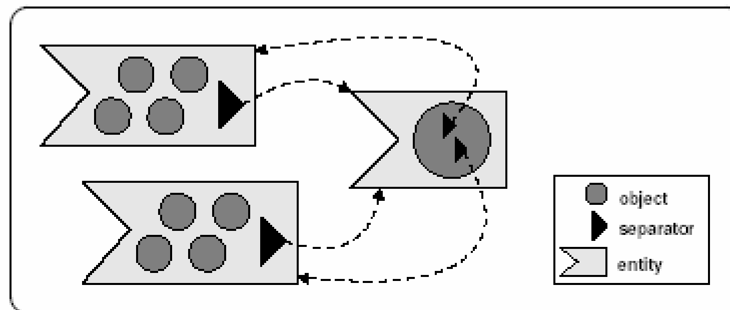
- **think, component interface...**



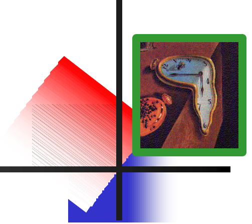
entities and separators



- separators (or entity references)
  - separate application state, application time
  - provide location independence
- method calls to entities
  - non-blocking
  - invoked at caller entity time
  - no continuation
    - neither return, nor exception

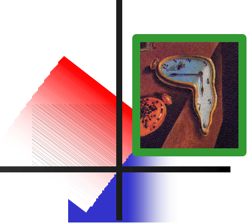


rewriting simulations



- dynamic class loader
  - no source code access
  - uses Apache Byte Code Engineering Library (BCEL)
  - ignores non-application packages
- steps
  - verification
  - add entity self reference
  - intercept entity state (field) access
  - add method stub fields
  - intercept entity invocations
  - modify entity creation
  - modify entity references
  - modify typed instructions
  - translate JiST API calls

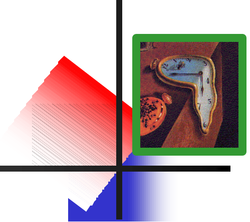
rewriting simulations



- **verification**
  - **entity state private and non-static**
  - **no native, abstract, non-static methods in entities**
  - **no continuations after entity invocations**
    - **entity methods should return void**
    - **exceptions escaping entities cause simulation failure**

```
public class MyEntity implements JistAPI.Entity
{
  public void event1(...) {
    ...
  }
}
```

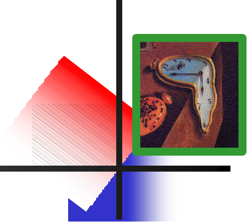
rewriting simulations



- **add entity self reference to entity**
  - **add self reference field**
  - **initialize self reference in constructor**
  - **implement `jist.runtime.Entity` interface**

```
class MyEntity implements JistAPI.Entity {
  private EntityRef _jistField__ref;
  public MyEntity(...)
  {
    super(...);
    this._jistField__ref =
      jist.runtime.Controller.registerEntity(this);
    ...
  }
}
```

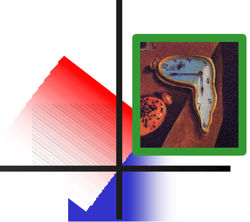
rewriting simulations



- intercept entity state (field) access
  - all entity fields made private
  - get and set accessor methods added for entity fields
  - `get/set-field/static` into method invocations

```
public class MyEntity implements JistAPI.Entity
{
   //public int i;
     private int i;
     public void _jistMethod_Set_i(int i) { this.i = i; }
     public int _jistMethod_Get_i() { return i; }
}
```

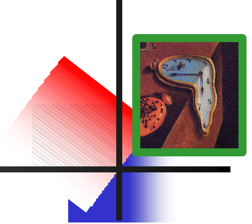
rewriting simulations



- **add entity method stub fields to entity**
  - **statically initialized**

```
class MyEntity implements JistAPI.Entity
{
  public void myEvent(...) { ... }
  public static Method _jistMethodStub_myEvent$signature$;
  static
  {
    jist.runtime.Rewriter.MethodStubInit("MyEntity");
  }
}
```

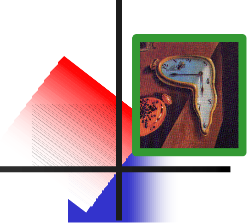
rewriting simulations



- intercept entity invocations
  - convert into method call to JiST runtime
  - pack arguments into object array (type safety)
  - pass correct method stub instance and entity instance

```
...
//myentity.event1(1, "foo");
jist.runtime.Controller.entityInvocation(
  MyEntity._jistMethodStub_event1$28ILjava$2elang$2eString$3b$29V,
  myentity,
  new Object {
    new Integer(1),
    "foo"
  });
...
```

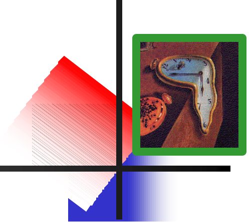
rewriting simulations



- **modify entity creation**
  - **creates a new entity**
  - **returns entity reference to new entity**

```
...
//MyEntity f = new MyEntity(...);
  EntityRef f = (new MyEntity(...))._jistField__ref
...
```

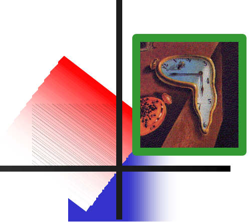
rewriting simulations



- modify entity references
  - field entity types
  - method parameter entity types
  - method return entity types

```
public class MyEntity implements JistAPI.Entity
{
  //public SomeEntity entity;
    public EntityRef entity2
  //public void event(SomeEntity e, int i) {
    public void event(EntityRef e, int i) {
      ...
    }
}
```

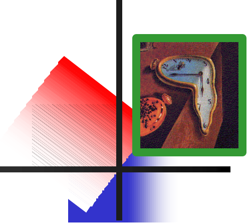
rewriting simulations



- **modify typed instructions**
  - **type casts**
- **translate JiST API calls**
  - `sleep(),getTime(),THIS,ref()`

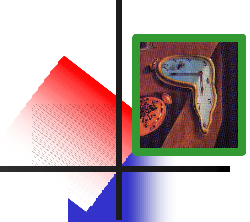
```
class MySim implements JistAPI.Entity {
 //public void myEvent(MySim sim) {
   public void myEvent(EntityRef sim) {
   //JistAPI.sleep(1);
     JistAPI_Impl.sleep(1);
     if ( JistAPI_Impl.getTime() < 100 )
       //sim.myEvent((MySim)JistAPI.THIS));
         sim.myEvent((EntityRef)JistAPI_Impl.getTHIS());
     System.out.println("myEvent, time="+
     JistAPI_Impl.getTime());
   }
}
```

benefits of rewriting approach



- standard Java compilation
- standard Java Virtual Machine
- no source code access required
- retains type-safety properties
- rewriting occurs once, at load time
- partitioning of application state into entities
- location independence of entities
- event loop embedded into virtual machine
- transparent parallel and optimistic execution
- dynamic and interpreted environment
  - yet, efficient…

benefits of rewriting approach



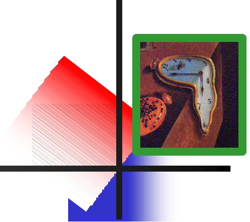
- micro-benchmark of event throughput
  - includes garbage collection
  - includes event scheduling
  - includes message passing
  - … still preliminary!

```
class MySim implements JistAPI.Entity
{
  private int data = 0;
  public void myEvent()
  {
    JistAPI.sleep(1);
    myEvent();
    System.out.println("myEvent, \
         sim-time="+JistAPI.getTime()+
         " data="+(data++));
  }
}
```

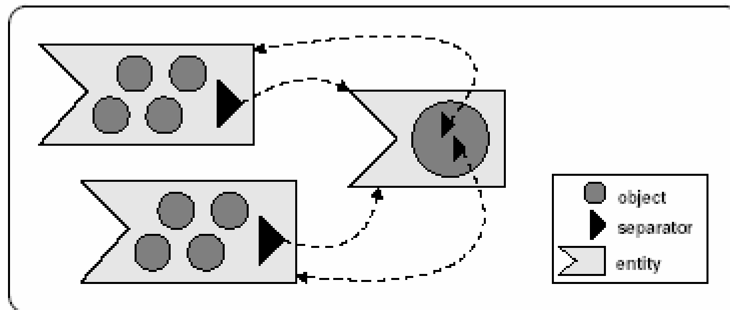
# events	JiST	GlomoSim	Ratio
10^5	0.22s	0.48s	45%
10^6	1.44s	3.18s	45%
10^7	13.55s	30.46s	44%
10^8	130.6s	292.5s	45%

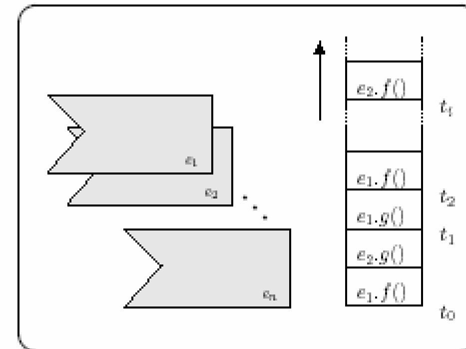
serial throughput increase of 2.2x

serial simulation time



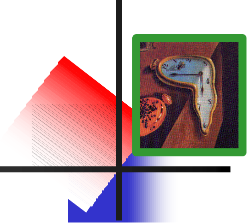
- program state in objects
- objects partitioned among entities
- separators of state, time
- serial execution





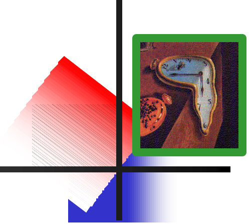
- inject orthogonal code
    - inspection, node mobility, debugging

current status



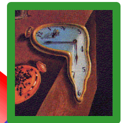
- rewriter working
- simulation infrastructure working
  - serial execution
- building swans
  - designing physical layer
- parallelization
- optimistic execution
  - check-pointing and undo
  - bounding, load balancing

coming soon: a real application

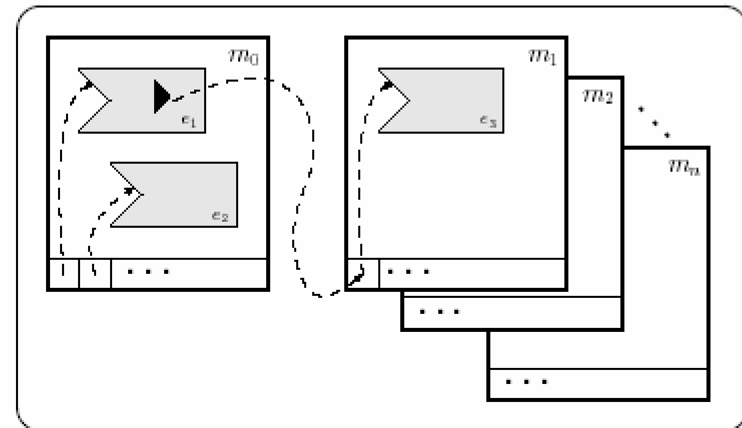


- **SWANS**
  - **Scalable Wireless Ad hoc Network Simulator**
- **implement**
  - **physical: propagation, reception**
  - **link: 802.11b**
  - **routing: DSR or ZRP**
  - **application: CBR**
  - **mobility model**

coming soon: parallel simulation time

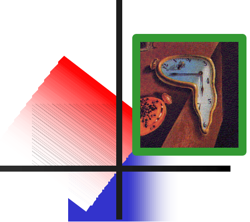


- **lock-step in simulation time**
  - **concurrent events**
  - **conservative**
- **separators**
  - **location-independence**
  - **entity tracking**

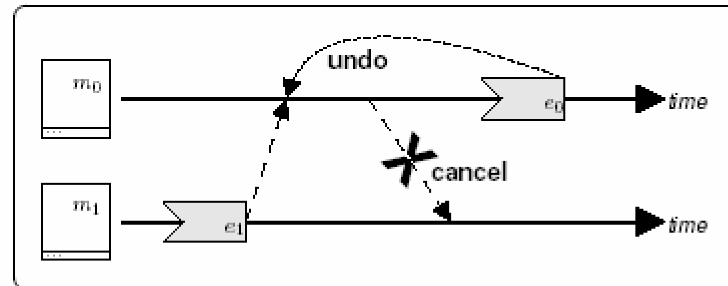


- **balance load**
- **minimize network overhead**

coming soon: optimistic simulation time

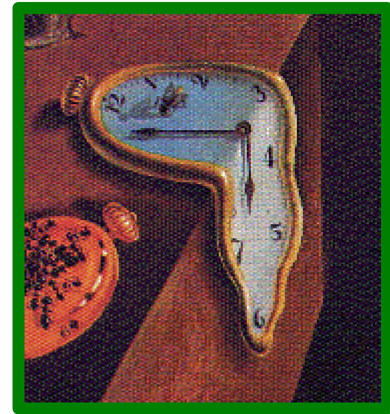


- checkpoint entities
- cascade undo
  - cancellation
  - propagation



- rollback interface
  - automatic rollback method generation
- balance forward progress of time

JIST:
Java In Simulation Time



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Thank you.

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