Distributed simulation of situated multi-agent systems

Franco Cicirelli, Andrea Giordano, Libero Nigro

Laboratorio di Ingegneria del Software
http://www.lis.deis.unical.it

Dipartimento di Elettronica Informatica e Sistemistica
Università della Calabria
87036 Rende (CS) – Italy

{f.cicirelli,a.giordano}@deis.unical.it, l.nigro@unical.it

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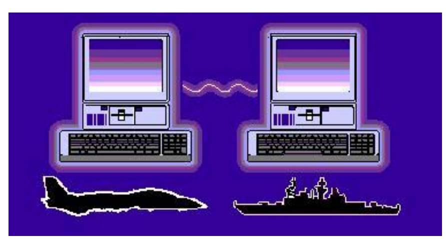
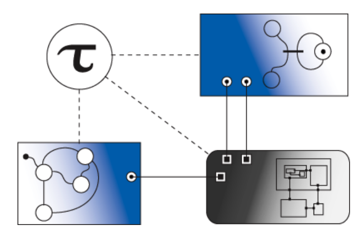




Goal

- proposing an approach and supporting framework, for **modelling and distributed simulation** of complex **situated multi-agent systems**

Presentation Outline

- **introducing** situated agents
- **discussing** distributed-simulation of situated agents
- **describing** the proposed approach and the developed framework
- **showing** achievable performance by means of a **TileWorld**-based simulation model

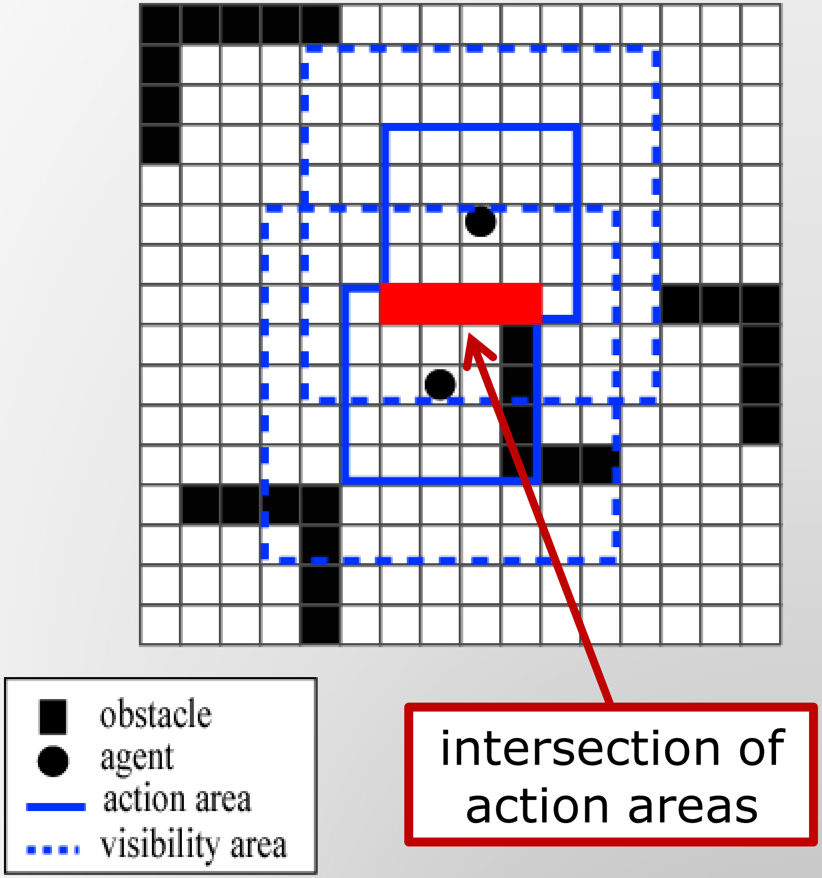
Situated agents

- are characterized by being **embedded** in a spatial **environment** (or **territory**) and by owning spatial **coordinates**
- their behaviour is strongly influenced by the owned position into the environment
- are able to **move on**, **perceive** and **act-upon** the territory
- **emerging properties** of modelled systems may arise by agent-to-agent or agent-to-environment interactions

Distributed simulation of situated agents

- situated agents are widely adopted for studying a broad range of phenomena and systems (e.g. in **biology**, **sociology**, **wildfires**)
- distributed simulation is often mandatory to cope with the **high resource demand** (both in terms of time and space) of such large models
- in a distributed context the environment becomes a **huge shared variable** of a **concurrent system**
- suitable environment **partitioning-schemas** and **approaches** regulating the access to the environmental data are required (e.g. for load balancing, data consistency, performance)

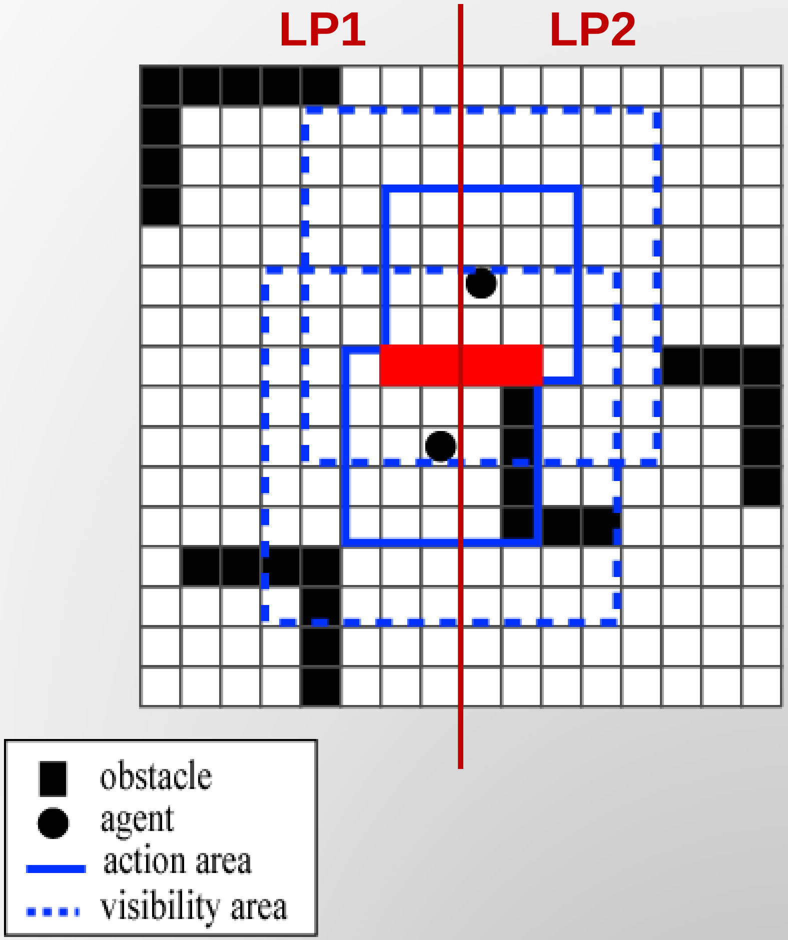
Distributing the environment (1)



A first scenario:

- the territory is modelled as a bi-dimensional grid
- limited sensing/control capabilities
- a hypothesis:
  - each cell may host at most one agent (a conflict occurs otherwise)
- sequential simulation and cooperative concurrency

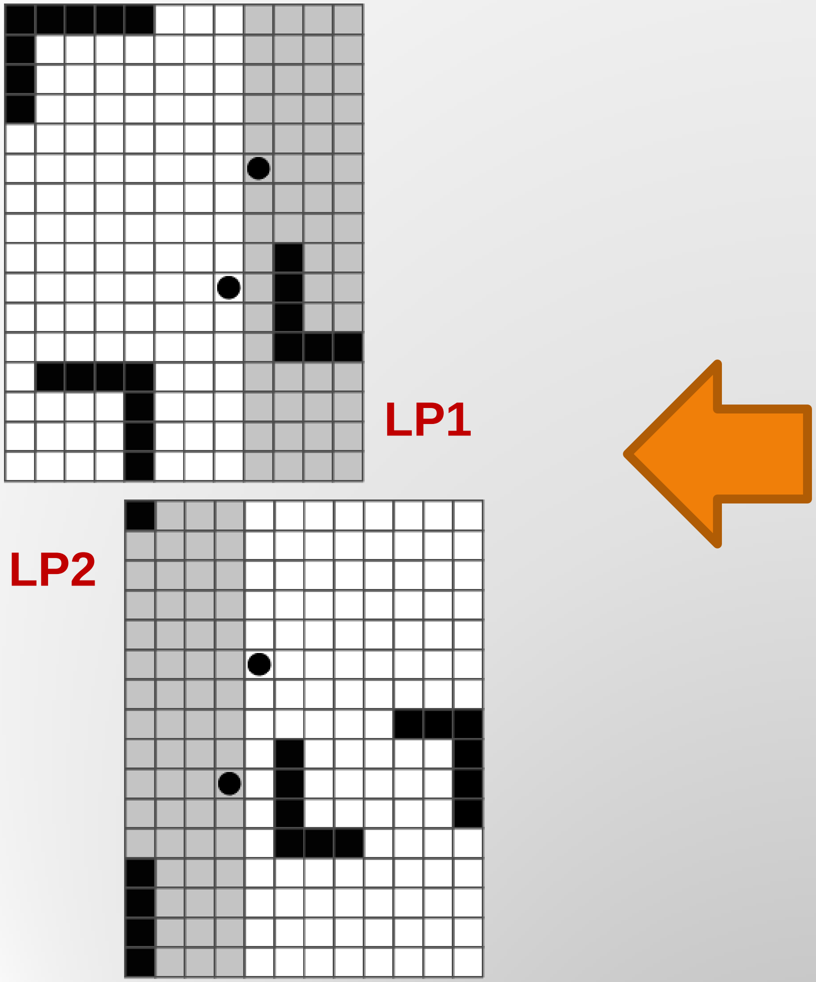
Distributing the environment (2)



A second scenario:

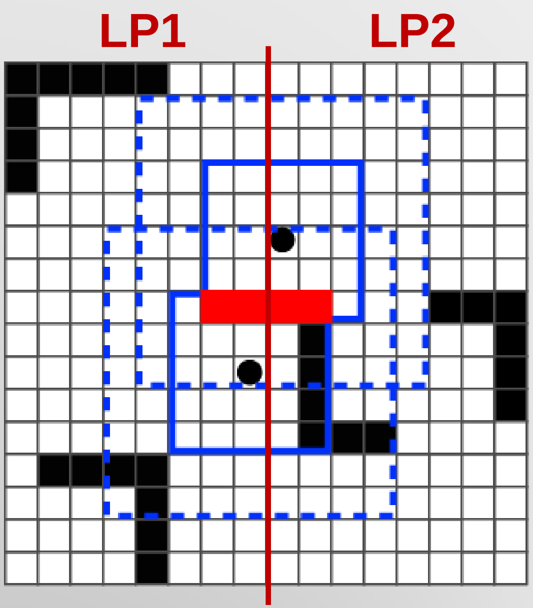
- distributed simulation (2 LPs)
- territory and agent population are split
- conflicts occur on red highlighted cells (real parallelism)
- remote communication is required between LPs

Distributing the environment: a solution (1)



Reducing remote communication:

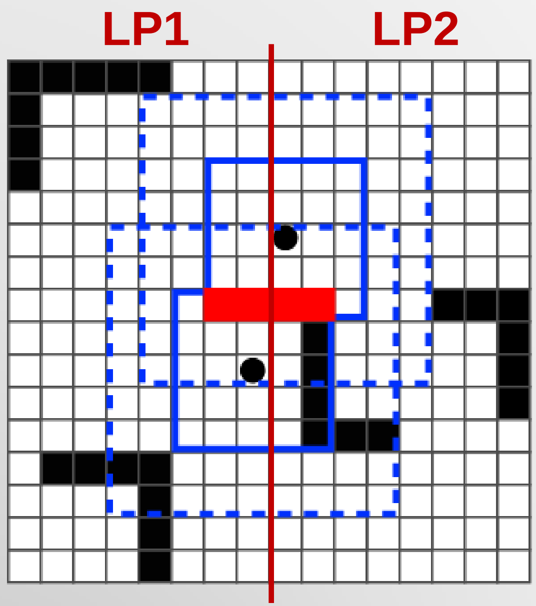
- border areas are replicated (gray parts)
- their size depend on visibility radius



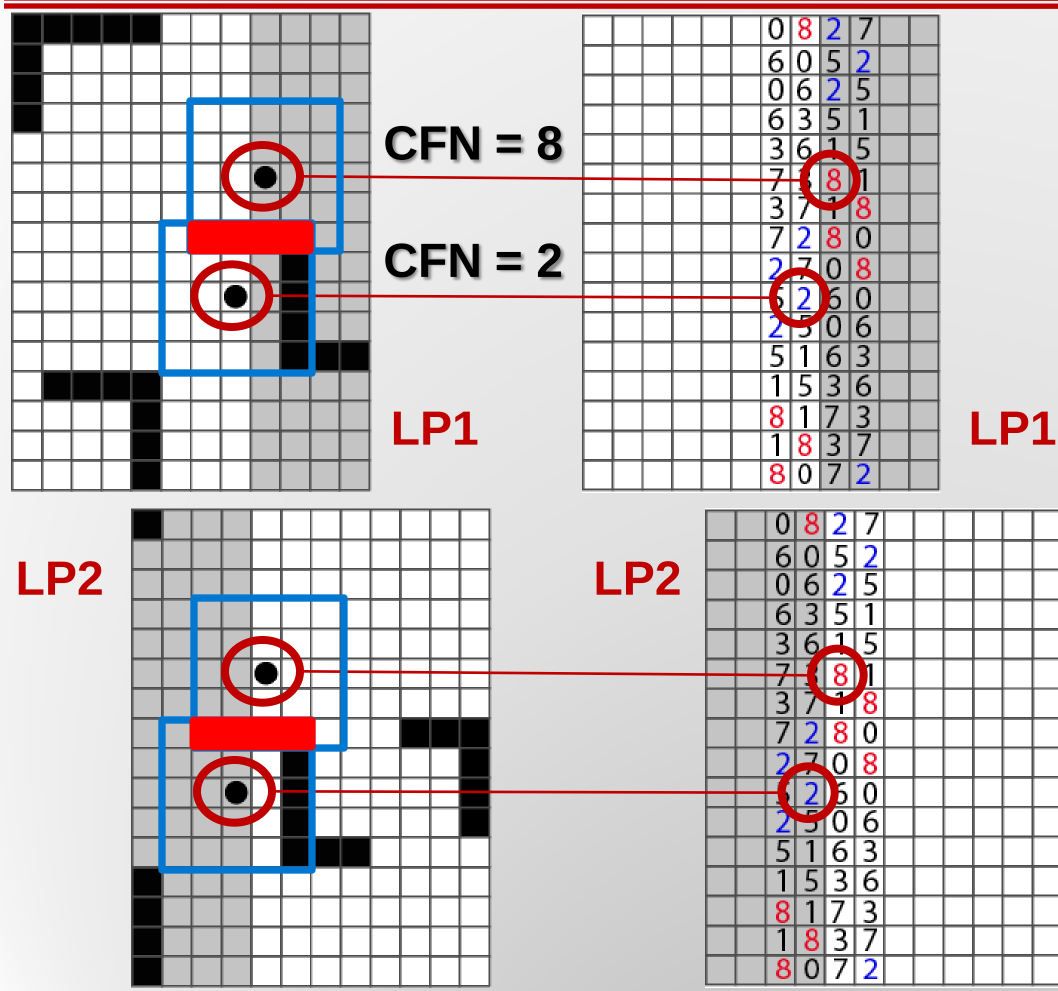
Distributing the environment: a solution (2)

Avoiding conflicts:

- a *Conflict Free* execution order is enforced among agents residing on different LPs
- conflicting agents are not allowed to act concurrently
- no control messages are exchanged among LPs
- no locks are used



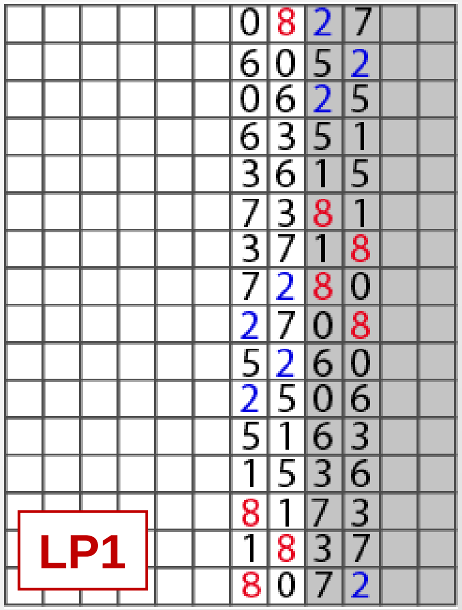
Distributing the environment: a solution (3)



Avoiding conflicts:

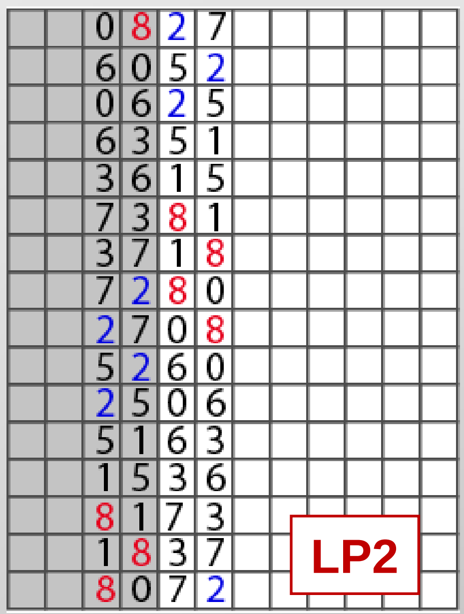
- Cells on border areas are tagged with *Conflict Free Numbers* (**CFNs**)
- two agents which are distant less than or equal to **2*actionradius** and belong to different LPs must be flagged with a different CFN
- CFNs are used to define a **conflict free execution order** among agents
- agents on different LPs having the same CFNs can really **act in parallel**
- tagging schema depend on action radius

Distributing the environment: a solution (4)



Avoiding conflicts:

- a **repetitive pattern**, favouring CFN reuse**,** is used (**shuffled** from time to time)
- CFN reuse favours parallelism



- the assigning algorithm scans the border area from **top to bottom** and from **left to right**
- the same assignment (despite shuffling) is made by two neighbouring LPs without requiring any interaction by using the current logical time as the **seed** for the pseudo random number generators

Enforcing the *conflict-free* execution order: the *composite logical time* (CLT)

< --------------- CLT -------------- >

[Virtual time | Epoch | CFN | Step]

- Virtual time: is the virtual time from the model point of view
- Epoch: manages multiple events at the same virtual time
- CFN: for conflict resolution
- Step: used to handle updates and agent migrations

- every time an event (message) is ready to be dispatched, its actual delivery occurs at a time which take into account the CFN of the receiving agent
- actions triggered by such event cannot cause conflicts

Distributing the environment: a solution (5)

proposed approach

territory and agent population are split among various LPs

each territory portion is called ***region***

the edge portions of adjacent regions (***borders***) are mirrored among LPs and kept updated

action and ***visibility*** radii are introduced (***neighborhood***)

such radii delimit the area within which an agent can **efficiently read** and **change** the status of the immediate surrounding territory

conflict resolution and data consistency rely on a ***composite logical time*** notion which makes use of CFN

migration is required when an agent moves among regions

Distributing the environment: the supporting framework

realized framework

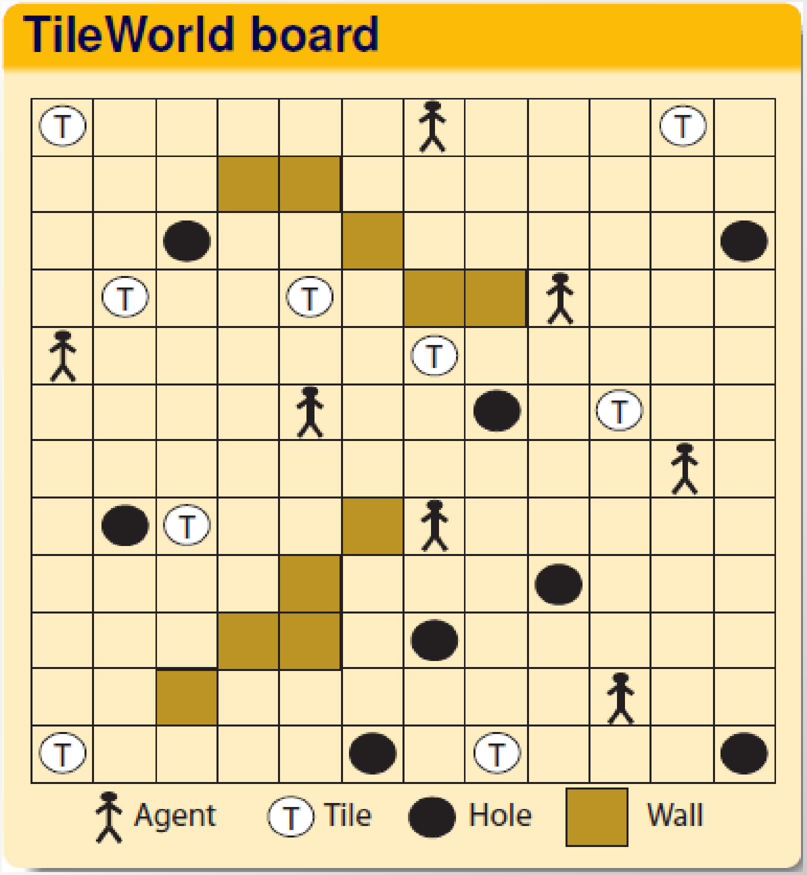
- is added into the **Theatre** multi-agent architecture
- relies on a lightweight ***actor*** model of computation
- promotes the environment as ***first-class entity*** (ActorEnv)
- allows the sharing of agent state
- within the agent ***neighborhood***, it permits ***synchronous*** access to the environment (asynchronous otherwise)
- simplifies M&S tasks by making the modeller ***unaware*** of distribution concerns

The supporting framework: the Neighborhood interface

```
Neighbourhood n = ActorEnv.getMyNeighbourhood();
```

```
Actor createAndLocate(String actClass, Position p);
void moveActor(Actor act, Position p);
void removeActor(Actor act);
List<Actor> getCell(Position p, Class actClass);
boolean isCellEmpty(Position p);
List<Actor> getActors(Class actClass);
Position getPosition(Actor act);
void addShared(String name, Class type);
<T> T getShared(String name, Class<T> type, Actor act);
<T> void setShared(String name, Class<T> type, T value, Actor
act);
```

A TileWorld Model as testbed



- agent's mission: move around to find and pick-up a tile and then move to fill an hole and so forth until no more tiles exist
- an hole is characterized by its depth
- holes and tiles may appear and disappear dynamically
- different game configurations with a huge number of randomly placed TileWorldActor(s), TileActor(s), HoleActor(s), and static obstacles, were experimented
- different values for the action and visibility radii were considered
- *the goal was not to compare agent strategies but only to check the achievable simulation performance*

A code excerpt of the TileWorldActor

```
//status MOVE_TO_HOLE
Neighbourhood n = ActorEnv.getMyNeighbourhood();
if( n.getShared("visible",Boolean.class,this.foundHole) ){
           nextPosition = makeAStepTowardAHole(this.foundHole);
           if (nextPosition.isReached( n.getPosition(this.foundHole) )){//fill the hole
           int d = n.getShared("depth",Integer.Class,this.foundHole);
           n.setShared("depth",Integer.Class,d-1,this.foundHole);
           if (n.getShared("depth",Integer.Class,this.foundHole)==0){
                      n.setShared("visible",Booelan.Class,false,this.foundHole);
                      this.score += n.getShared("score",Double.Class,this.foundHole);
                      become(LOOK_FOR_TILE);//change status}
      }else
           if (!n.getCell(nextPosition,ObstacleActor.class).isEmpty())
                      nextPosition = changeDirection();//avoid the obstacle
      n.moveActor(this,nextPosition);
}else{//Explore
           this.foundHole = null;
           for(HoleActor a:n.getActors(HoleActor.class))
           if (n.getShared("visible",Boolean.class,a)){
                      this.foundHole = a;
                      nextPosition = makeAStepTowardAHole(this.foundHole);
                      n.moveActor(this,nextPosition);
                      break;}
           if (this.foundHole == null)
           become(LOOK_FOR_HOLE);//change status
}
```

access to neighbourhood

manage shared state

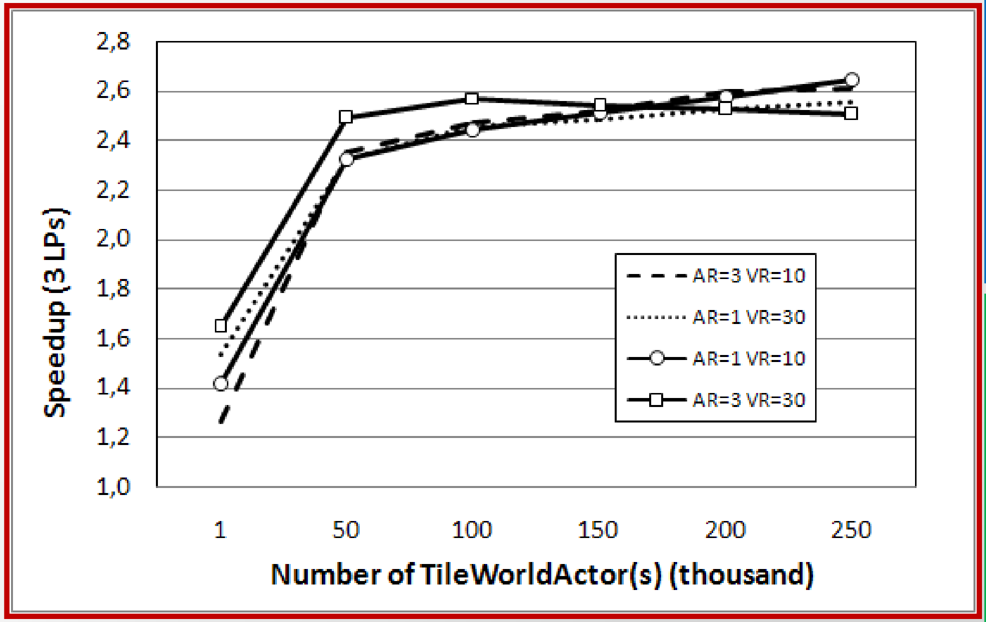
move on the territory

explore the territory

distribution aspects and conflict management are completely hidden

Speedup vs. TileWorldActors (variable load)

1



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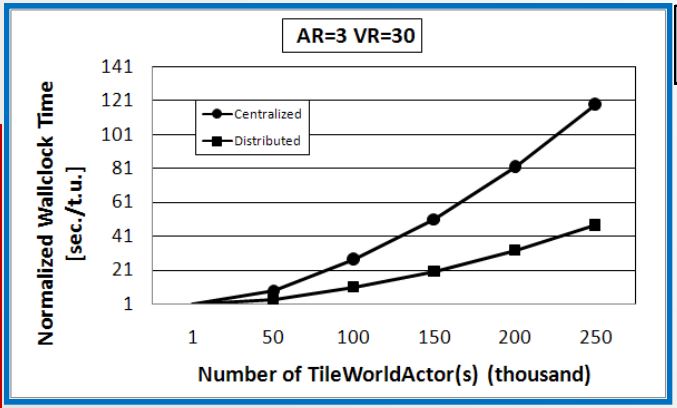

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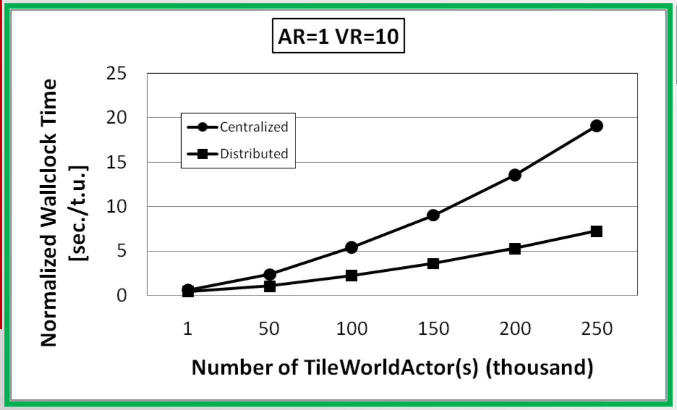
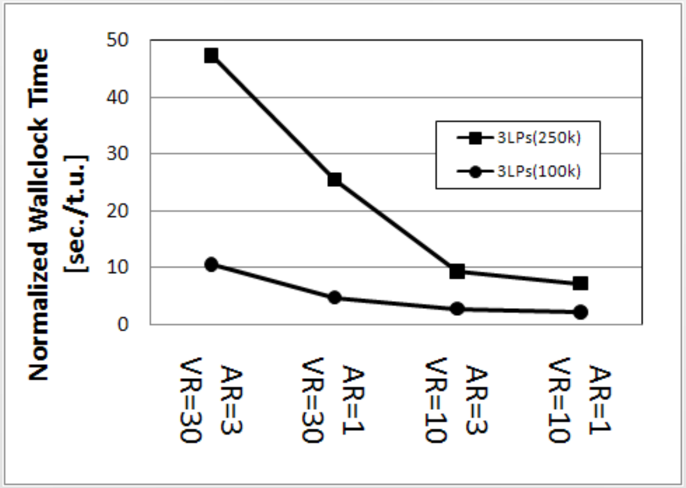


- three LPs/federates allocated on three WinXP (32 bit) Intel i7 CPU 960, 1-core, 3.20 GHz, 3GB RAM, interconnected by a Gigabit Ethernet switch in the presence of HLA pRTI 1516
- each federate hosts a region composed of 1200x900 cells (overall territory is 1200x2700 cells)

The *variable-load* scenario: is it appropriate?

1



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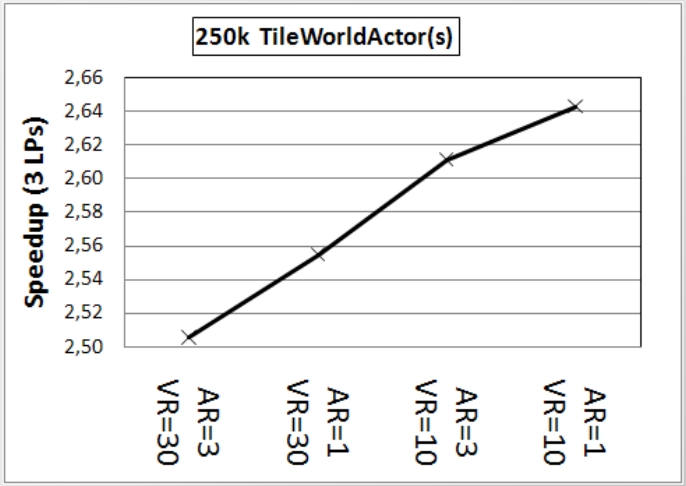

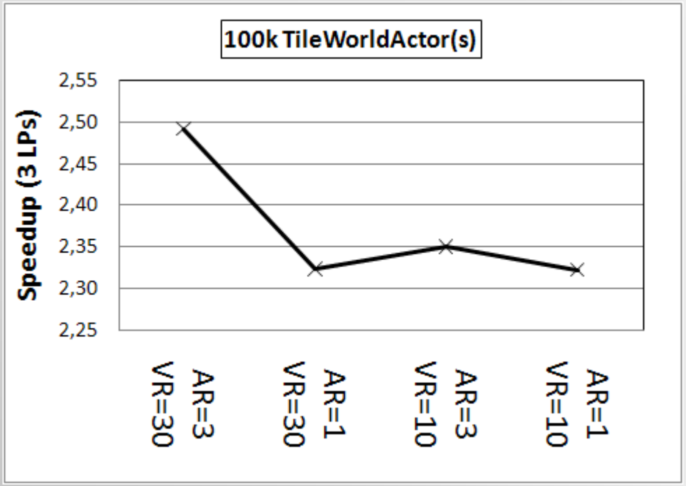

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Speedup vs. Action and Visibility radii (constant load)

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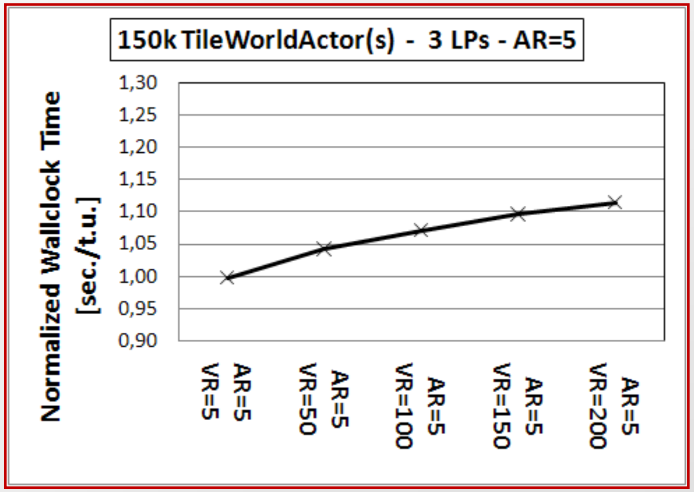

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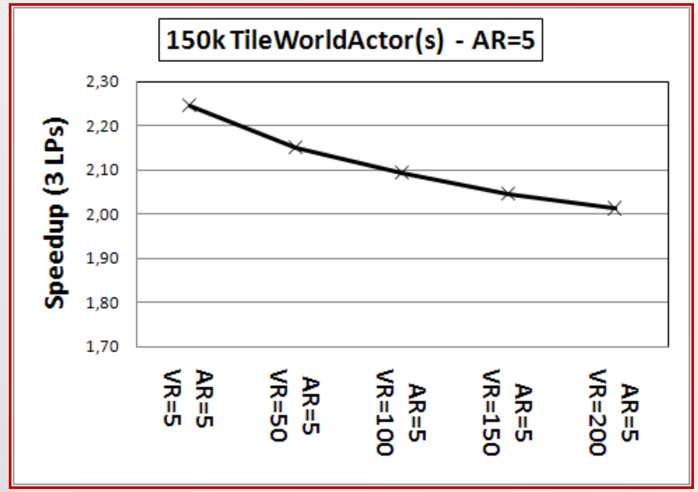

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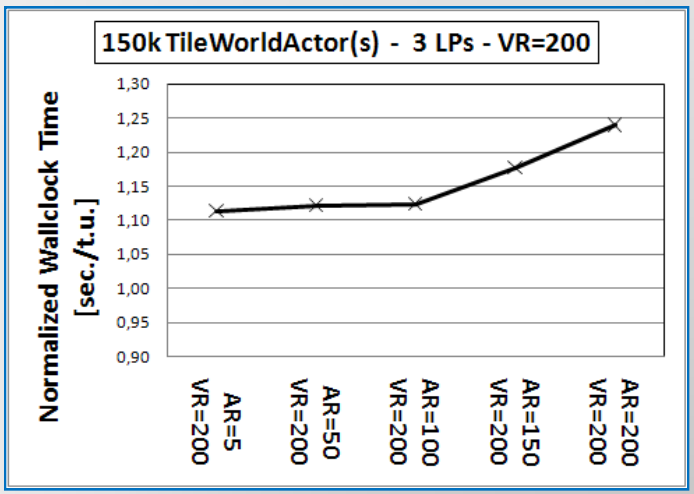

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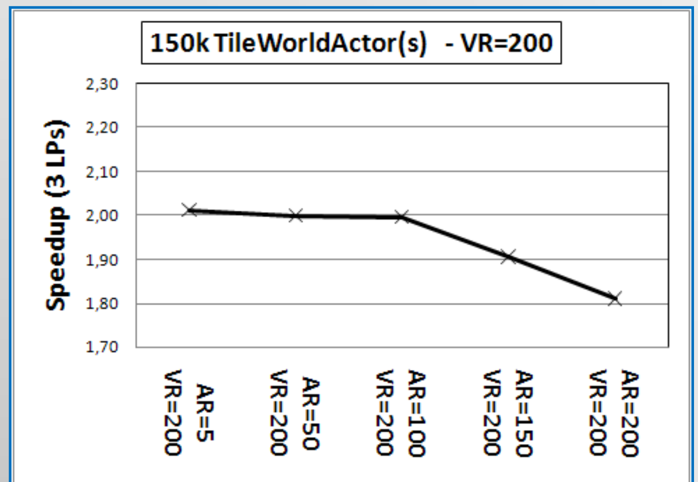

On-going and future work

- experimenting with the use of the infrastructure in large and highly dynamic systems (e.g. inspired by biology or social science)
- improving the ActorEnv interface (e.g. by allowing a more fine grained read/write control on shared data and by providing a more complex pattern-matching schema for neighbourhood exploration)
- specializing the approach so as to exploit the potential of modern multi-core hardware
- generalizing territory management (e.g. toward hexagonal space cells, continuous spaces, diffusive spaces and n-dimensional spaces)