Supporting the Design of Self-Organizing Ambient Intelligent Systems Through Agent-Based Simulation

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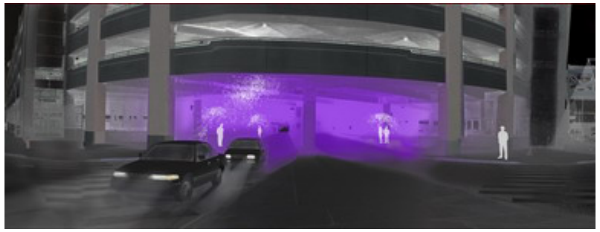
WOA08 - 18/11/08

Introduction

- This work is about the design and realization of an *adaptive illumination facility*, that is being designed and realized by the Acconci Studio in Indianapolis
- In particular the adopted approach employs *Cellular Automata* as a model supporting self-organization among cells comprising sensors and actuators
- We realized a *simulator* (agent-based) to envision the dynamic behaviour of the proposed approach and to support the tuning of the self-organization model before actually implementing the physical infrastructure



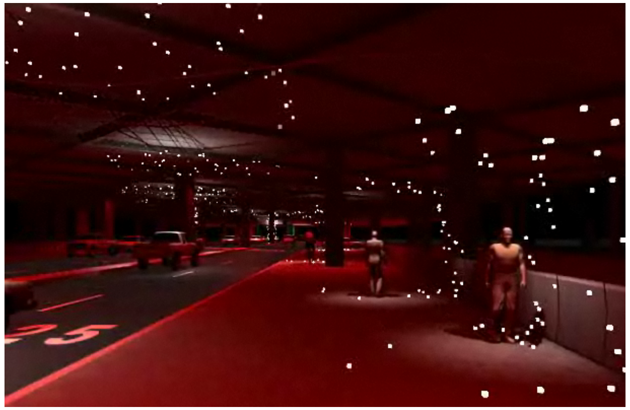
Pictures appear courtesy of the Acconci Studio (http://www.acconci.com)

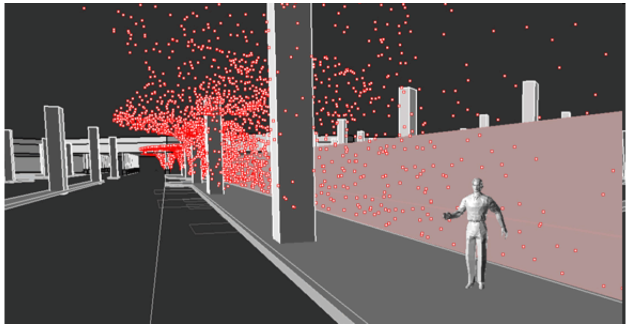
Scenario

- The Acconci Studio is involved in a project for the renovation of the Virgina Avenue Garage in Indianapolis; the planned renovation for the tunnel comprises a *dynamic lighting facility*

- Some of the lights should behave like a *'swarm of bees'* that follow a pedestrians, cars and bike riders

- In this way the lights behave like a *personal illuminator* through the tunnel





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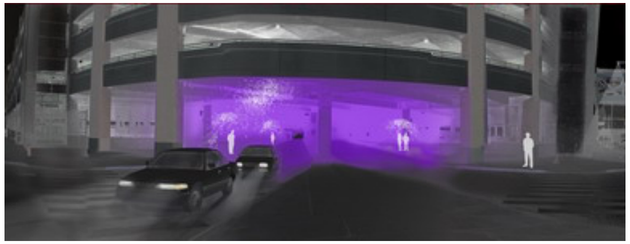
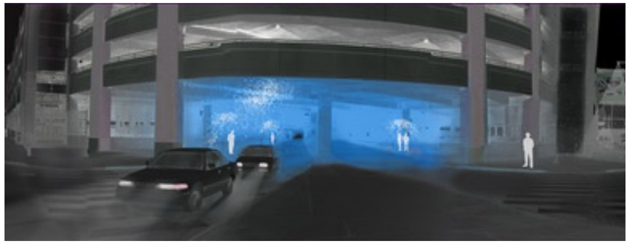
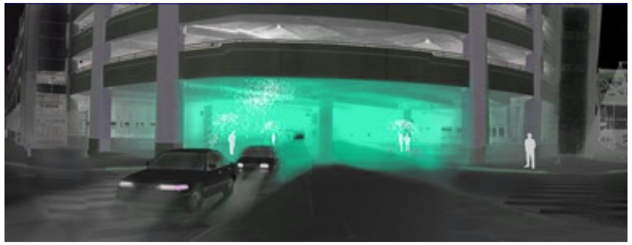
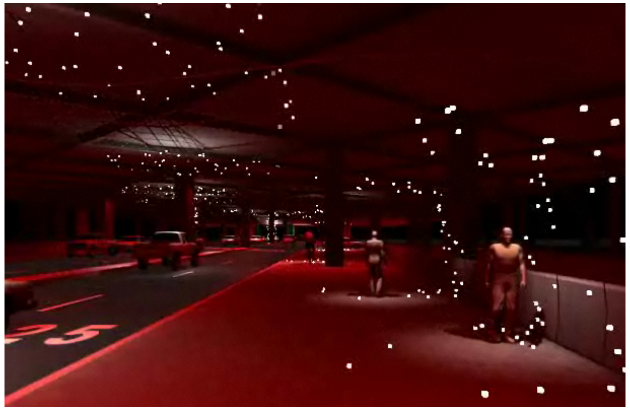
Scenario

- The desired adaptive environment comprises two main effects of illumination:
  - an overall effect of *uniformly coloring* the environment through a background, ambient light changing through time, but slowly with respect to the movements and immediate perceptions of people passing in the tunnel
  - a *local effect of illumination* immediately reacting to the presence of pedestrians, bicycles, cars and other physical entities
- The first effect can be achieved in a relatively simple and centralized way, requiring in fact a *uniform type* of illumination that has a *slow dynamic*
- The second requires a different view on the illumination facility:
  - it must *perceive* the presence of pedestrians, in other words it must be endowed with sensors
  - it must exhibit *local changes* as a reaction to the outputs of the aforementioned sensors, providing for a *non uniform* component to the overall illumination









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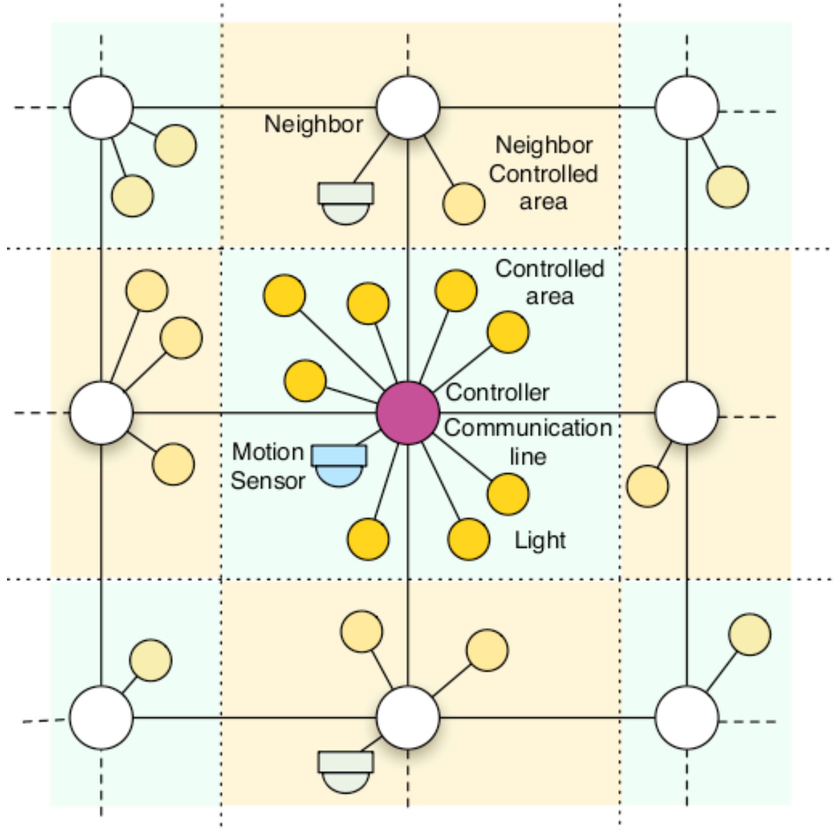
The Proposed Approach

- We proposed the adoption of *distributed control system* composed of a set of controllers distributed throughout the system
- Each controller has the responsibility of a part (*a portion of space*) of the whole system
- The controllers must be able to *interact*, to influence one another to achieve more complex illumination effects than just providing a spotlight on the occupied positions

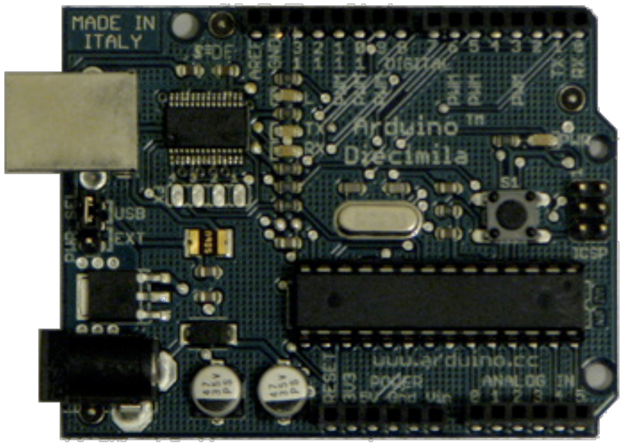


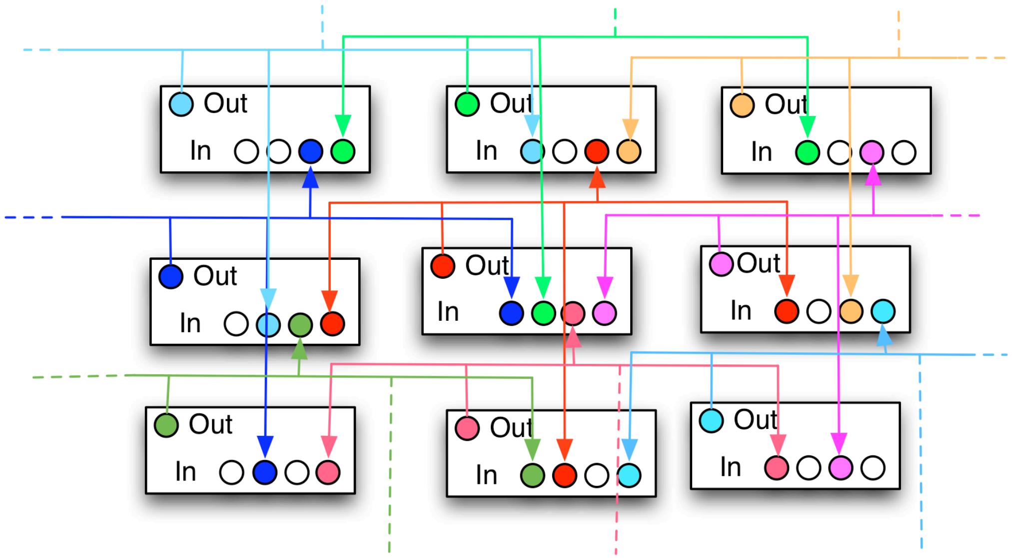
The distributed control system architecture

Sample Hardware for a Controller

- ATmega 168
  - 16Mhz 8 bit micro-controller
  - 1Kb data memory
  - 16Kb program memory
  - 14 IN/OUT Lines
  - 6 Analog IN/OUT Lines
- 40 Leds
- 1 Passive IR Motion Sensor

Arduino Diecimila board





Connections between the microcontrollers

The Self-Organization Model

- Physical environment as an *assembly of local subsystems* arranged in a network
- Each subsystem is able to *regulate its own state* according to a local stimulus and according to the *influences of neighbours*

→ *Cellular Automata* can be a suitable model to represent the described the illumination facility and its dynamic behaviour

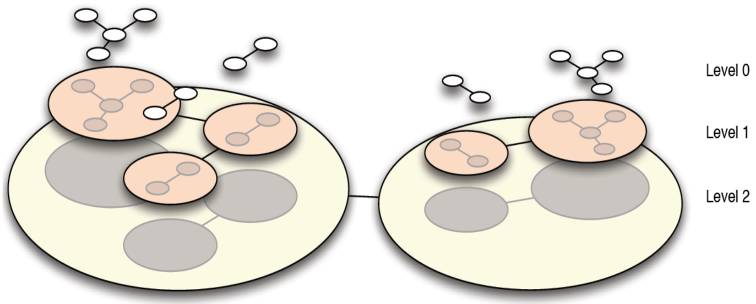
Cellular Automata

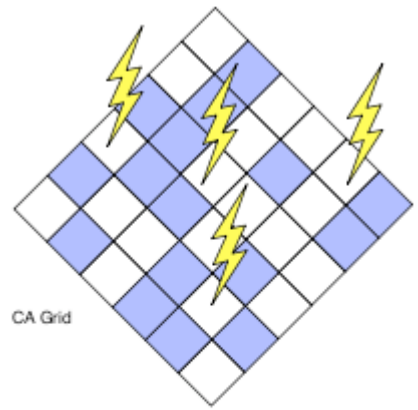
Multilayered Automata Network

Dissipative Cellular Automata

The Model

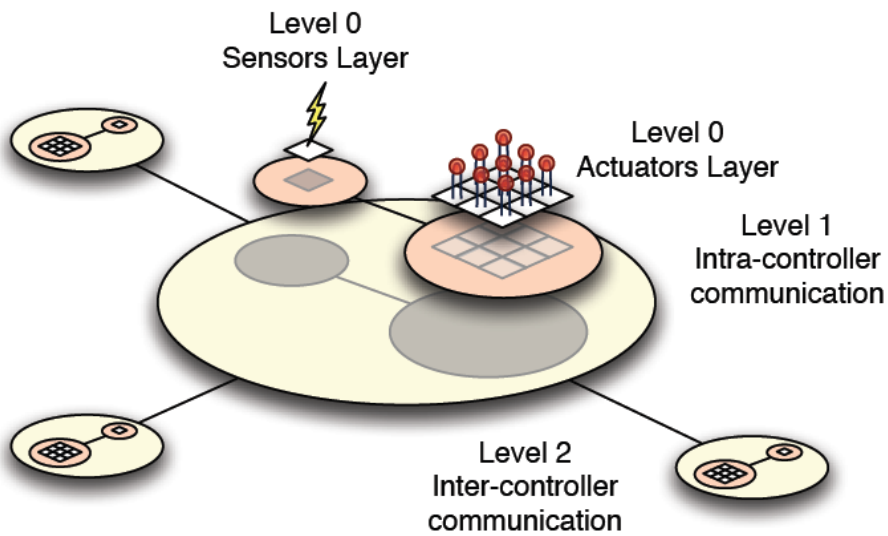
- *Automata Networks* are CA with an "irregular" structure; *Multilayered Automata Networks* are *hierarchical structures,* nested graphs in which nodes are Automata Networks
- *Dissipative Cellular Automata (DCA)* are *open* and asynchronous CA; their cells are characterized by a thread of control of their own, autonomously managing the elaboration of the local cell state transition rule
- In order to take advantages of both these models, we introduced a new class of automata called *Dissipative Multilayered Automata Network (D-MAN)*
- Informally, D-MAN as Multilayered Automata Network in which the cells update their state in an asynchronous way and they are open to influences by the external environment





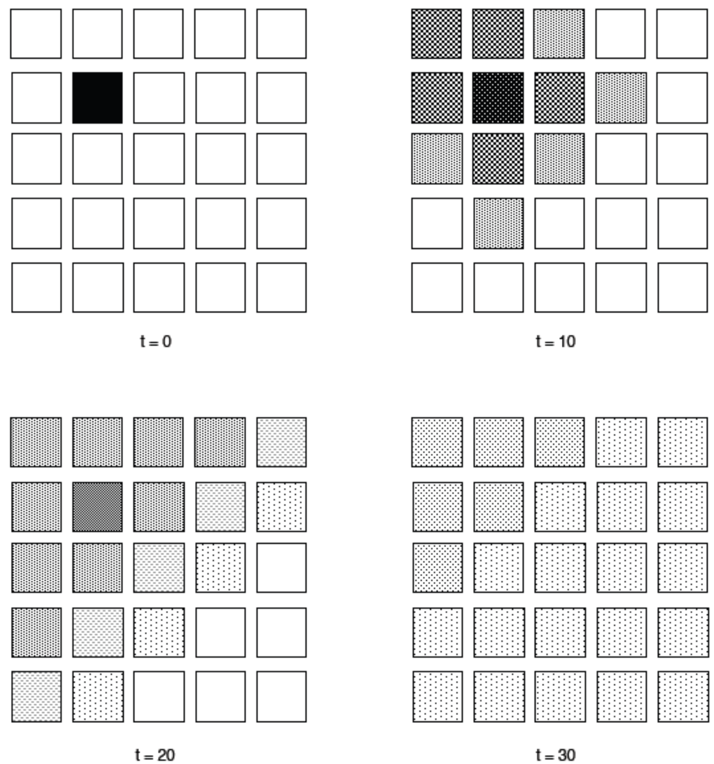
The Network Structure

- Every controller is mapped to and manages an automata network of *two nodes*
  - one node is a *sensor communication layer* and it represents a space in which every sensor connected to the microcontroller has a correspondent cell
  - The other node represents the *actuators' layer* in which the cells pilot the actuators (lights, in our case)
- In our case, the sensor layer contains just one cell (i.e. sensor) and the actuators' layer contains 9 cells (i.e. lights)



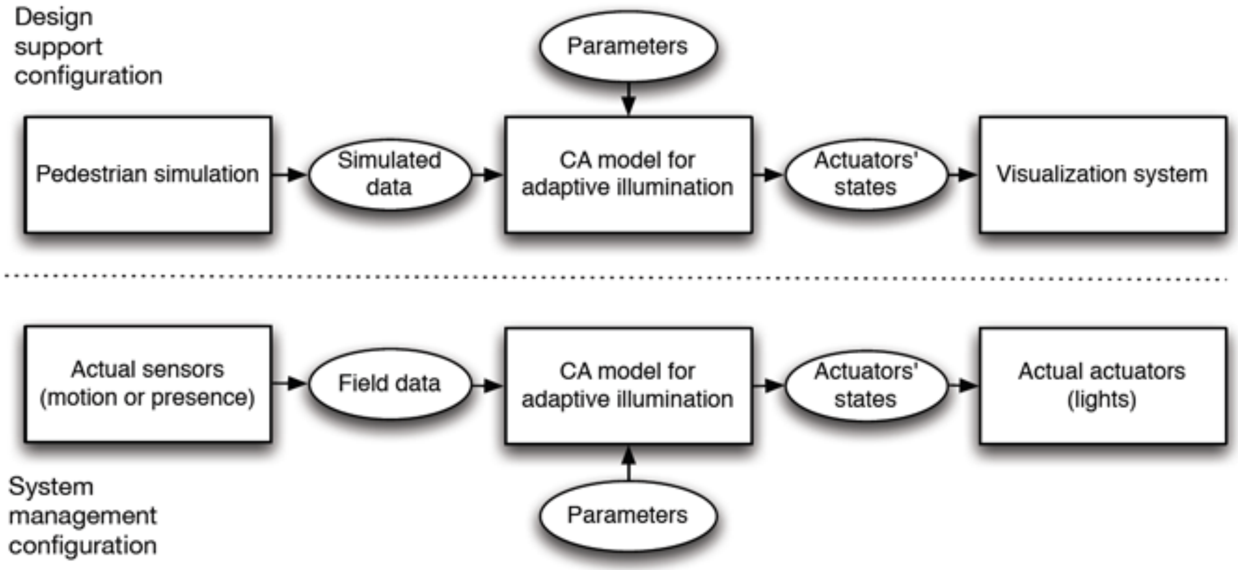
The Diffusion Rule

- At a given time, every *level 2* (intra-controller layer) cell is characterized by an *activation intensity* of the signal, *v*
- Informally, the value of *v* at time *t + 1* depends on
  - the value of *v* at time *t* (*memory*)
  - the activation intensity of neighbours (*diffusion*)
  - the state of the motion sensor (*external stimulus*)
- The intensity of the signal decreases over time, in a process called evaporation
- The *state of actuators* is derived by the activation intensity of the level 2 cell



An example of the dynamic behaviour of a diffusion operation. The signal intensity is spread throughout the lattice, leading to a uniform value; the total signal intensity remains stable through time, since evaporation was not considered

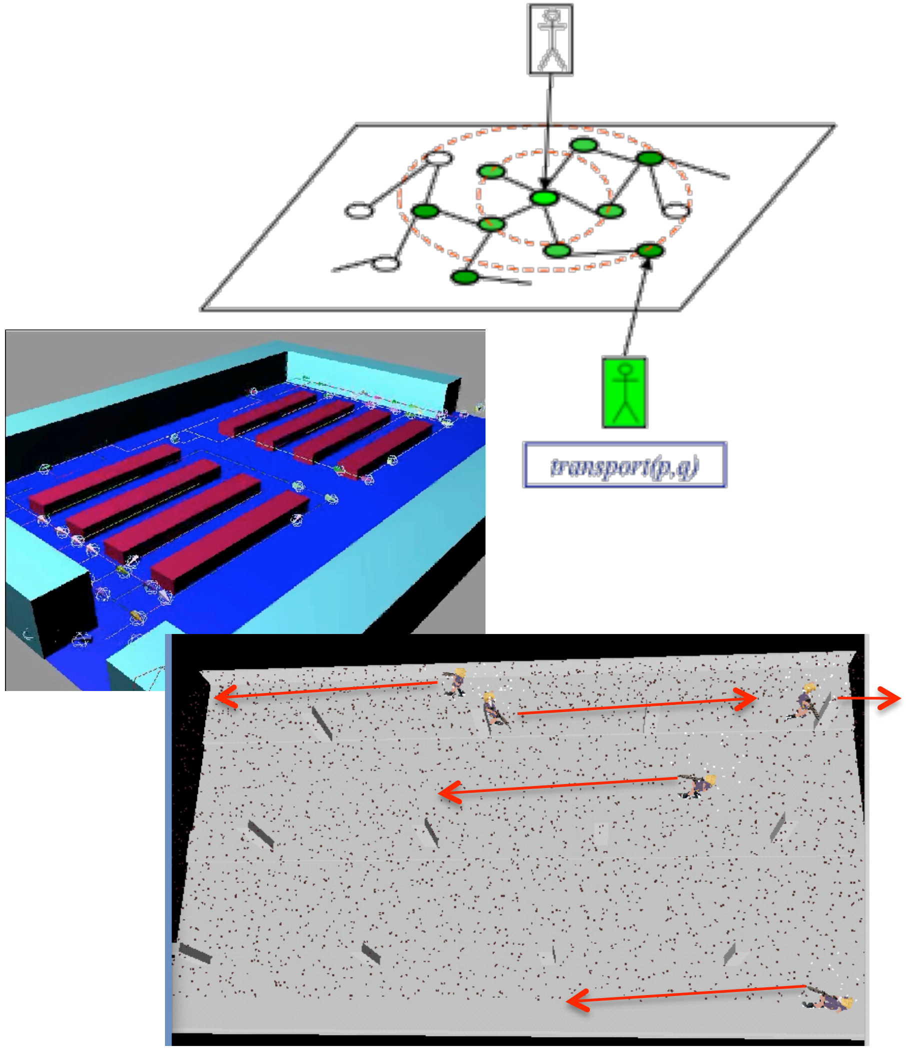
Simulation Supported Design Environment



- In theory, the described model can represent a suitable self-organization "engine"…
- … but *does it really work*?
- … and how do I select values for the significant *parameters* (not only for the CA model, but also for the illumination facility in general)?
- The model can be *tested in silico*, before actually implementing it, by feeding it with *simulated data* about the movement of pedestrians (and other vehicles) in the tunnel

Pedestrian Simulation Model

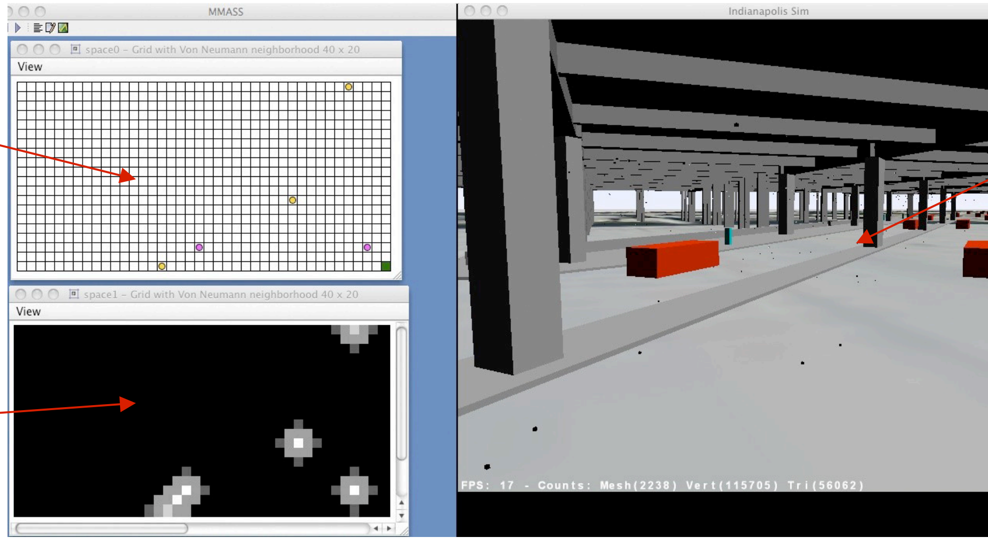
- The pedestrians (and vehicles) simulation model is *based on MMASS*
- Previously adopted for various simulation scenarios, in particular for modeling *crowds of pedestrians*
- Very simple scenario
  - Two *types of agents*, respectively heading towards the two exits of the environment
  - Obstacle avoidance through *lane change* in random side
  - Collision avoidance (with other pedestrians) through *presence fields*, considered as repulsive
- Discrete spatial structure of the environment derived directly from the 3D model realized by designers



The Simulation Environment

Pedestrian Simulation View

3D View

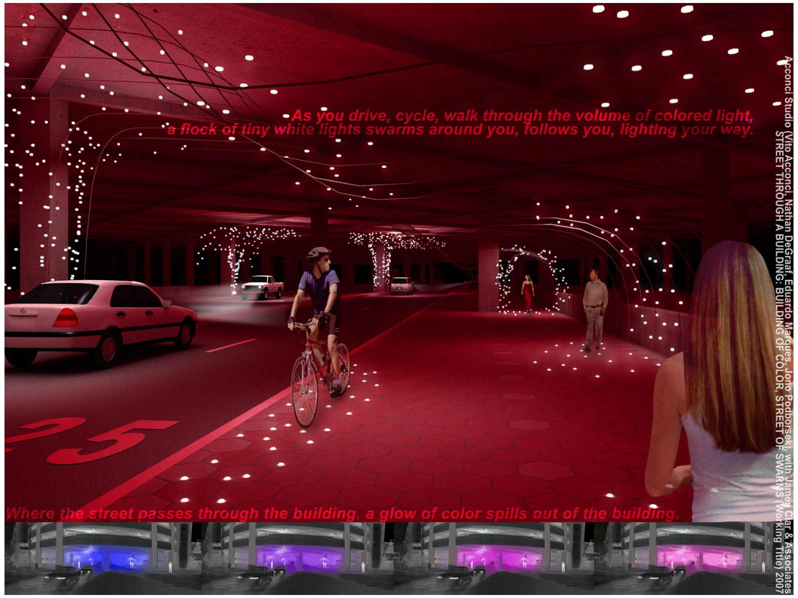


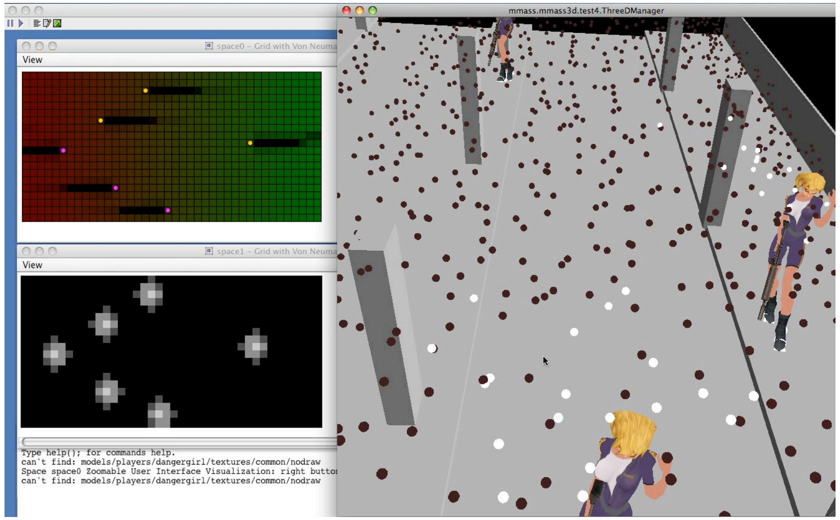
Controllers Simulation View

- The simulation environment is composed of two parts simulating
  - the *network of controllers* (with sensors and actuators)
  - the *actual environment* in which the network is situated
- The second one produces *simulated inputs* for the first one
- The simulation shows how controllers react when a simulated person (or vehicle) enters in the range of the sensors; the designer can thus effectively *envision the interaction* between the people an the adaptive environment
- The simulation environment allows the design configuring the network, defining the type, number, position of the sensors and actuators and specify a behavior for the controllers

Future Developments

- Explored the possibility of realizing an ad hoc tool *integrating traditional CAD systems* for supporting designers in simulating and envisioning the dynamic behaviour of complex, self-organizing installations
- Used to understand the *adequacy of the modeling approach* in reproducing the desired self-organized adaptive behaviour of the environment to the presence of pedestrians
- Currently *improving the prototype*,
  - provide a better support for the Indianapolis project
  - generalize the framework for other kinds of dynamic self-organizing environments
- Investigating the possibility of "closing the loop", *influencing the movement of pedestrians* (e.g. showing indications towards the "best" paths for evacuation)





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Thank you