Agent Based Modeling and Simulation

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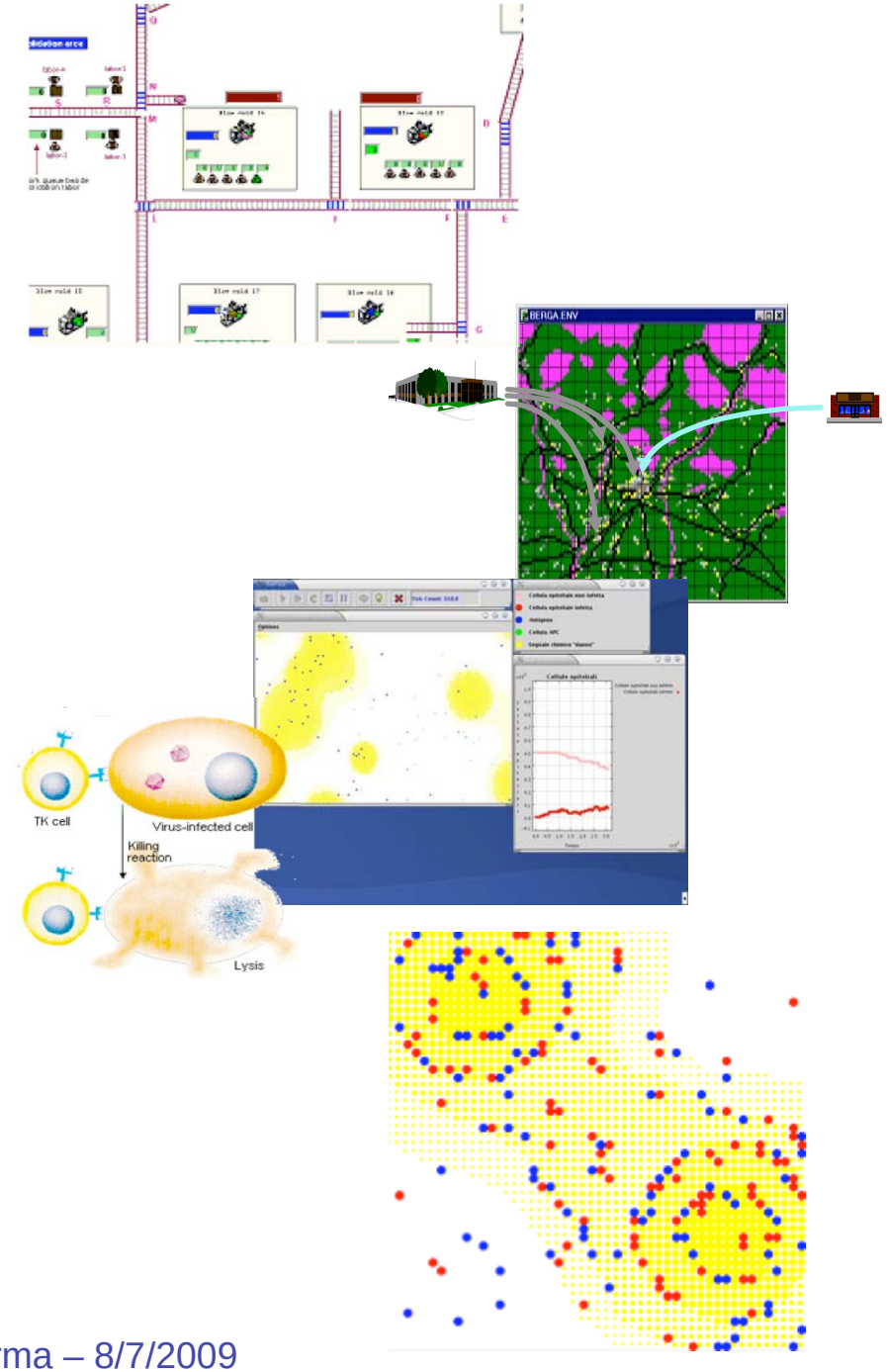
Agenda

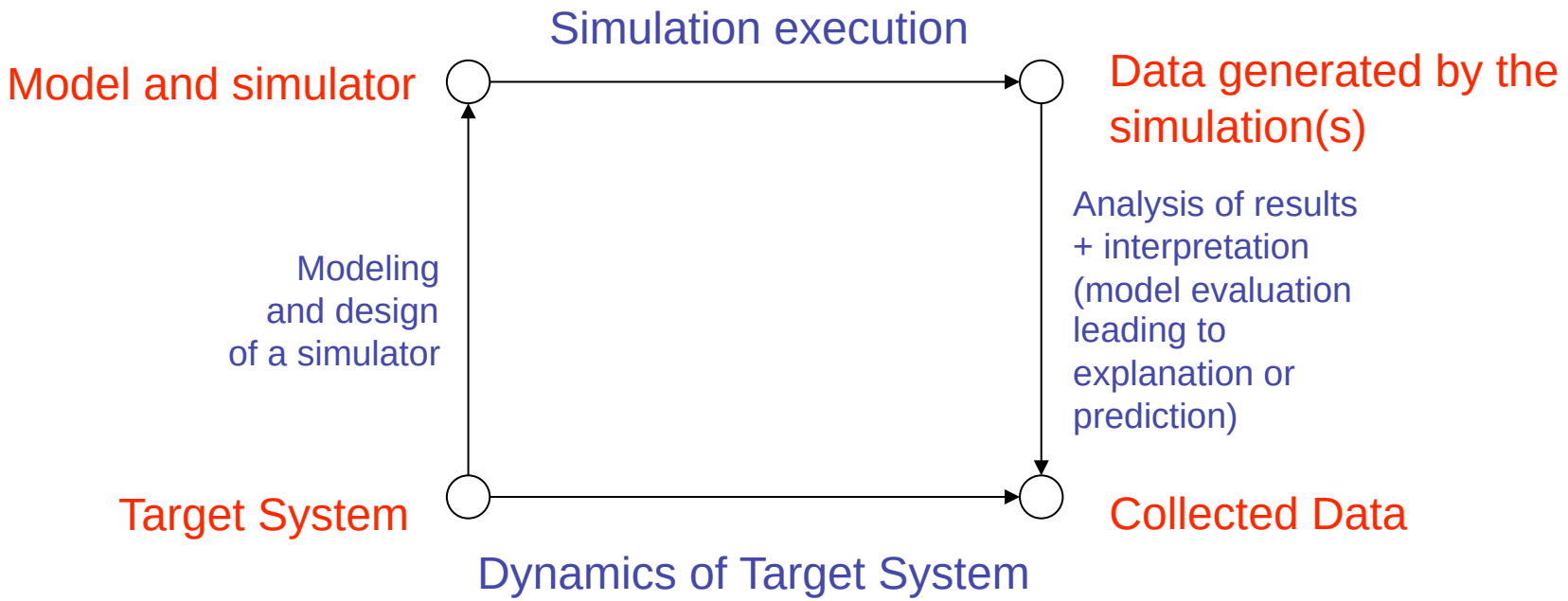
- Simulation: a definition and motivations
- Agent Based Simulation
  - Differences from other approaches
  - Peculiarities, advantages and risks
- A Case Study: Crowd Modeling
- Some reflections
  - From reality, to models, to a simulation
  - The role of the environment and indirect interaction models
- Conclusions

Simulation: a definition and motivations

- (Computer) Simulation represents a way to exploit a *computational model*
  - to *evaluate designs and plans* without actually bringing them into existence in the real world
  - to *evaluate theories and models* of complex systems by envisioning the effect of the modeling choices, with the aim of gaining insight of their functioning
- The use of *"synthetic environments"* is sometimes necessary, because the simulated system cannot actually be observed
  - Because it *is actually being designed*
  - For *ethical or practical* reasons



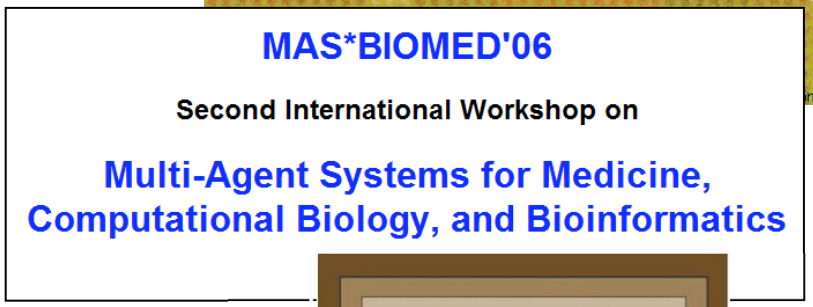
Simulation life-cycle

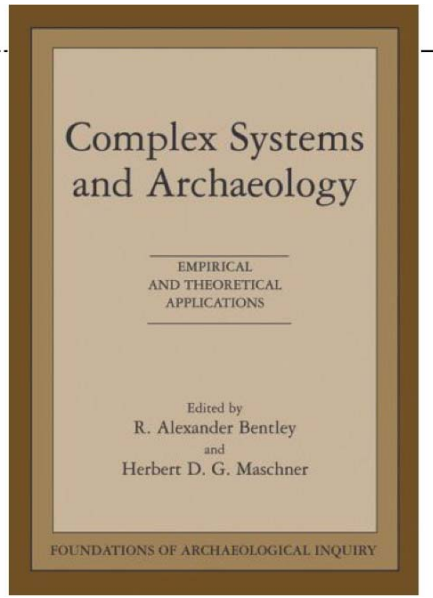


- From the *target system* to its *computational model* and a *simulator*
- Execution of a *simulation campaign*
- *Evaluation/validation* of the model (and simulator) against *collected data*
- Possible usage for *explaination* and/or *prediction*

Agent Based Modeling and Simulation

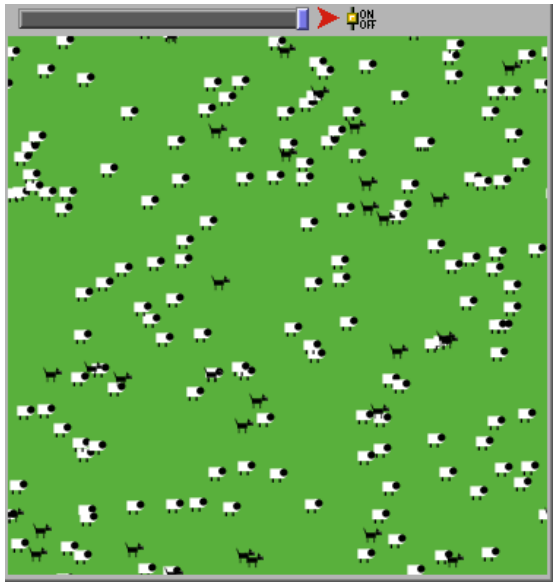
- Several situations are characterized by the presence of *autonomous entities* whose actions and interactions determine (in a non-trivial way) the evolution of the system
- A *growing number* of disciplines are interested in considering and studying effects of
  - *decentralized* decision making
  - *local-global* interaction, *self-organization*, *emergence*
  - *heterogeneity* in the system
- *Agent based models* are particularly suited to represent these situations, and to support this kind of study and analysis

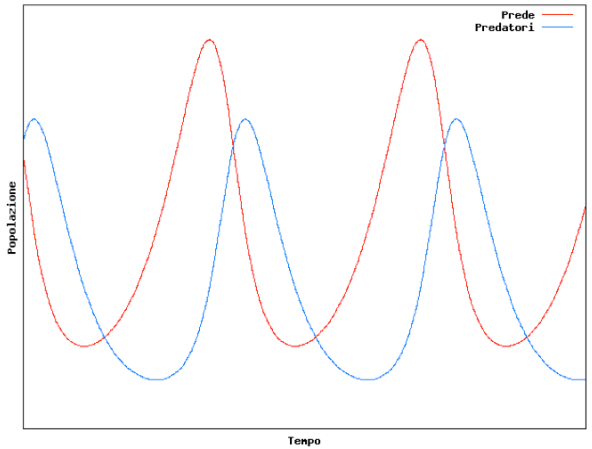




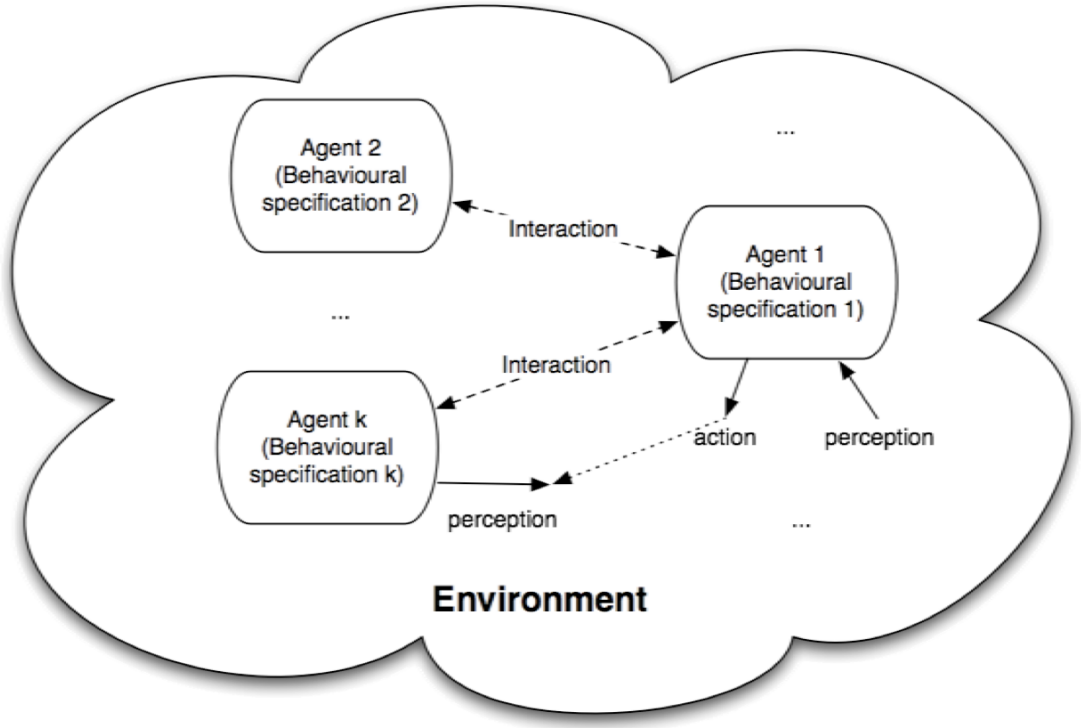
Agent Based Models for simulation: peculiarities, advantages, risks

- The *analytical unit* is the *individual agent*, not aggregate variables
- This means, on one hand, that *additional insight* on the modeled system *is required*
- On the other hand such a model should be able to
  - Generate *the same aggregate dynamics* as traditional ones
  - Be able to represent, manage, analyze *additional aspects*, such as for instance spatial ones





A possible reference model for Agent Based models



- *Different disciplines* interested in the subject, *different modeling styles*
- Relatively *young* approach

→ *extremely high heterogeneity* in models that legitimately claim to be agent based

A *reference model* can be useful to present, schematize, compare different approaches, models, experiences

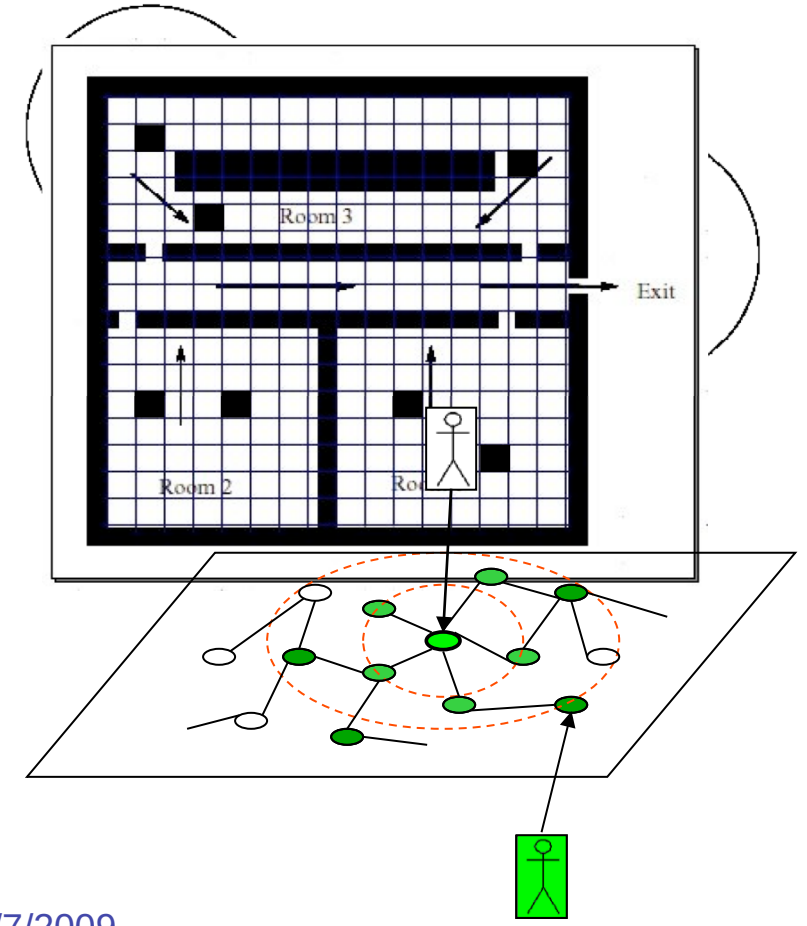
Crowd modeling and simulation: motivations

- Designer's *decision support*
  - Evacuation situations
  - Positioning of signs
  - Malls and shopping centres
- Support the study of *pedestria*
  - Envisioning of different behavioural mo realistic environments
  - Possibility to perform 'in-machina' expe

Possible modeling approaches

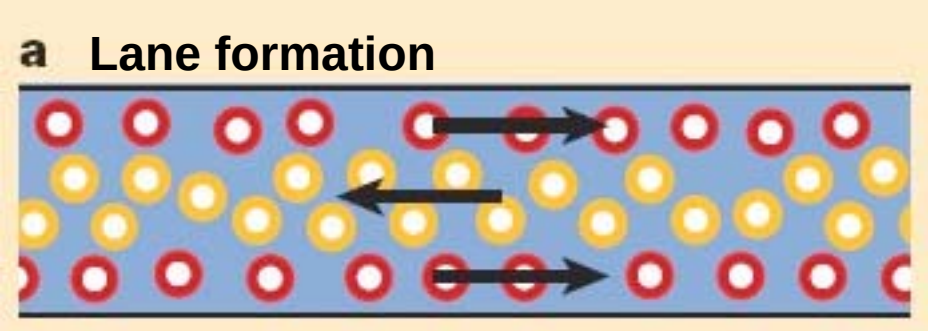
- Analytical
  - May handle *large* simulation scenarios
  - Entities as ‘mere’ *numbers*
  - Continuous representation of space
- Cellular Automata based
  - May handle a *large* number of entities
  - Explicit *discrete* representation of the environment
  - Entities are *homogeneous* (they are conceived as particular states of cells)
  - *Extensions* to the basic model are often required (e.g. action-at-a-distance)
  - Complex behaviours require a very large cell state and transition rule
- Multi-Agent Systems (MAS) based
  - May handle a *smaller* number of entities
  - Entities are clearly *separated* by the environment
  - Entities may be *heterogeneous*
  - Only a few approaches and models provide a representation of the environment

$$m\frac{d\mathbf{v}_i(t)}{dt} = m\frac{v_o\mathbf{e}_i - \mathbf{v}_i(t) + \xi_i(t)}{\tau} + \sum_{j(\neq i)} \mathbf{f}_{ij}(\mathbf{x}_i(t), \mathbf{x}_j(t)) + \mathbf{f}_b(\mathbf{x}_i(t))$$



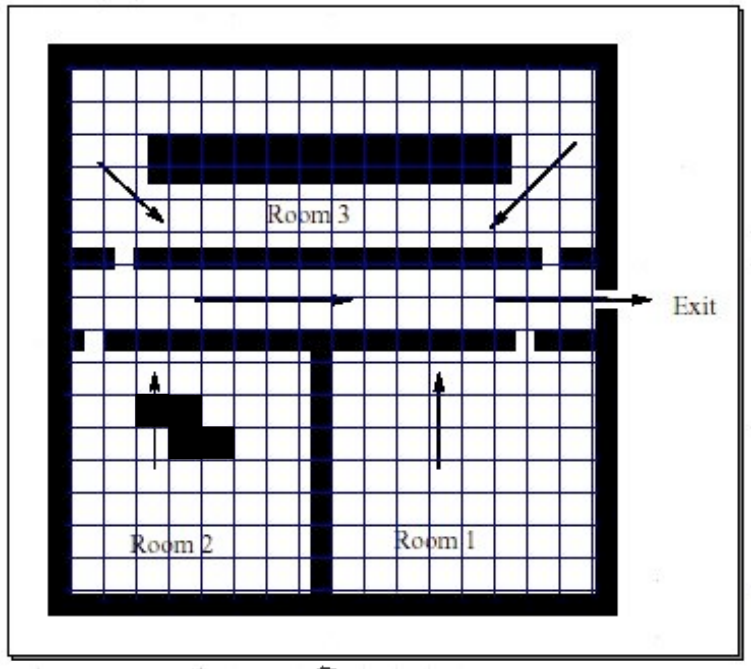
Analytical (physical) approach

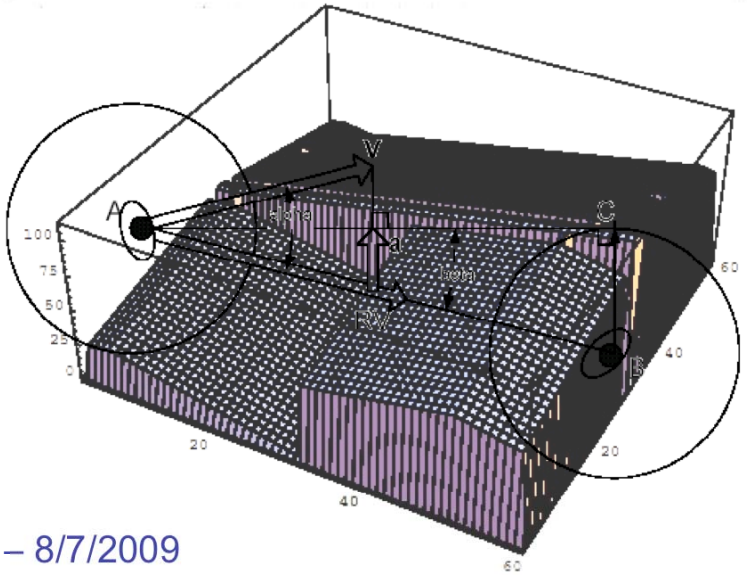
- Pedestrians → *particles* subject to *forces*
- Goals: *forces of attraction* generated by points/reference point in the space
- Interaction among pedestrians: *forces* generated by particles
- Social forces
  - *Repulsive* → tendency to stay at a distance
  - *Attractive* → imitative mechanisms



Cellular Automata and crowd modelling

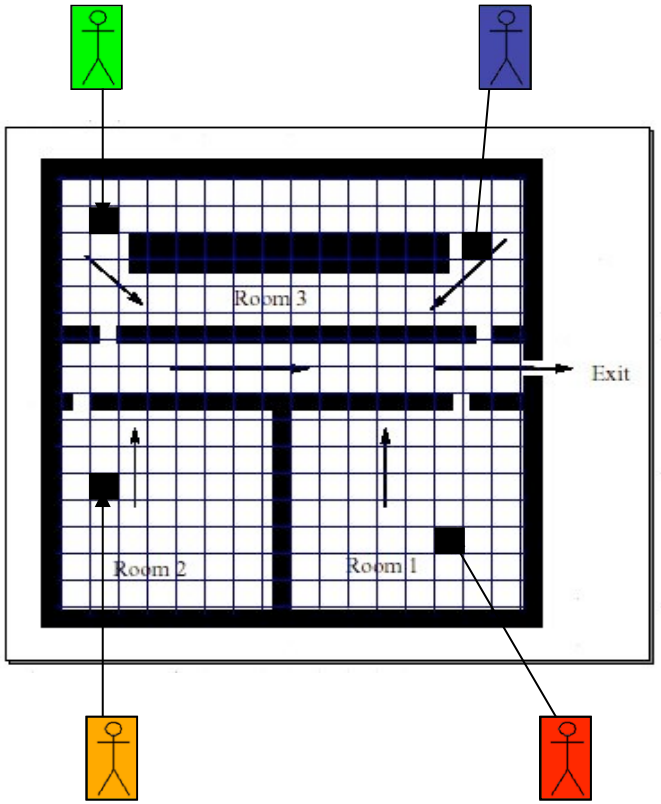
- Environment → bidimensional *lattice of cells*
- Pedestrian → specific *state of a cell* (e.g. occupied, empty)
- Movement → generated thanks to the *transition rule*
  - an occupied cell becomes empty and an adjacent one, which was previously vacant, becomes occupied
- Choice of destination cell in a transition generally includes information which is *not provided by basic CAs*
  - Benefit-Cost/*Gradient*: predefined information related to cell desirability
  - *Magnetic Force*/Social Force: model the effect of presence of other agents in the environment (attraction/ repulsion of crowds)





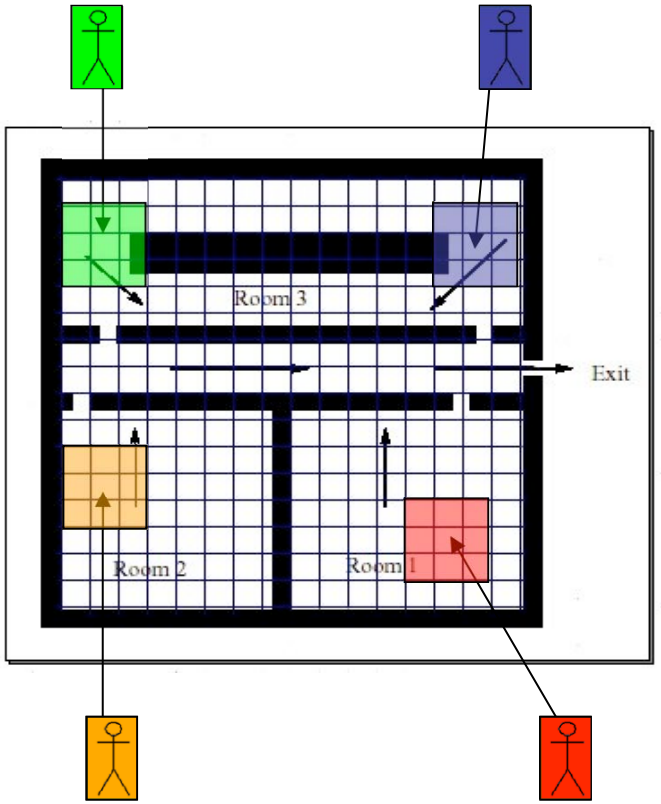
From CA to Situated MAS

- Entities are reified, *separated from the environment*
  - Agents, not just cell states
- They may have *different behaviours*
  - Possibility to integrate several *different action deliberation* models
  - Possibly *heterogeneous* system
- Entities interact by means of mechanisms not necessarily related to underlying cell's adjacency
  - Action at a distance is allowed



Situated MAS: action and interaction

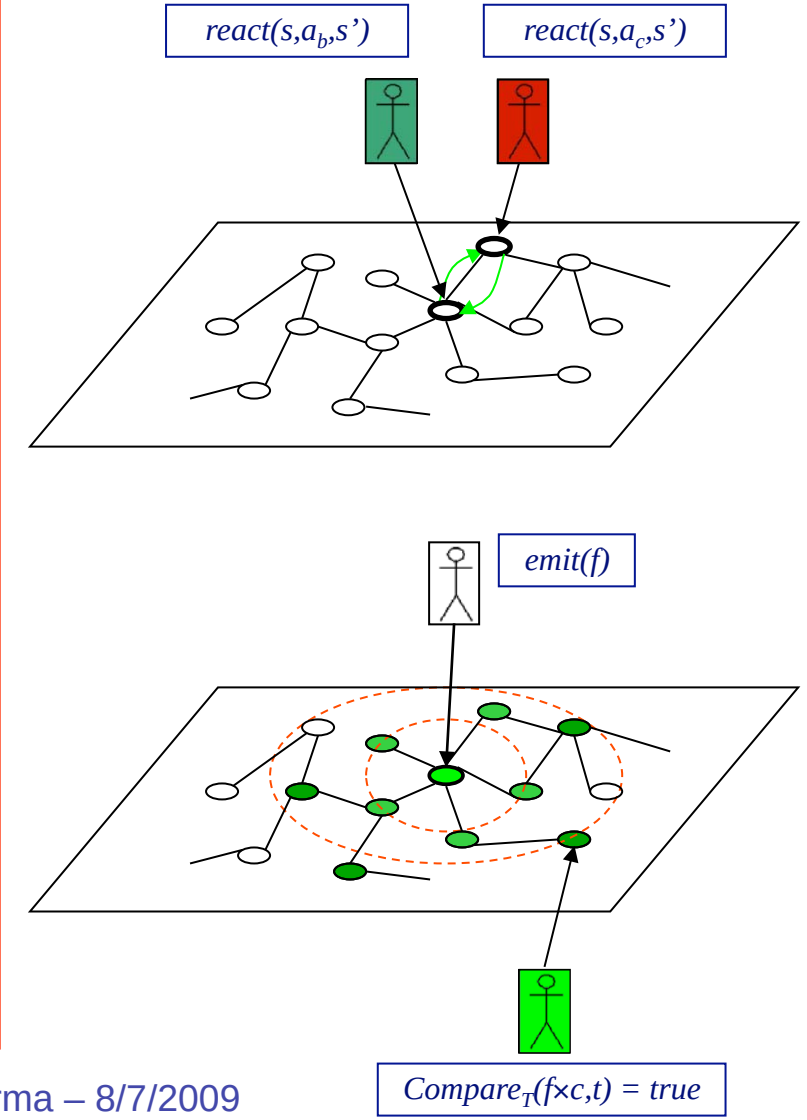
- Agents are *situated*
  - they *perceive* their context and situation
  - their behaviour is based on their *local point of view*
  - their possibility to act (move) and interact is *influenced by the environment*
- Situated Agents Interaction models
  - Often inspired by *biological systems* (e.g. pheromones, computational fields)
  - Generally provide a *modification of the environment*, which can be perceived by other entities
  - But may also provide a *direct communication* (as for CAs interaction among neighbouring cells)



Situated Cellular Agents (SCA)

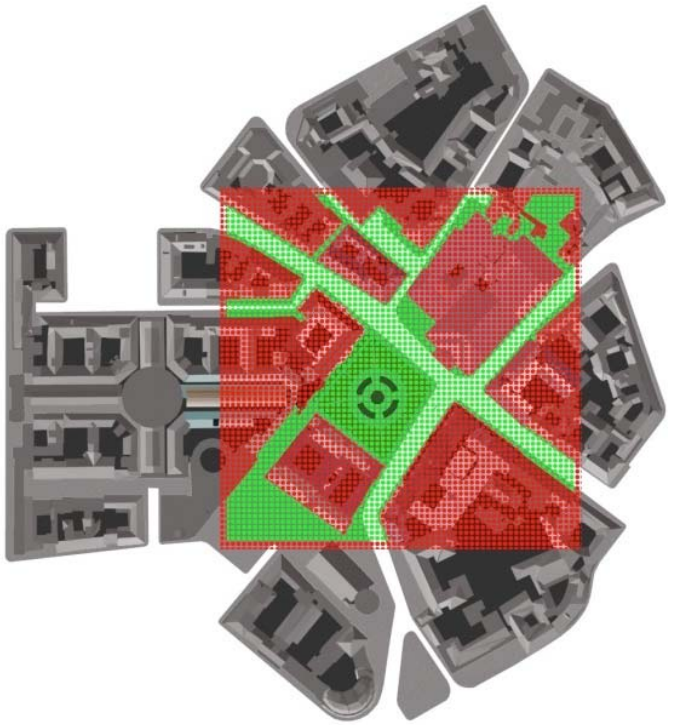
Multi Agent model providing

- *Explicit representation* of agents' environment
- Interaction model strongly *related to agents' positions* in the environment
  - Among adjacent agents (reaction)
  - Among distant agents, through field emission-diffusion-perception mechanism
- Possibility to model *heterogeneous agents*, with different perceptive capabilities and behaviour

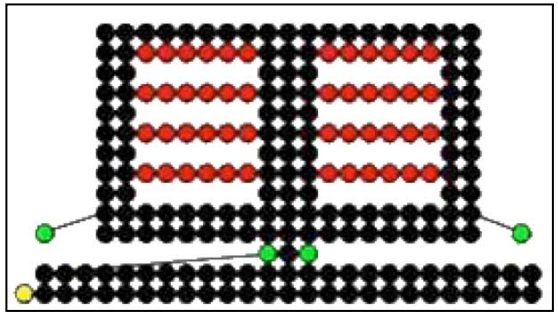


Situated MAS and crowd modelling

- Pedestrians → *agents*
- Environment → *graph*, as an abstraction of the actual environmental structure
- Movement → generated thanks to the *field diffusion-perception-action* mechanism
  - Sources of signals (fields): *objects*, gateways, but also *agents*
  - Agents are *sensitive* to these signals and can be *attracted/ repelled* by them
  - Possible *superposition* of different such effects (amplification/ contrast)



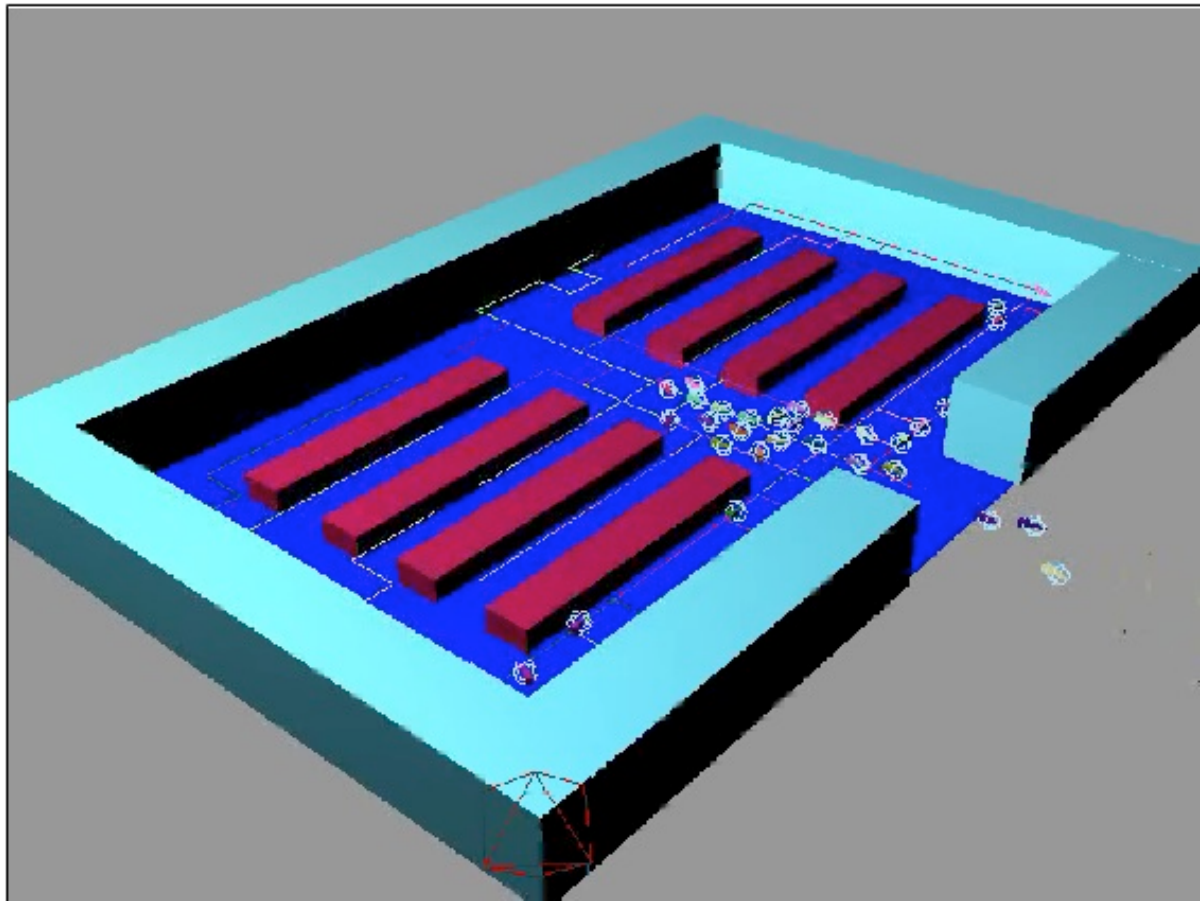
Sample Application: Lecture hall (I)



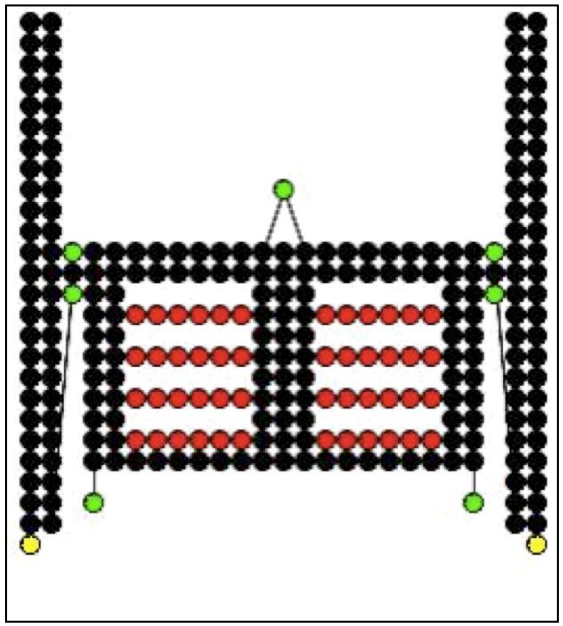
Single exit

- *Field sources* in green: emergency lights related to corridors and exit
- Static *obstacles* in red

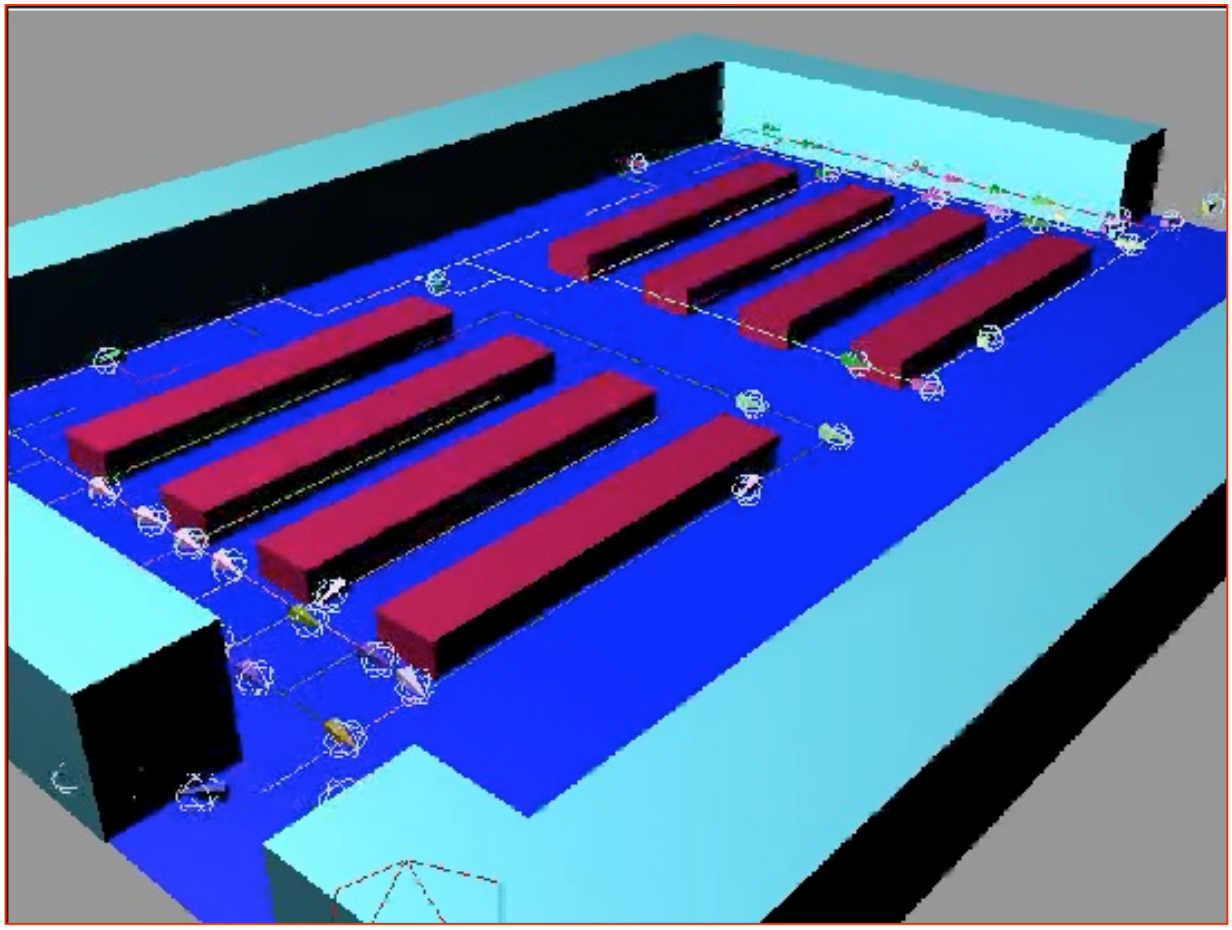
- CA models of the same scenario can be found in the literature [Kirchner, Schadschneider, et al.; Henein & White]



Sample Application: Lecture hall (II)

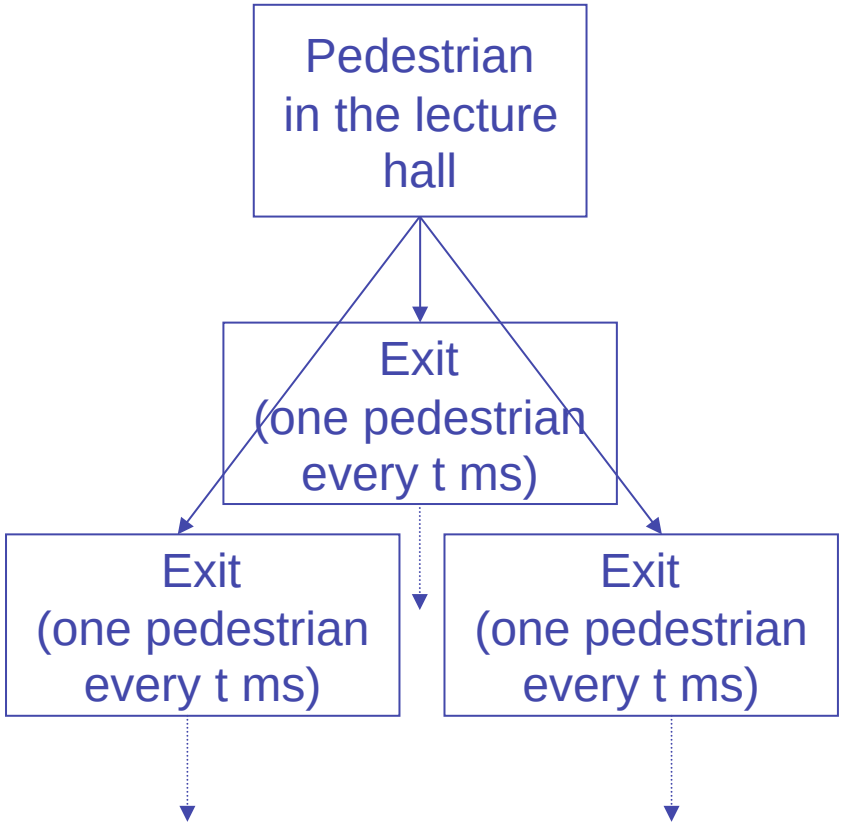


Two exits



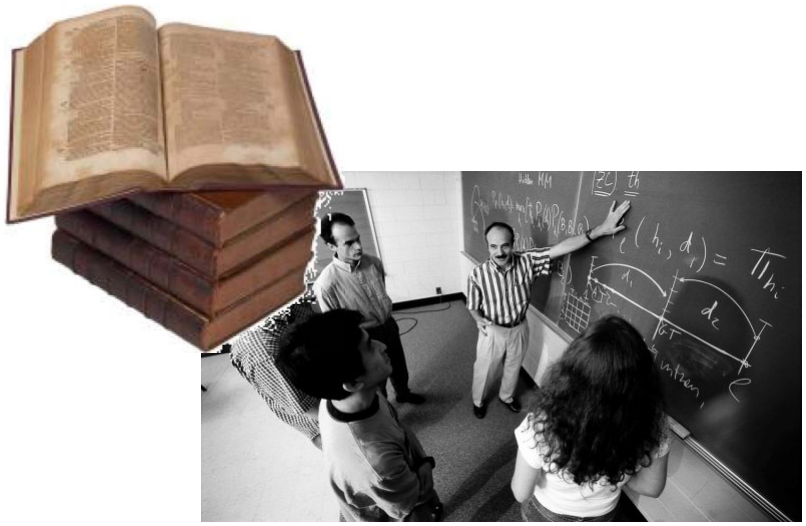
Why not use simple queues?

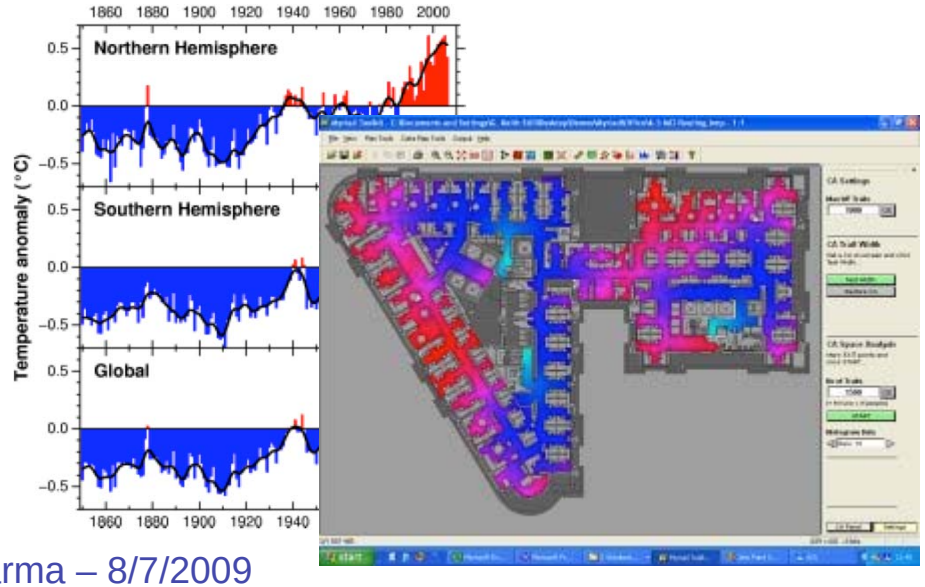
- One could model such a system with one (or more) *simple queues*...
- ... but the model would *not be able to 'answer' some of the questions* we can pose to the previous models
  - What if t is *unknown*?
  - Only *aggregate* quantities are managed
  - No *heterogeneity*
- Moreover, it would be very difficult to manage *more complex* situations, in terms of:
  - *Environmental structure*
  - *Possible behaviours* for the pedestrians



So, no “best” modeling approach?

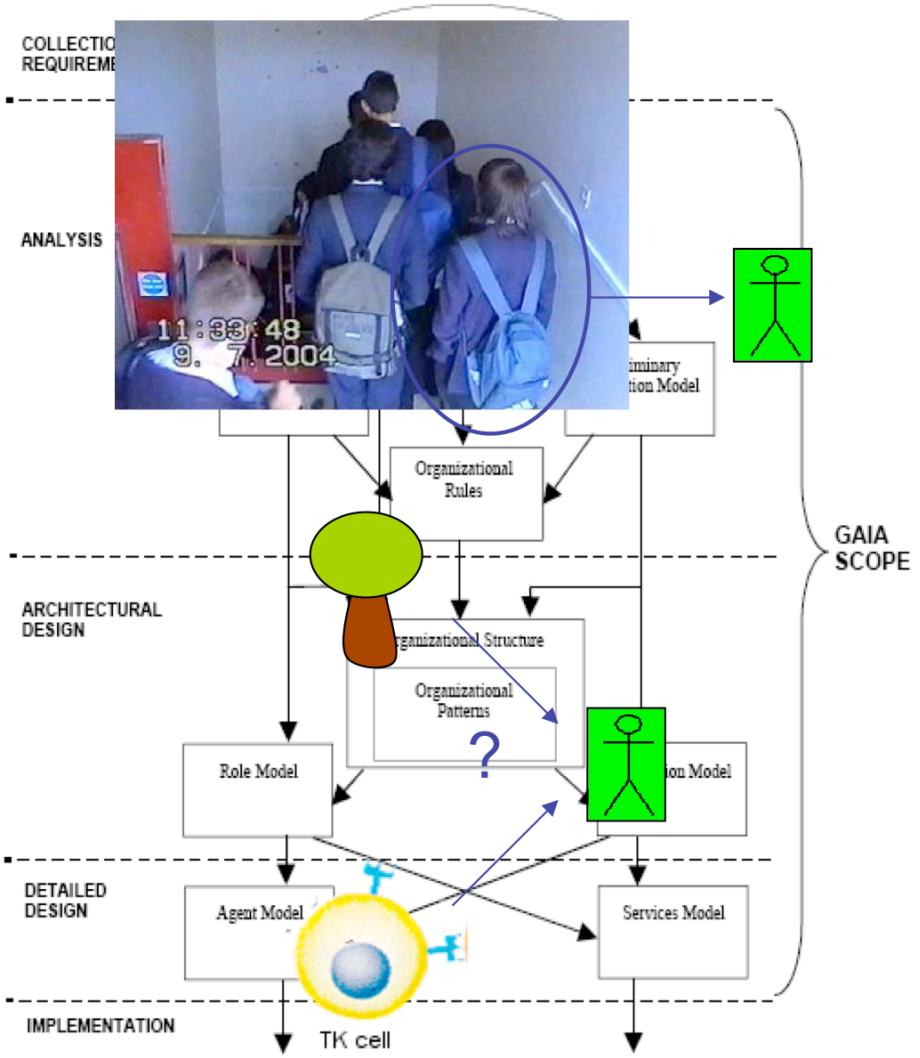
- The choice of the abstract/ computational model depends on several factors:
  - Available *knowledge* on the simulated phenomenon/ situation/reality
  - Available *data* on actual scenarios, for sake of calibration, verification and validation
  - *Goals* of the simulation activity
- *Possible tension* between these elements!





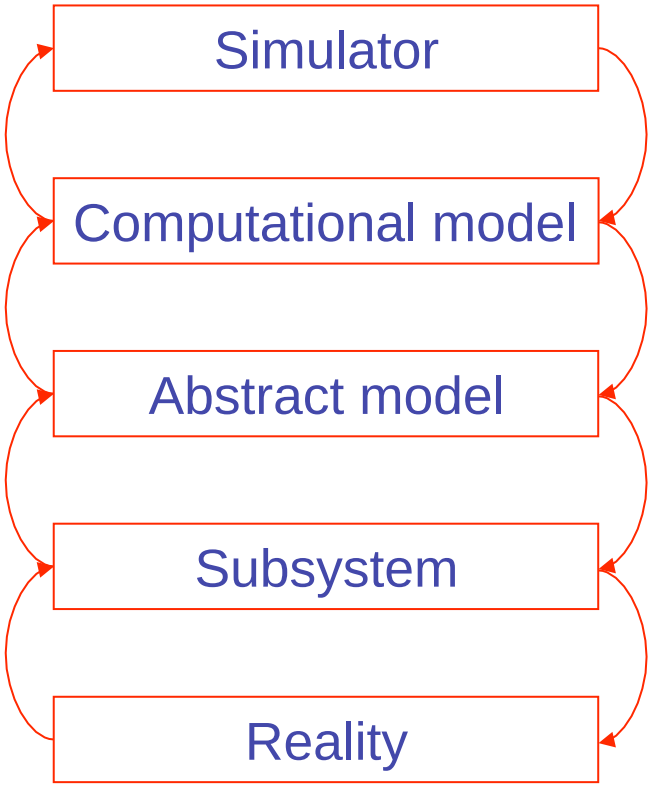
What about Agent Based Modeling and Simulation methodologies?

- It is very difficult to define a methodology that is both *general* and actually *useful*
- General methodologies tend to define *well understood macro phases*, but no useful suggestion on *how* actually carry them out in a *specific context*
- For instance, in different domains it is not even clear what is the most proper *modeling granularity level*
  - In crowd modeling, a pedestrian is modeled as an agent
  - But in biological systems, what should be represented as an agent? An *organism*? An *organ*? A *cell*? A *molecule*?
- Specific useful (more or less) formalized modeling approaches and methodologies *only in specific contexts*



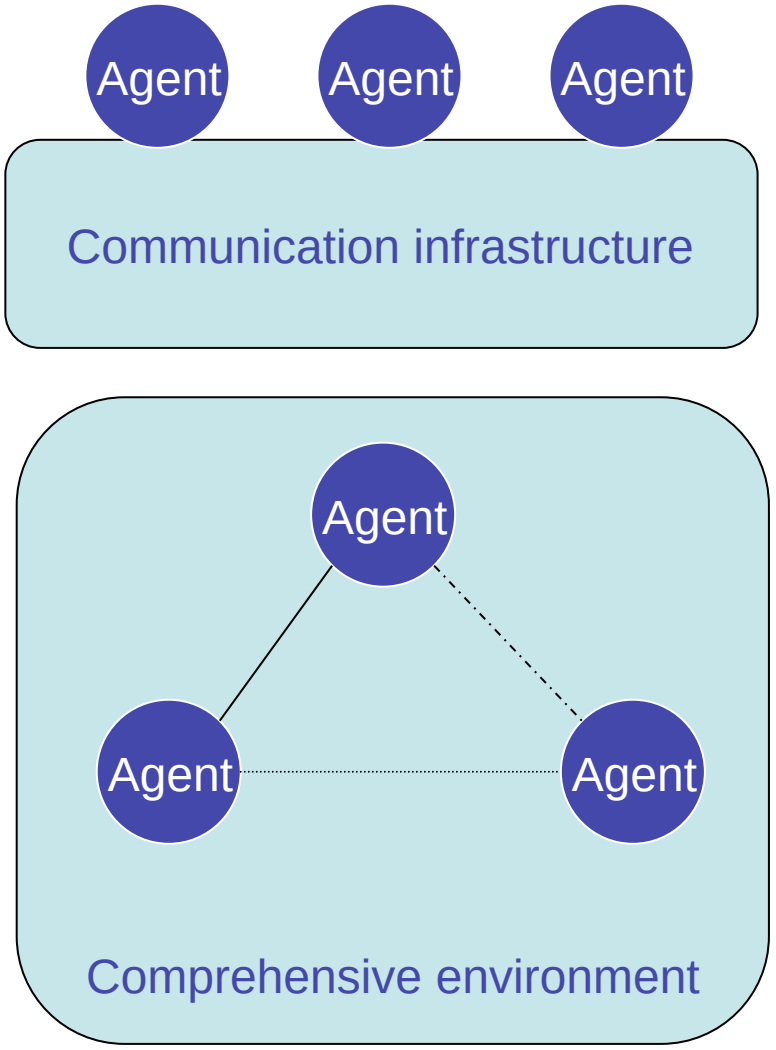
A reflection: from reality, to models, to a simulation

- The overall simulation project involves several *phase*, *roles*, types of *knowledge* and *competences*
- The frequent passages (translation, encoding, decoding, interpretation...) between *different levels of abstraction* can lead to several problems
  - *Non documented assumptions*
  - Unrealistic/unfeasible *simplifications*
- Simulation projects are *difficult*
  - R. Shannon, “Introduction to the *Art and Science* of Simulation” (1998)
  - ... But some even talk of *“dark arts”* [J.P. Marney and H. Tarbert, “Why do simulation? Towards a working epistemology for practitioners of the dark arts” (2000)]



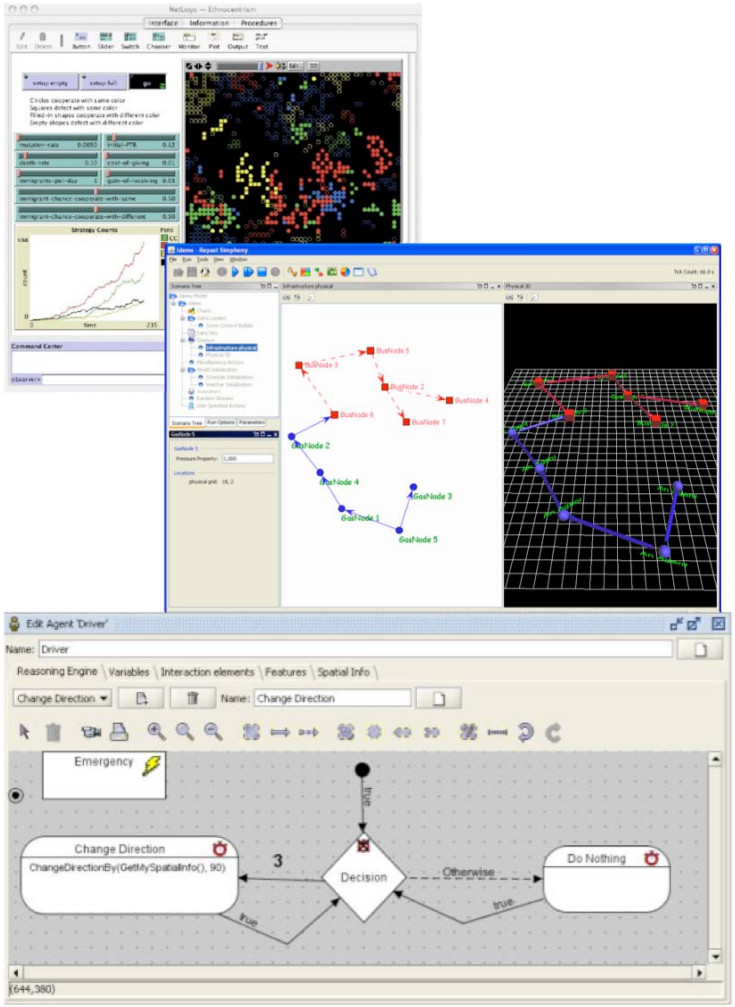
The role of the environment

- Most agent definitions include the term environment, but in some cases it is conceived as a *mere communication infrastructure*
- In most simulation scenarios the environment plays a *more relevant role*, since
  - *Spatial features* of the environment *influence agents behaviour*
  - Relevant *simulation results* are often *spatially related*
  - The environment is used as a *'channel' for (indirect) agent interaction*
  - Some *laws and properties* must be enacted and preserved: the environment is the best 'place' to do so



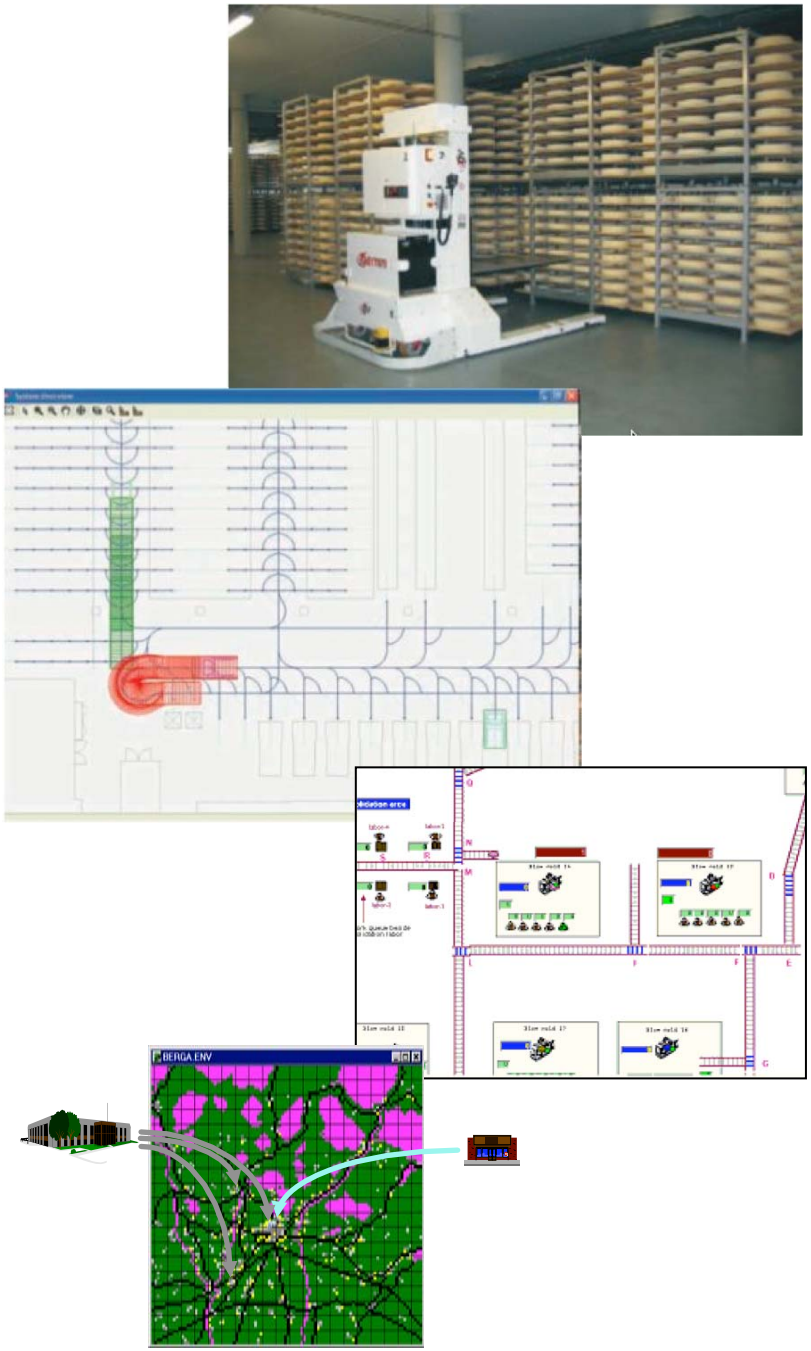
Agent Based Modeling and Simulation Frameworks

- They provide tools facilitating the development of agent-based simulations
  - in terms of abstractions and mechanisms
  - in terms of generic functionalities (e.g. monitoring and visualization, scheduling and control of the simulation, data export and analysis)
- Three main categories
  - General purpose frameworks based on ‘ad-hoc languages’ (e.g. Logo dialects)
  - General purpose frameworks based on general purpose languages (e.g. Java)
  - Model specific frameworks (SimSesam)



Agent Based Simulation Industrial Applications?

- Several specific applications in logistics
  - Danny Weyns, Kurt Schelfthout, Tom Holvoet, Tom Lefever: Decentralized control of E'GV transportation systems. AAMAS Industrial Applications 2005: 67-74
  - Cornelia Triebig, Tanja Credner, Peter Fischer, Titus Leskien, Andreas Deppisch, Stefan Landvogt: Agent-Based Simulation for Testing Control Software of High Bay Warehouses. MATES 2005: 229-234
  - …
- Pedestrian modeling and simulation
  - Most commercial tools adopt an individual based approach (not necessarily agent-based)
- Several applications to support decision/policy makers:
  - Electronic market:
    - Isabel Praça, Carlos Ramos, Zita A. Vale, Manuel Cordeiro: Mascem: A Multiagent System That Simulates Competitive Electricity Markets. IEEE Intelligent Systems 18(6): 54-60 (2003)
    - …
  - Urban planning:
    - Saarloos, D.J.M., Arentze, T.A., Borgers, A.W.J. and Timmermans, H.J.P. 2005. "A multi-agent model for alternative plan generation." Environment and Planning B: Planning and Design. vol. 32. 505-522
    - …



Conclusions

- Agent Based models represent a *useful kind of instrument*
  - for the *study of complex systems*
  - to realize simulators *support decision making* activities (system design, configuration, operation)
- These models have *different requirements* and ‘performances’ from traditional approaches, but there is *no silver bullet*...
- Simulation is a *complex activity*, with several possible pitfalls
- Benefits of being aware of the approaches, techniques and advances of *different disciplines* in this topic

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Thank you!

References (very partial...)

- General resources
  - *Growing Artificial Societies: Social Science From the Bottom Up*, Joshua M. Epstein and Robert L. Axtell, MIT Press 1996
  - MABS workshops serie (Lecture Notes in Computer Science vol. 1534, 1979, 2581, 2927, 3415, 3891, Springer-Verlag) (http://www.pcs.usp.br/~mabs/)
  - Agent Based Modeling and Simulation Symposium, at EMCSR (www.lintar.disco.unimib.it/ABModSim)

References (very partial...)

- Pedestrian modeling
  - Environment and planning B, vol. 28 no. 3, Theme issue: Pedestrian modeling, Editor: Michael Batty
  - In general Environment and planning is a good source of papers adopting agent based models in the architecture and urban planning area
- Social simulation
  - Simulation for the Social Scientist, Nigel Gilbert, Klaus G. Troitzsch, Open University Press
  - Journal of Artificial Societies and Social Simulation (http://jasss.soc.surrey.ac.uk/JASSS.html)
- Biomedical context
  - MAS*BIOMED workshop serie

References (very partial...)

- Some additional links
  - SWARM Development Group Wiki (http://www.swarm.org): “A resource for agent- and individual-based modelers and the home of Swarm”
  - Individual-Based Models (http://www.red3d.com/cwr/ibm.html): an annotated list of links by Craig Reynolds (the author of the Boids model)

Quotes...

"What is MABS? It could be:

- *Entertainment* – a sort of intellectual computer game where one sets up an artificial system with lots of agents and then play with it to see what sort of effects one can get;
- *Art* – MAS designed and/or constructed for others to admire and enjoy;
- *Illustration* – multi-agent systems designed to animate or otherwise illustrate some sociological, philosophical or mathematical principle, in other words, a sophisticated pedagogic tool;
- *Mathematics* – using simulation as a stand-in for symbolic deduction in distributed systems where such deduction is impractical;
- *Communication* – multi-agent systems as an interactive medium for social exploration, negotiation and communication; or
- *Science* – multi-agent systems as a tool for understanding observed systems.

All of the above are legitimate uses of multi-agent systems. Each has different goals. Each has different roles in society. Each has different criteria for success. It is not obvious that academics who attend MABS workshops have decided what MABS is. Indeed, it is not immediately obvious that there is a need to decide – these different activities can have much to contribute to each other."

[Bruce Edmonds, The Use of Models - Making MABS More Informative, MABS 2000]

Quotes...

- “New approaches based on modeling individual objects, agents, and particles take a very different view of probability than that used in more traditional transport and traffic models. We now have sufficient knowledge of the limits to prediction in human systems to know that the search for total predictability is a myth.”

  [Mike Batty, Editorial, Environment and Planning B: Planning and Design 2001, volume 28, no.3]