Simulation

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Outline

1. **Lecture presentation**
2. **Numerical simulation**
3. **Multi-Agent Based Simulation (MABS)**
4. **Coupling Simulation platforms**

Lecture presentation

Objectives

Organization of the sessions

Project

Lecture presentation

Objectives

- **Understanding basics of the simulation domain**
- **Focusing on Multi-Agent Based Simulation (MABS) domain**
- **Experimenting MABS platforms**
- **Using MABS for evaluating a toy problem**

Lecture presentation

Organization

- **Theoretical session**
  - 09/18: Simulation domain lecture

- **Practical sessions**
  - 09/25 (FB)
    - Reactive agent based simulation platform
    - Netlogo platform
  - 03/10 (AN)
    - Cognitive agent based simulation platform
    - Repast platform
  - 12/10 (AN)
    - Cognitive agent based simulation platform
    - Repast platform

Lecture presentation

Project

- Simulation project
  - Propose a decentralized strategy for the management of a fleet of vehicles ensuring an online dial and ride service
  - Dynamic resource allocation problem of traveler requests (resources) to vehicles (consumers).
  - Your strategy to solve this problem is performed by agents, i.e. the vehicles, which have to process at least 90% of traveler requests. Agents are mobile, distributed and communicate with a global network.

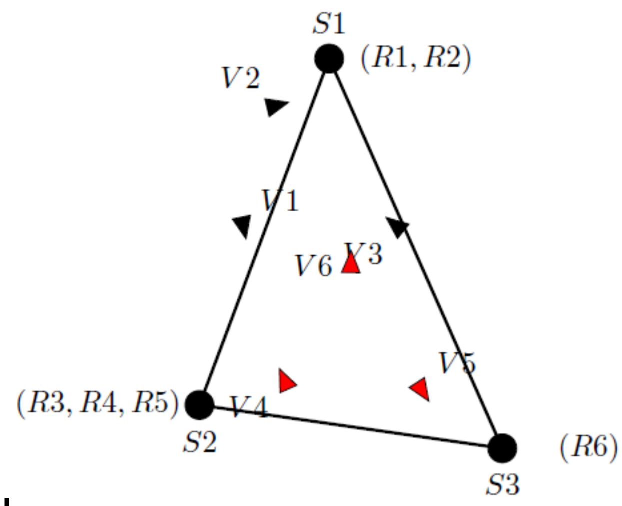


Figure 1: Vehicle fleet management example

- The choice of the MABS platform is free

Numerical simulation

Presentation

Designing a simulation model

Executing a simulation model

Simulation challenges

Numerical simulation

Presentation

Designing a simulation model

Executing a simulation model

Simulation challenges

Numerical Simulation

Presentation - Context

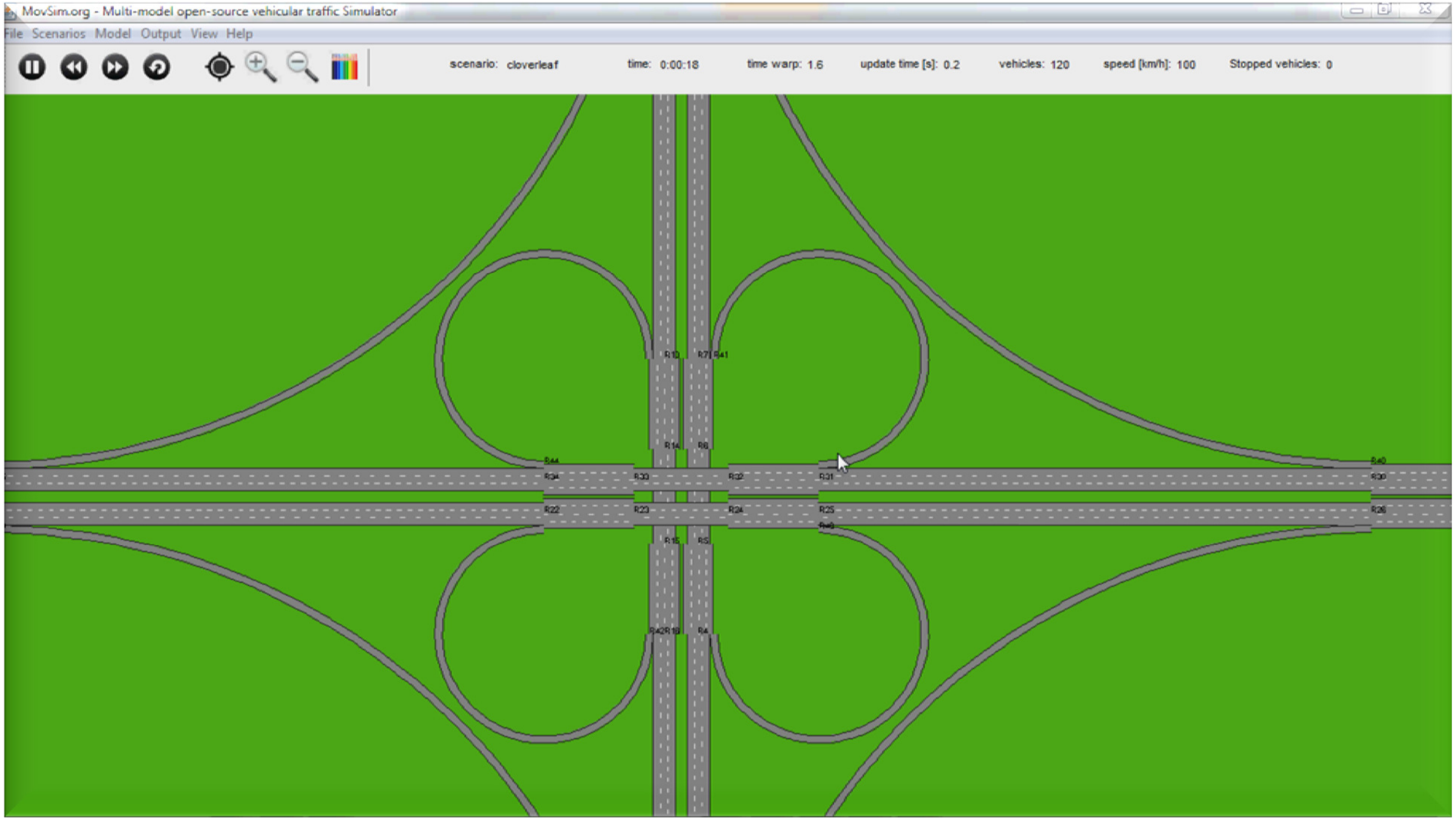
- **Informal definition**
  - A simulation is an imitation of the operations of a real-world system
  - A numerical simulation generates an artificial history of a system

- **We need**
  - Imitation of the operation of a real-world system
    - ➢ A model of the reference system
  - Generation of an artificial history of a system
    - ➢ A temporal model
    - ➢ A simulation platform

A simulation model

Numerical Simulation

Presentation - Example



www.movsim.org

https://liris.cnrs.fr/~mgueriau/wiki/doku.php?id=fr:teaching:entpe

Numerical Simulation

Presentation - *Use case*

- **Understanding, Exploration, Clarification**
  - to understand the behavior of the reference system thanks to a model that is considered as a miniature reproduction of the reference system.
    - *Observation without interruption of the reference system*
    - *Observation without modification of the reference system*
- **Validation, Assessment, Verification**
  - to test an hypothesis of the reference system, to validate or to certify the underlying theory.
    - *As many tests as necessary without additional costs*
    - *Test the limits of the reference system without damages*
- **Control, action**
  - to support a decision process or a control that will influence the state of the real reference system.
    - *Adapted to the "what-if" decision approach*

Numerical Simulation

Presentation - *Use case*

- **Forecast, Prediction, Anticipation**
  - to predict the possible evolutions of the reference system following evolutions or disturbances.
    - *Give a temporal overview of the reference system behavior*
    - *Give a temporal overview of the consequences in time of the reference system*
  - to study new designs without needing extra resources

- **Communication, Formation, Visualization**
  - to show and share the model of the dynamic of the reference system.

Simulation is a solution to perform less dangerous, expensive, intrusive "manipulation" of a real-world system

Numerical Simulation

Presentation - *Definition*

- **Simulation**
  - "*The process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or a set of criteria) for the operation of the system.*" (Shannon 1976)
  - "*Simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output*" (Fishwick 1994)

Numerical Simulation

Presentation - *Definition*

Simulation

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Numerical Simulation

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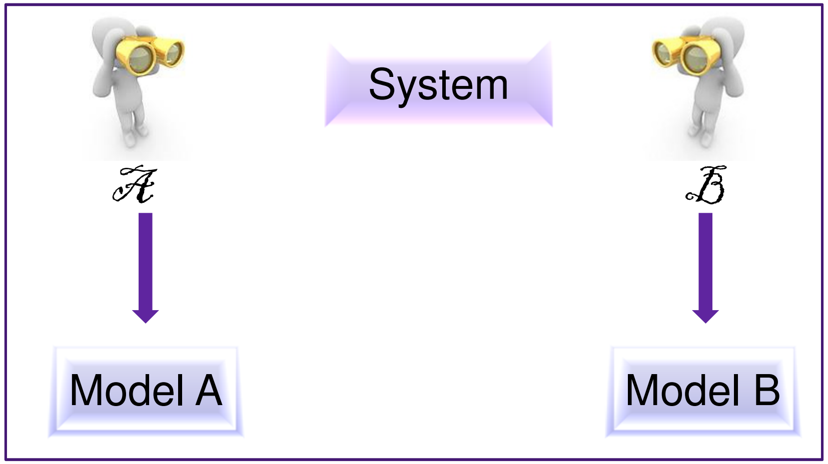
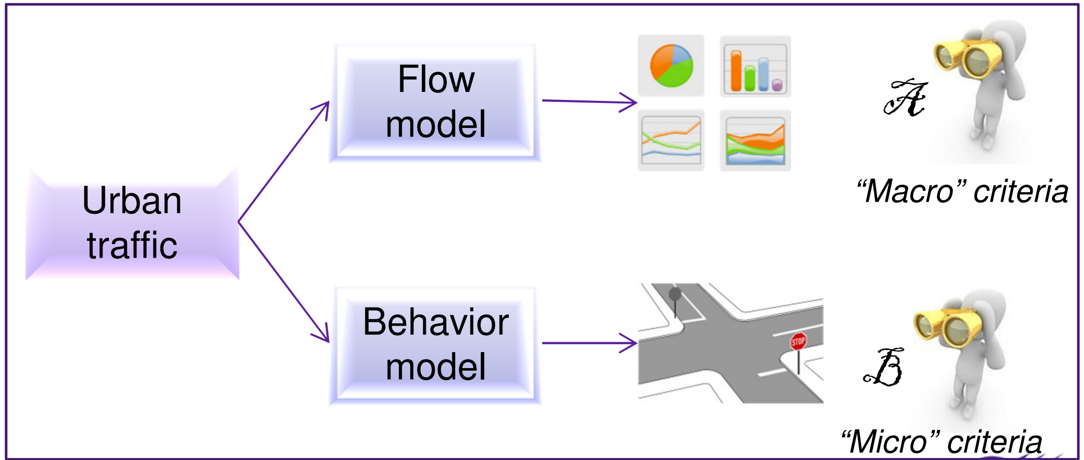
Numerical Simulation

Presentation - *Definition*

- **System**
  - Definite set of discrete elements which are connected or in interaction.



- **Model**
  - “To an observer B, an object A is a model of an object A to the extent that B can use A to answer questions that interest him about A.
- **Types of model**
  - Mathematical
    - Example: Physical laws
  - Logical
    - Example: digital circuits
  - Algorithmic
    - Example: human behavior



Numerical simulation

Presentation

Designing a simulation model

Executing a simulation model

Simulation challenges

Numerical Simulation

Designing a simulation model - *models*

- **Conceptual model**

  The conceptual model is a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model.

  (Robinson'06)

- **Two types of conceptual models** (Lacy et al.'01)
  - A *domain-oriented* model that provides a detailed representation of the problem domain
  - A *design–oriented* model that describes in detail the requirements of the model and is used to design the model code.

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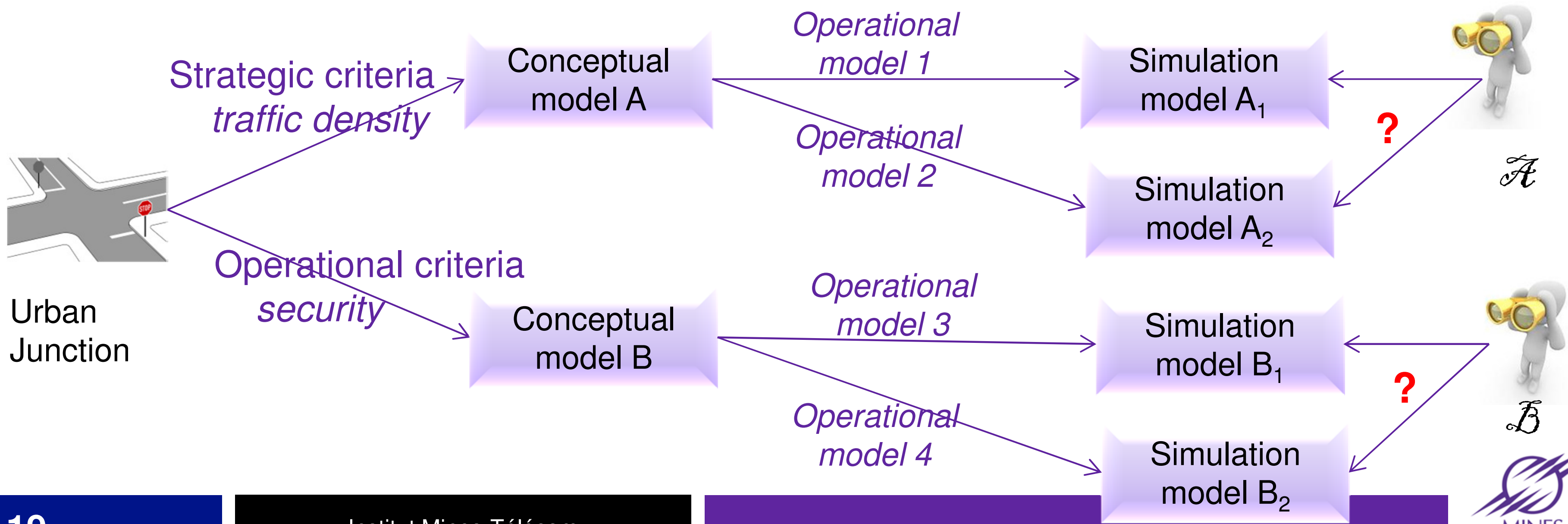
Designing a simulation model - *models*

- **Operational model**
  - The model of the numerical system processing the simulation
    - A temporal processing model
    - A model to represent elements of the conceptual model
- **Simulation model**
  - The resulting translation of the conceptual model according to the operational model



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Designing a simulation model - *example*

- **Intelligent Driver Model (Treiber'00)**
  - Mathematical

$$\frac{dv}{dt} = a\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*(v,\Delta v)}{s}\right)^2\right]$$

$$s^*(v,\Delta v) = s_0 + \max\left[0,\ \left(vT + \frac{v\Delta v}{2\sqrt{ab}}\right)\right]$$

- Desired speed when driving on a free road, $\mathbf{v_0}$
- Desired safety time headway when following other vehicles, **T**
- Acceleration in everyday traffic, **a**
- "comfortable" braking deceleration in everyday traffic, **b**
- Minimum bumper-to-bumper distance to the front vehicle, s_0
- Acceleration exponent, δ.

- Algorithm

new speed:

$v(t+\Delta t)=v(t) + (dv/dt)\ \Delta t$,

new position:

$x(t+\Delta t)=x(t)+v(t)\Delta t+1/2(dv/dt)\ (\Delta t)^2$,

new gap:

$s(t+\Delta t) = x_l(t+\Delta t) - x(t+\Delta t) - L_1$.

- dv/dt is the IDM acceleration calculated at time t,
- x is the position of the front bumper,
- L_l the length of the leading

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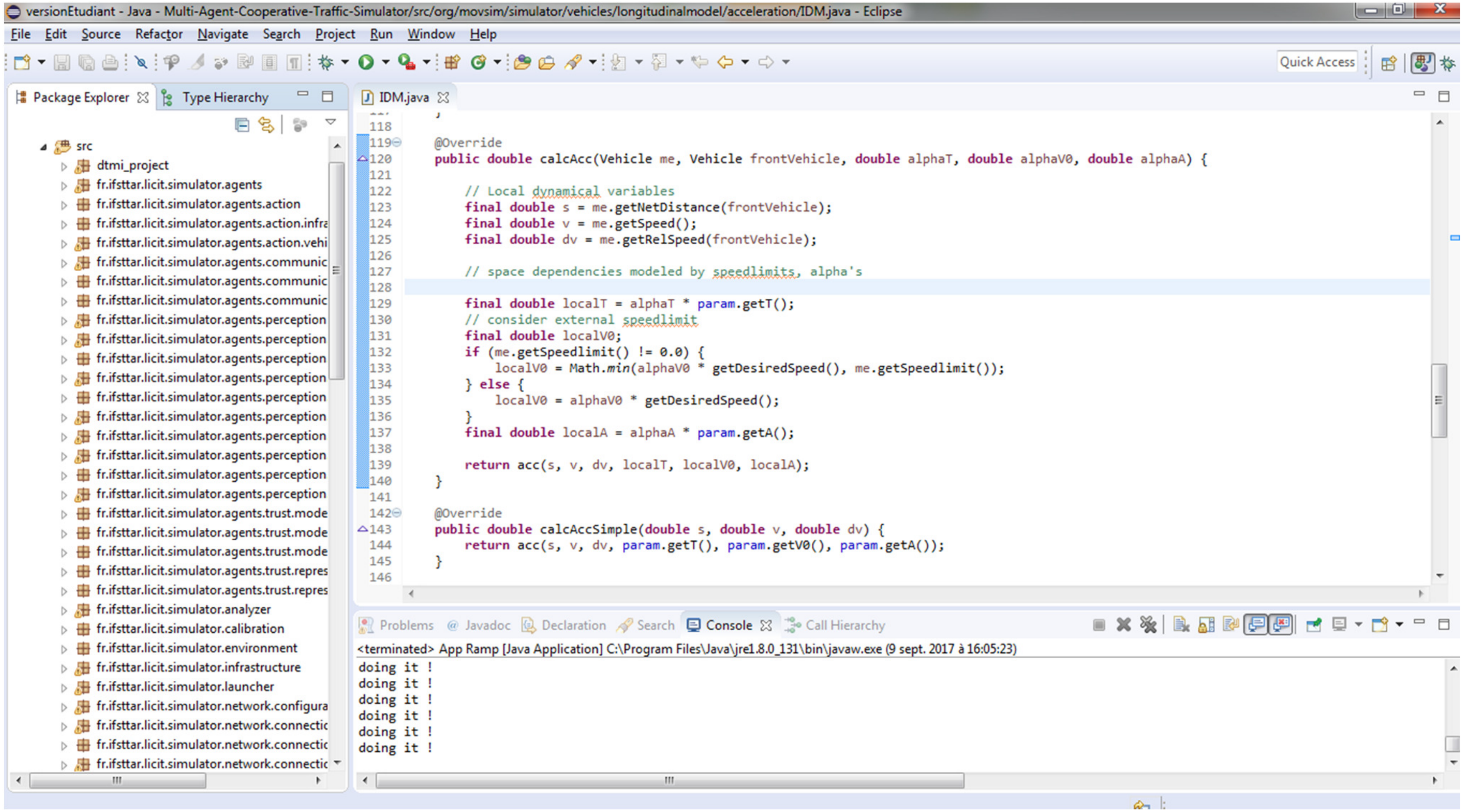
Designing a simulation model - *example*



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Designing a simulation model - *methodology*

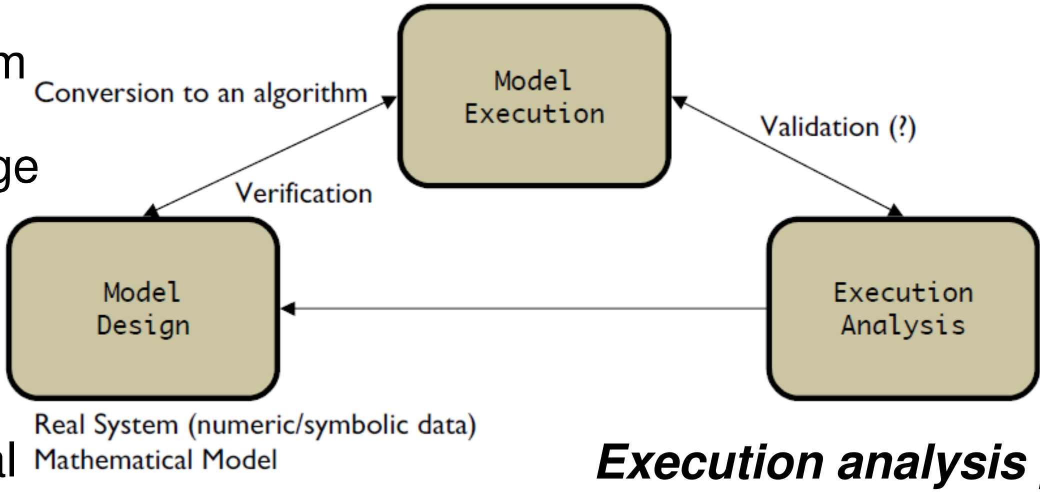
Model design phase associates the real system with a representation of this system (*the model*).

This model is built from real observations (objective) or knowledge (subjective).

Data are usually formalized using formal semantics or mathematical logic to reduce ambiguities as much as possible.

It is then converted to algorithms,

Model execution phase is the processing of the algorithm to produce numerical outputs.



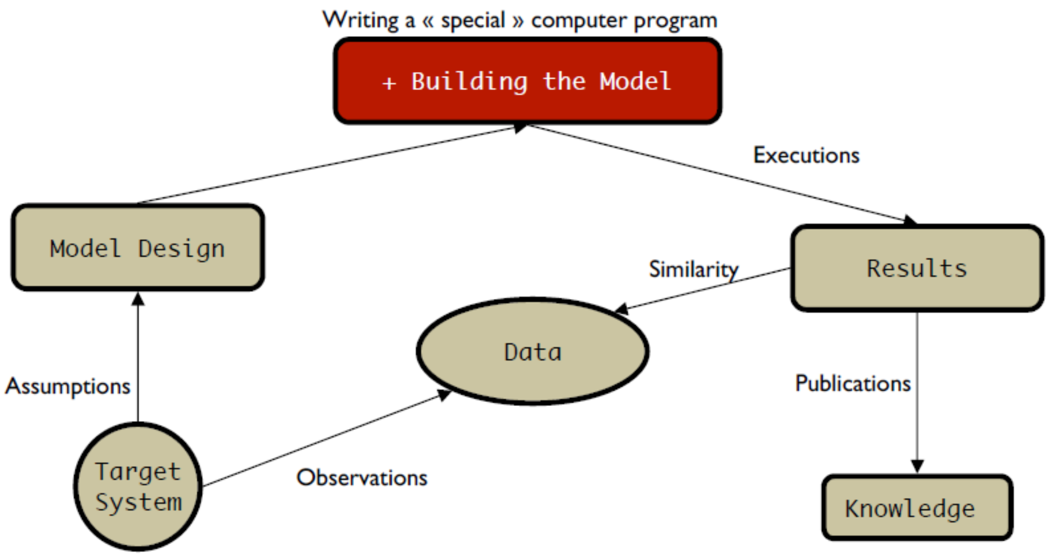
Execution analysis phase deals with the analysis and confrontation of the results of the program with the behaviors observed in the model.

Fiswick proposal (taken from Drogoul'03)

Numerical Simulation

Designing a simulation model - *methodology*

- **Refine the Fishwick proposal with the addition of the model building phase**
- **The initial model is written into a computer program: the operational model**
  - Adaptation to the simulator
  - There are both operational models and Simulators.
  - The differences between models introduces bias.



Gilbert, N., Troitzsch'99 *proposal (taken from Drogoul'03)*

Numerical Simulation

Designing a simulation model - *Conceptual modeling*

- Key facets of conceptual modeling (Robinson'06)
  - *"Conceptual modeling is about moving from a problem situation, through model requirements to a definition of what is going to be modeled and how.*
  - *Conceptual modeling is iterative and repetitive, with the model being continually revised throughout a modeling study.*
  - *The conceptual model is a simplified representation of the real system.*
  - *The conceptual model is independent of the model code or software, while model design includes both the conceptual model and the design of the code (Fishwick 1995).*
  - *The perspective of the client and the modeler are both important in conceptual modeling. "*

Numerical simulation

Presentation

Designing a simulation model

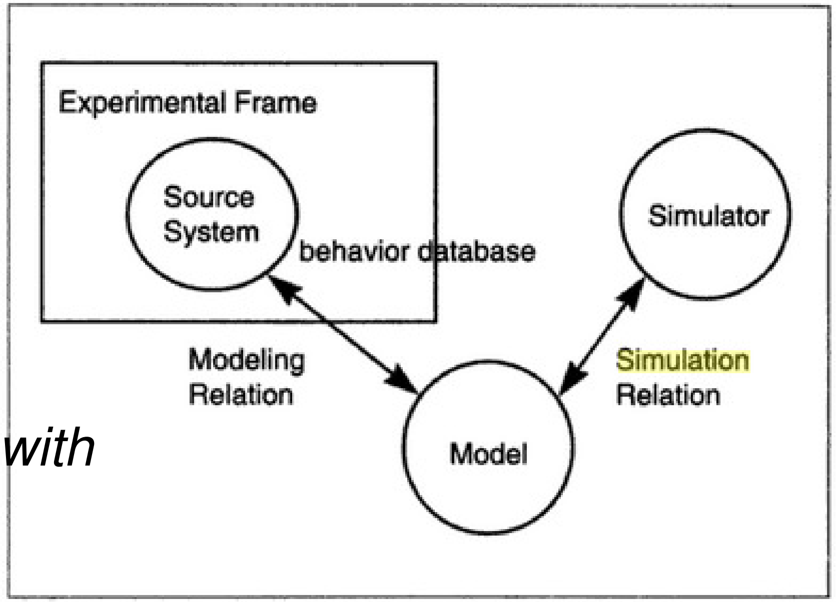
Executing a simulation model

Simulation challenges

Numerical Simulation

Executing a simulation model - *Abstraction*

- ***Source system***
  - *Real or artificial source of data*
- ***Behavior database***
  - *Collection of gathered data*
- ***Experimental frame***
  - *Conditions under which the system is observed or experimented with*
- ***Model***
  - *Instruction for generating data*
- ***Simulator***
  - *Computational device for generating behavior of the model*



From Zeigler'00

What is the relation between the process "generating behavior of the model" and time ?

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Executing a simulation model - *Time*

- ***Role***
  - *Create a reference for ordering events and observations of the simulated system*
- ***Time taxonomy***
  - *Physical time*
    - *Measured by ticks of physical clocks*
  - *Logical time*
    - *Measured by ticks of a clock somehow embedded in the system*
  - *Global time*
    - Valid for the global system
  - *Local time*
    - Valid for a subset of components of the system
- ***Simulation***
  - *Mainly considered as logical and global*

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Executing a simulation model - *Temporal model*

- **Definition**
  - A temporal model rules how the value of the time variable evolves in time during the simulation execution

Let M be the numerical simulation of the system S, what is the value M(t) with t<T, T being the time horizon?

- **The time value *t* can evolve**
  - *Continuously*
    - *t* is a real number.
    - Events and observations can be stamped at every time values.
  - *Discretely*
    - t is a multiple of a time step.
    - Events and observations can only be stamped at one of these multiples.
  - By events
    - Time value evolves following a set of predefined or computed events
    - Observations can only be stamped at one of these time value.

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Executing a simulation model - *Continuous temporal model*

- **Formalism**
  - *DESS* : Differential Equation System Specification.
  - Derivative functions specify the rate of change of the state variables.
    - At any particular time instant on the time axis, given a state and an input value, we only know the rate of change of the state.
    - From this information, the state at any point in the future has to be computed.
  - *Example*

$$\frac{dx(t)}{dt} = x(\alpha - \beta y) \quad \text{et} \quad \frac{dy(t)}{dt} = -y(\gamma - \delta x)$$

    - With
      - x: number of preys
      - y: number of predators
      - $\alpha,\beta,\gamma,\delta$ specify the interactions between preys and predators.

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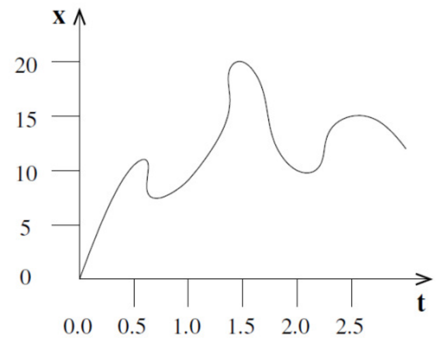
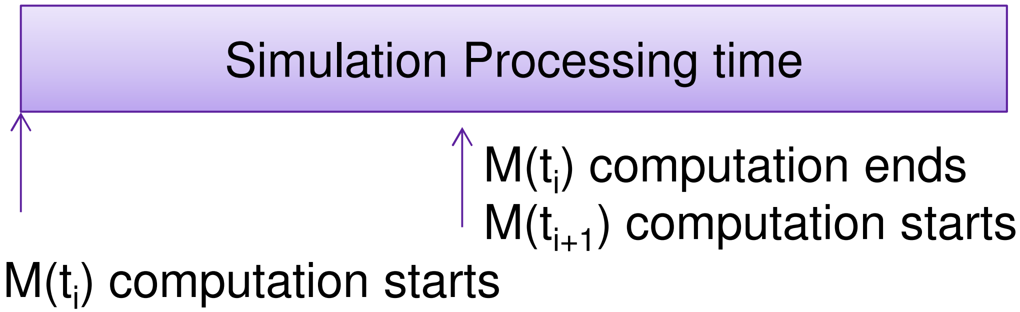
Numerical Simulation

Executing a simulation model - *Continuous temporal model*



Conceptual Model evolution following a continuous temporal model



- **The processing time is discrete**
  - a nonzero interval between two simulation processing moments ($[t_i, t_{i+1}]$)
  - Computation has a duration
- **Model is supposed to be operating in continuous time during this interval**
- **The value of the input variable values has to be estimates at time t_{i+1} from the known output values at time t_i**

Solution: numerical integration methods

Numerical Simulation

Executing a simulation model - *Discrete temporal model*

- **Formalism**
  - DTSS: Discrete Time System Specification
  - Time advances in discrete step, which are integer multiples of some basic period such as 1 second, 1 day or …
  - If the state at time *t* is *q* and the input time *t* is x, then the state at time t+1 will be $\delta(q,x)$. δ is called the state transition function
- **Example**

new speed:

$$v(t+\Delta t)=v(t) + (dv/dt)\,\Delta t,$$

new position:

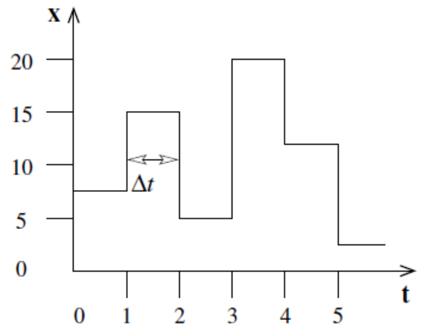
$$x(t+\Delta t)=x(t)+v(t)\Delta t+1/2(dv/dt)\,(\Delta t)^2,$$

new gap:

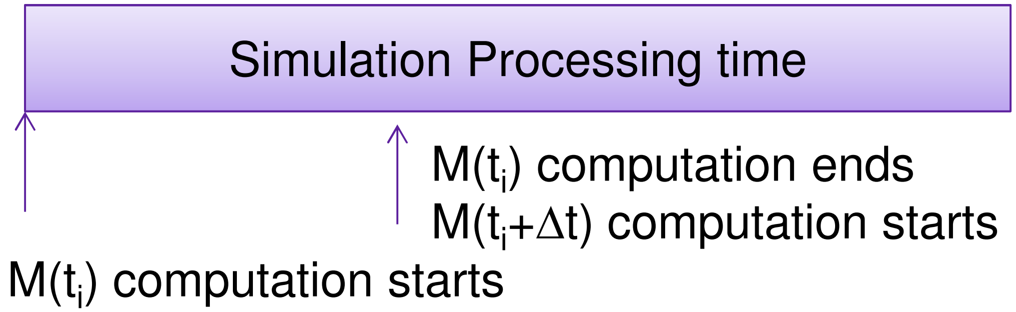
$$s(t+\Delta t) =xl(t+\Delta t)- x(t+\Delta t)- L_1.$$

Numerical Simulation

Executing a simulation model - *Discrete temporal model*



Conceptual model evolution following a discrete temporal model



- Time has a logical value that can be uncorrelated of the duration of the computation of a simulation step
- Simulation time is modified by the simulator

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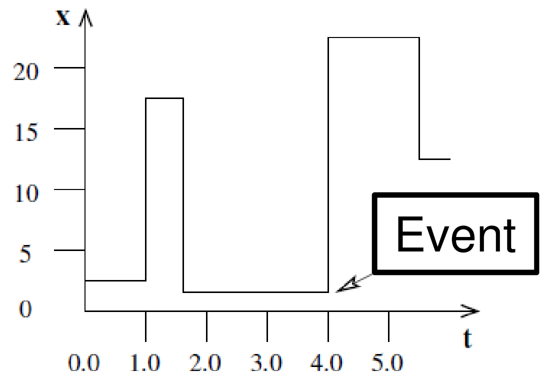
Numerical Simulation

Executing a simulation model – *Event temporal model*

- **Formalism**
  - DEVS: Discrete EVent Simulation.
  - Time value evolves following a set of predefined or computed events.

- **Examples of event**
  - a customer arrives at a shop,
  - a truck finishes unloading,
  - a conveyor stops,
  - a new product is launched,



Numerical simulation

Presentation

Designing a simulation model

Executing a simulation model

Simulation challenges

Numerical Simulation

Simulation Challenges – *Simulation modeling*

- **Issue**

  "*The design of the model impacts all aspects of simulation study*"

  (Robinson'06)

- **In particular** (Robinson'00)
  - Data requirements,
  - The speed with which the simulation model can be developed,
  - The validity of the model,
  - The speed of the experiments,
  - The confidence that is placed in the results.

- **A conceptual model should be**
  - Complete
    - Every vague, incomplete or ambiguous knowledge of the expert has been clarified
  - Realistic
    - It is close enough of the real model and can be numerically simulated,
    - Maintaining a relation between the duration of simulated process in silico and in vivo
  - Valid
    - It reproduces the input-output behaviors with sufficient fidelity within the experimental frame

Numerical Simulation

Simulation Challenges – *Simulation executing*

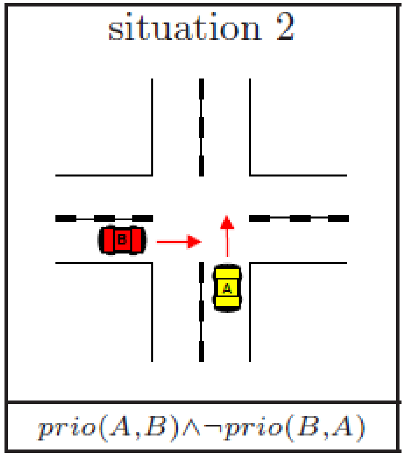
- **Time management**
  - Ensuring a global time when
    - Simulator is distributed among computer nodes in a network,
    - Simulator is interacting with real world components
      - Human in the loop
  - Ensuring a pseudo simultaneity between parallel, simulated processes
    - Ensuring equity in execution between processes,
    - Ensuring coherence of shared resources like spatial environment.
    - Ensuring reproducibility of interactions between parallel process

- Simulation management
  - Ensuring simulation determinism and reproducibility,
  - Ensuring scalability of the simulation.

Numerical Simulation

Simulation Challenges – *Simultaneity*

- **Microscopic simulation with discrete temporal model**
  - Let *t* be the simulation time value and $a_i(t,q(t))$ the action of the i^{th} agent following the current state of the simulated system q(t)
  - How to ensure that q(t) will be the same for a_i and a_{i+1} since $a_i(t,q(t))$ modifies the current state



Doniec'05

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Multiagent-based Simulation (MABS)

MABS modeling approach

MABS platforms

MABS discussions

Multiagent-based Simulation (MABS)

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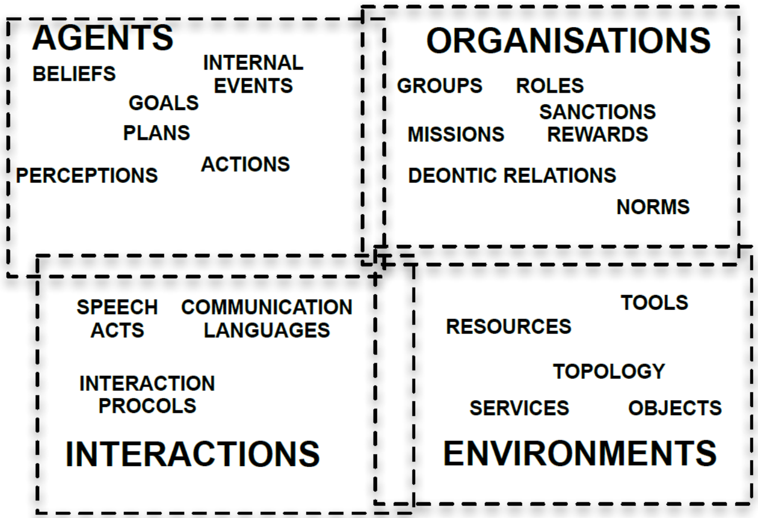
Multiagent-based Simulation (MABS)

MABS modeling approach – MAS

A Multi-Agent Oriented (**MAO**) Modeling of a multi-agent system **MAS** consists in identifying the agents' e*nvironment* ***E***, the set of *agents* ***A***, the agents' *organization* ***O*** and the interactions ***I*** taking place among the elements of A, of A with the elements of E under the coordination and regulation of O

***MAS* = < *A, E, O, I* >**



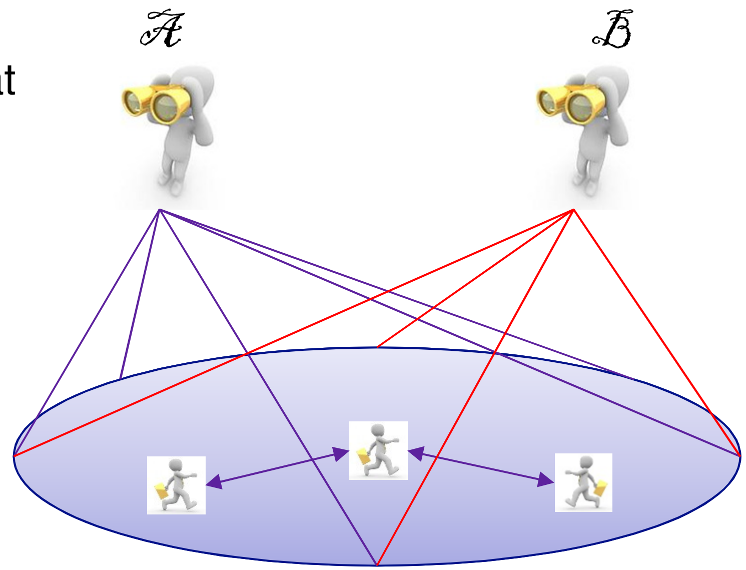
VOWELS Dimensions (Demazeau'95)

Multiagent-based Simulation (MABS)

MABS modeling approach – MAS to MABS

- **MAS: bottom-up modeling approach**
  - Modeling of the behavior of the components of the real system.
    - The components: the agents
    - Their relation: interaction and organization at a microscopic level.
  - Observation, analyze of properties of the system at a macroscopic level.
- **MABS: executing a MAS model**
  - Conceptual model: MAS concepts
    - A: reactive, cognitive, hybrid agents ???
    - E: physic, social, … ????
    - O: regimentation, enforcement, … ???
    - I: direct indirect, negotiation protocols, ???
  - Operational model: MAS dimensions implementation
    - Implementation MAS conceptual model in MAS platform X
    - Implementation MAS conceptual model from scratch
  - Simulation model: executing MAS following a temporal model

Observation of the simulation model at macro level.

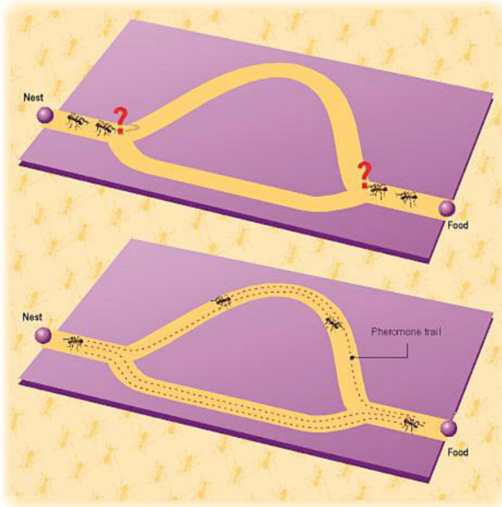


modeling of the reference system at micro level.

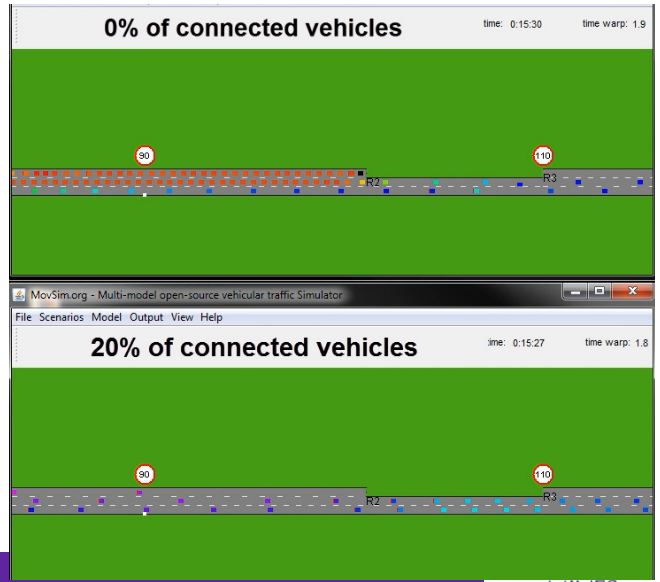
Multiagent-based Simulation (MABS)

MABS modeling approach – MAS to MABS

- **Example: Ants**
  - *Conceptual model*
    - Ants are reactive agents (A) which move (E - I) and put pheromones (I) in the environment. The MAS find the shortest path (O)
  - *Operational model*
    - Ants are Turtles, Environment is a grid of patches, ….



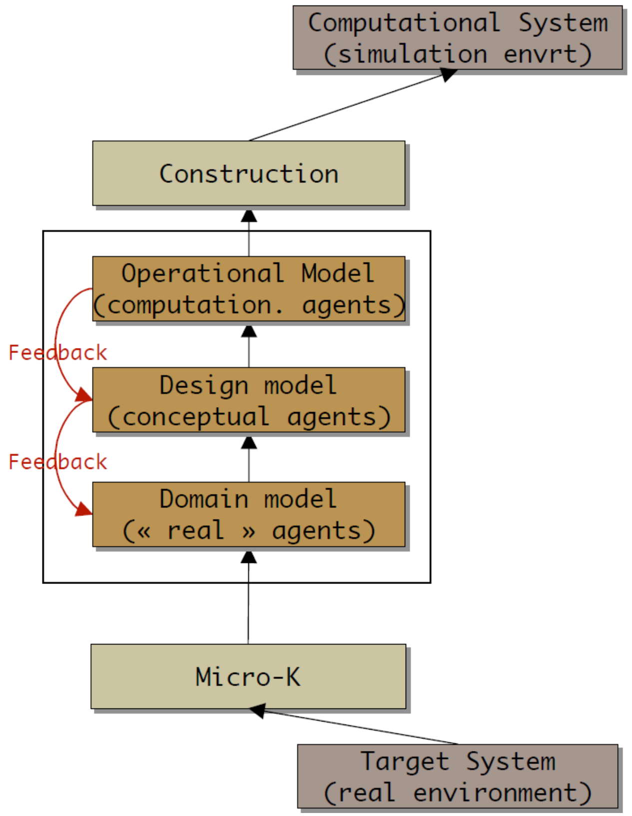
- **Example: Traffic**
  - *Conceptual model*
    - Connected vehicles are agents (A) which move (E - I) and communicate by messages (I). The MAS improve the fluidity of the traffic (O).
  - *Operational model*
    - Connected vehicles are Vehicles, Environment is a graph, communication is based on broadcast …



Multiagent-based Simulation (MABS)

MABS modeling approach – methodology

- **The Thematician (expert of the domain)**
  - *Role*: Defines the intention of the simulation process.
  - *Result*: the domain model which describes the multiagent model of the reality. The agents are informally associated to the components of the system and their relations are identified (interaction, organization).
- **The modeler**
  - *Role*: He translates the knowledge of the thematician.
  - *Result*: the design model where the agents are a refinement of the agents in the domain model. Their properties are expressed using concepts taken from multiagent domain (behavioral model, communications, …)
- **The Computer Scientist**
  - *Role*: He designs the operational model and writes the computer program.
  - *Result*: the computational system where agents are computational agents.



From Drogoul'03

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Multiagent-based Simulation (MABS)

MABS modeling approach

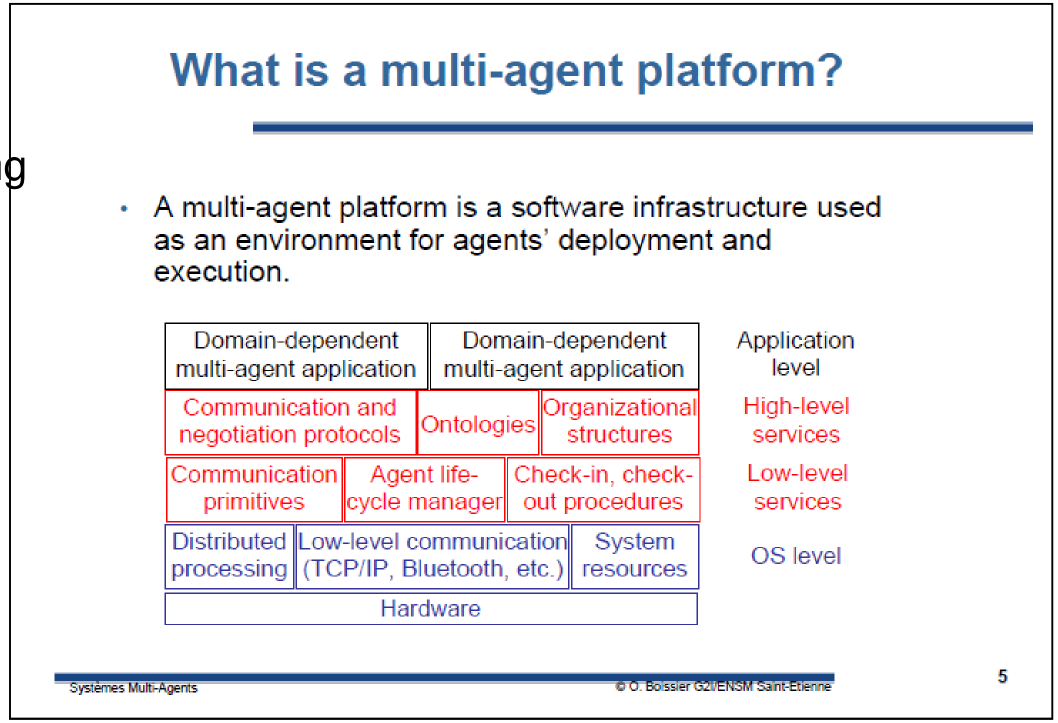
MABS platforms

MABS discussions

Multiagent-based Simulation (MABS)

MABS platforms – Taxonomy

- **MAS Abstract architecture**
  - OS Level: interface with resources (processor, network, file system
  - Low-level services: platform management:
    - commands for sending/ receiving messages
    - commands for creating, executing, killing agents
    - commands for check-in/check out agents
  - High-level services: operational model implementation
    - Interaction protocols
    - Organization management
    - Environment: Global Knowledge, physical representation
  - Application level: operational model instantiation



- **Simulation with a MAS abstract architecture**
  - New component: a scheduler
    - Respect a temporal model
      - *Continuous*: time value is used to synchronize agents' behavior BUT does not schedule their behaviors
      - *Discrete/Event*: time value is used to schedule agent behavior
    - Execute a scheduling policy
      - Defines the rules to activate or deactivate an agent during the simulation process.
      - Two scheduling model
        - Preemptive

"In computing, preemption is the act of temporarily interrupting a task being carried out by a computer system, without requiring its cooperation, and with the intention of resuming the task at a later time" (Wikipedia)

- Cooperative (non preemptive)

"the operating system never initiates a context switch from a running process to another process. Instead, processes voluntarily yield control periodically or when idle in order to enable multiple applications to be run simultaneously." (Wikipedia)

Multiagent-based Simulation (MABS)

MABS platforms– Multiagent scheduler

- **Scheduling algorithm based on a continuous temporal model with a preemptive policy**

```
T /* duration of the simulation */
time = System.time();
T = time + T
Agents = {agents of the simulation};
for (a : Agents)
        activate(a)
while (time < T)
   time = System.time();
```

The agents' behavior is parallelized

→ Additional and independent synchronization mechanism(s) can be required

Simulation duration is the processing duration

→ Simulation duration analyze must integrate information about the configuration of the material

Agents are not conscious of their interruption

→ Non coherent behaviors are possible

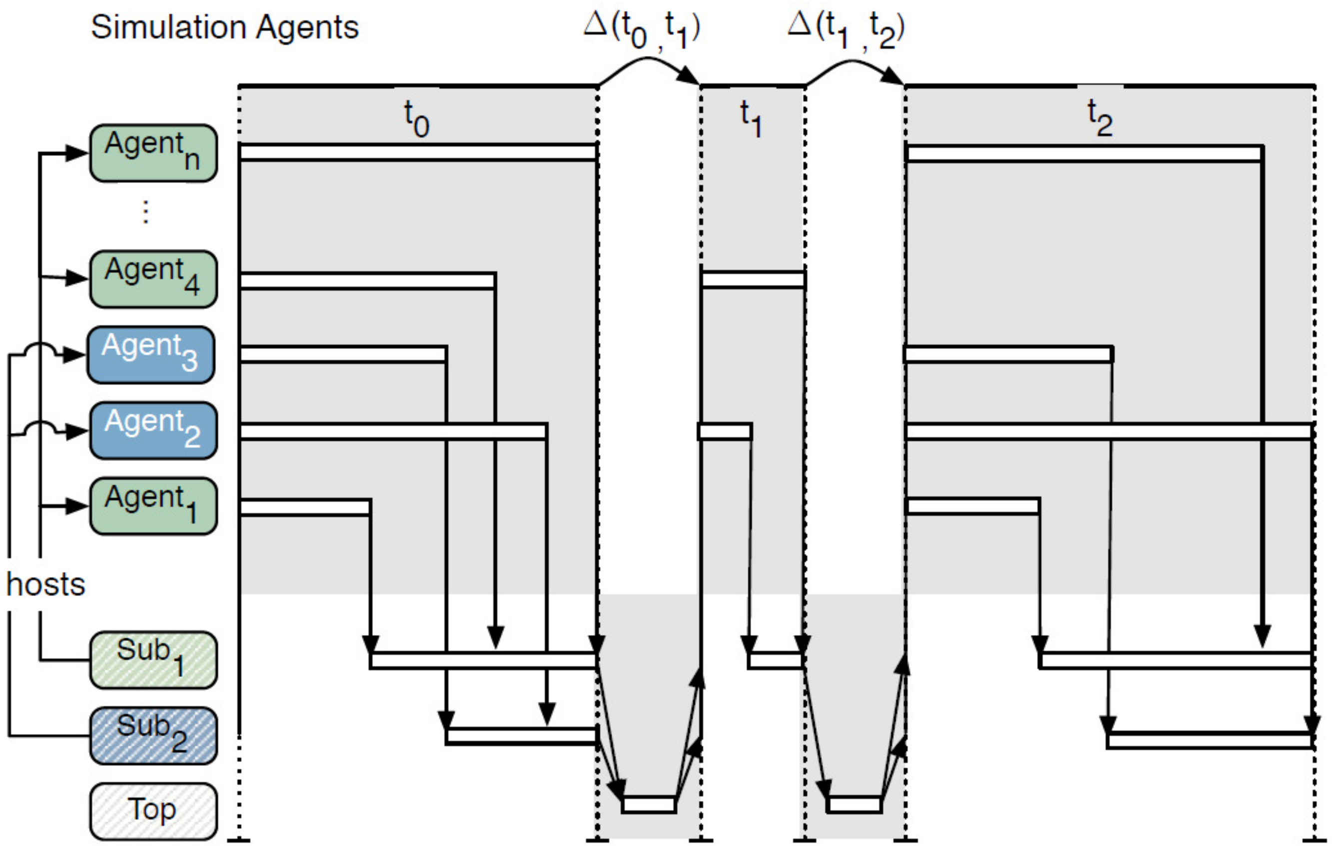
Multiagent-based Simulation (MABS)

MABS platforms– Multiagent scheduler

“The platform is based on the FIPA-compliant Java Agent Development Framework (JADE). JADE offers components for agent communication and coordination. PlaSMA extends this architecture as a simulation middleware for discrete event time progression.”

plasma.informatik.uni-bremen.de

(Warden’10)



Multiagent-based Simulation (MABS)

MABS platforms– Multiagent scheduler

- **Scheduling algorithm based on a discrete temporal model and a cooperative policy**

```
T  /* duration of the simulation */
delta /* step of the simulation */
time = 0;
Agents= {agents of the simulation};
while (time < T) {
    for (a: Agents){
      /* activate(a) */
        contextComputation(a)      ┐
        decisionProcess(a)         ├ A cycle
        actionProcessing(a)        ┘
    }
    time = time + delta
}
```

The agents' behavior is scheduled
- → Each agent execute one cycle in his turn
- → Costly repetitive useless computation

Simulation duration has a logical value (number of cycles) and a physical value (simulation duration)
- → Modeler must cut Agent behavior in actions with a similar duration to respect a temporal equity between agents.

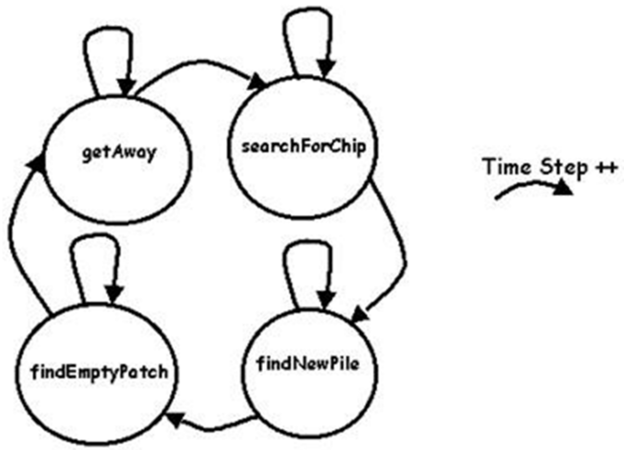
Agents are conscious of their interruption
- → At the same time step, the agents execute action according to the current simulation context
- → Simultaneity must be simulated and managed: for the same time step, the agents have different context

MABS platforms– Multiagent scheduler

- **Alternative scheduling algorithms**
  - A common objective: using contextual information to limit the cost of the activation process
  - Agents are activated by the scheduler according to their contexts
- **Solutions**
  - Netlogo like scheduling algorithm: automate management
    - Scheduler activates action according to the automat of the agents
  - In Jedi platform: interaction matrix management
    - Scheduler computes relevant interaction and activates agents with this information
  - In Repast Simphony platform: “watchers” management
    - Scheduler monitors watchers that allow an agent to be notified of a state change in another agent and schedule the resulting action.
  - In EASS platform: “filters” management
    - Scheduler manages a set of filters, each of them defines a context and the associated action.

Netlogo like scheduling algorithm

```
time = 0; Turtle = {turtles of the simulation}; T duration of the simulation
while (time < T)
        for (t: Turtle)
                t.currentAction = scheduler.getCurrentActionTurtle(t)
                t.nextAction = activate(t,currentAction)
                scheduler.setCurrentActionTurtle(t,nextAction)
 time++
```



Multiagent-based Simulation (MABS)

MABS platforms– Multiagent scheduler

- **In Jedi platform: interaction matrix management (Kubera'11)**
  - Scheduler computes relevant interaction and activates agents with this information

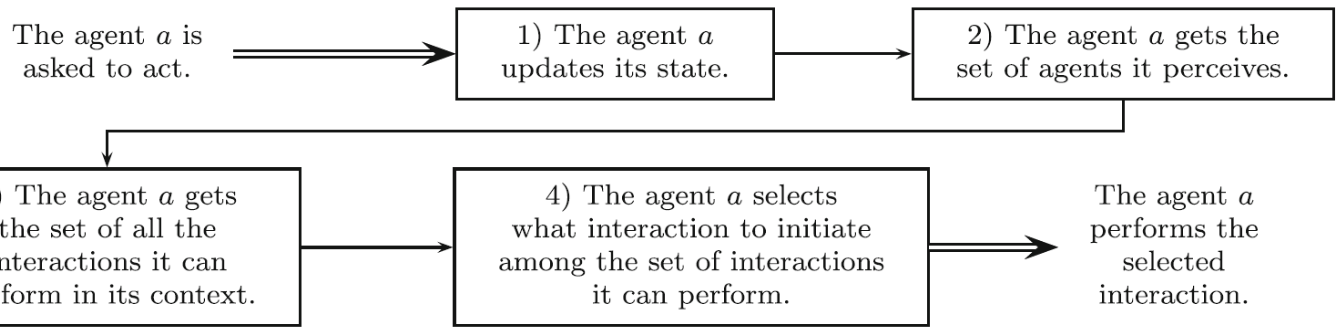
Table 2 Raw Interaction Matrix of an ecosystem simulation, where wolves, sheep, goats and grass agents evolve

Source \ Target	∅	Grass	Sheep	Goat	Wolf
Grass	(Grow)				
Sheep	(Move)	(Eat, d = 0)	(Procreate, d = 1)		
Goat	(Move)	(Eat, d = 0)		(Procreate, d = 1)	
Wolf	(Move)		(Eat, d = 3)	(Eat, d = 3)	(Procreate, d = 1)

The element *(Eat, d = 0)* at the intersection of the row starting with *Sheep* and the column starting with *Grass* is read "Sheep agents are able to initiate the Eat interaction with a target Grass agent at a maximal distance of 0 from the source"

Interaction Matrix example

Activation process



Multiagent-based Simulation (MABS)

MABS platforms– Multiagent scheduler

- **In EASS platform: "filters" management (Badeig'10)**
  - Scheduler manages a set of filters, each of them defines a context and the associated action.

Modelling agent behavior

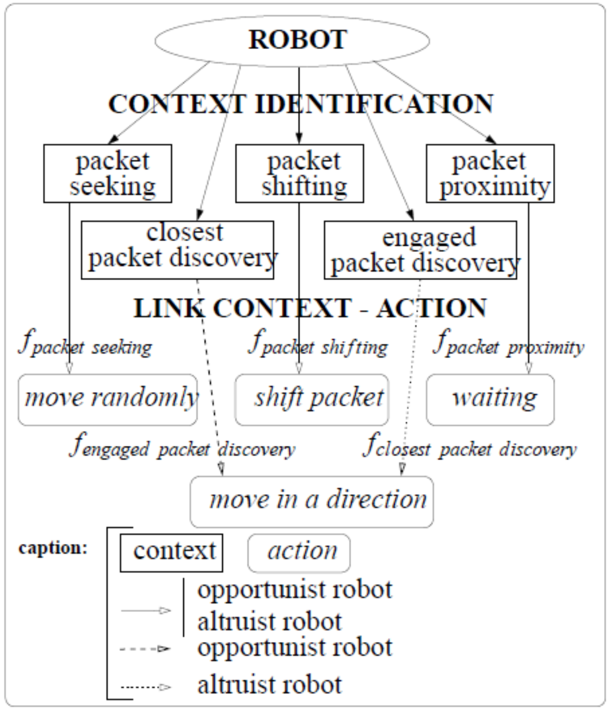


Figure 2: agent behaviors and activation context.

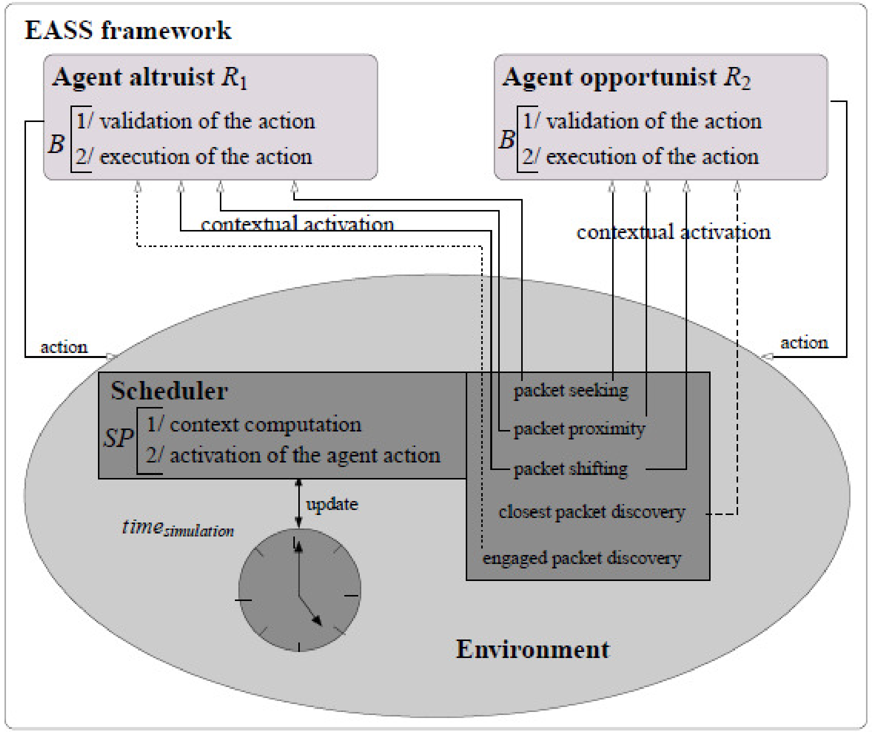


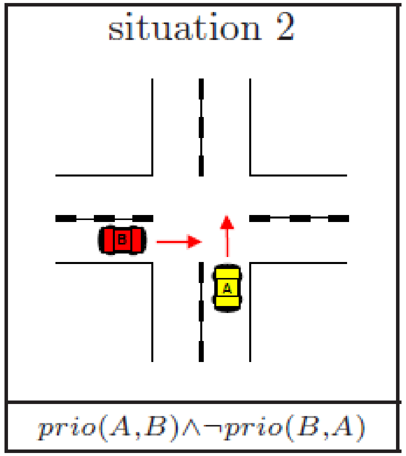
Figure 3: Contextual activation approach.

Activation process

Numerical Simulation

Simulation Challenges – *Simultaneity*

- **Microscopic simulation with discrete temporal model**
  - Let *t* be the simulation time value and $a_i(t,q(t))$ the action of the i^{th} agent following the current state of the simulated system q(t)
  - How to ensure that q(t) will be the same for a_i and a_{i+1} since $a_i(t,q(t))$ modifies the current state



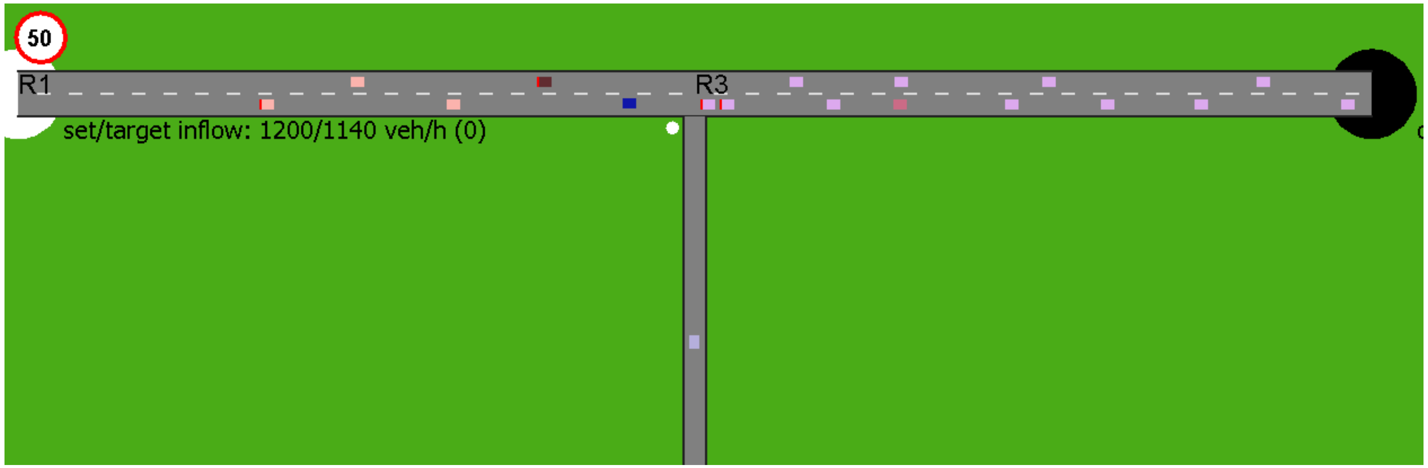
Doniec'05

Doniec'05

Numerical Simulation

Simulation Challenges – *Simultaneity*

- **Solution based on the scheduling policy**
  - The activation order of the agents is randomized
  - If the number of agents and simulation steps are important then no agent should be advantaged.
  - If the simulation must be replayed, the random process has to be taken into account by the simulation model.



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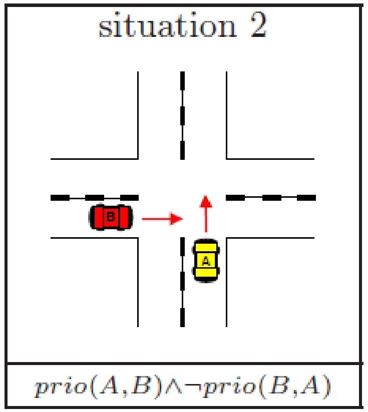
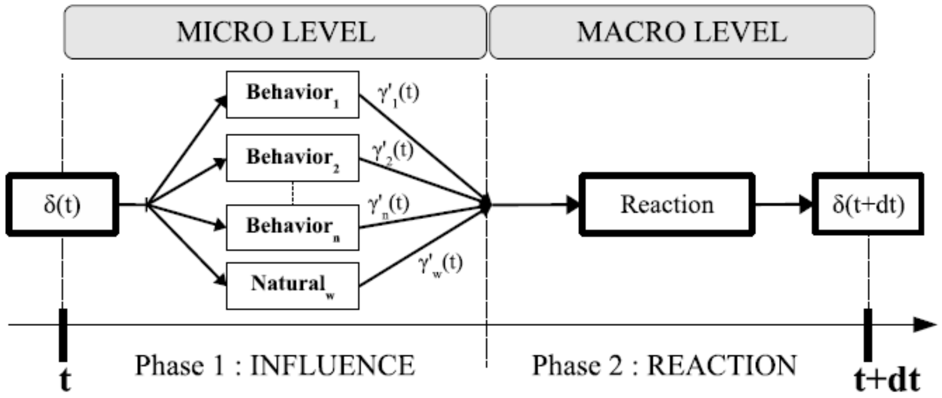
Simultaneity issues

Solution

- **Solution based on a conflict resolution process**
  - The agents are activated in the same simulation state and the antagonism between their action is resolved by a decision process.
  - Influence / reaction model: The agents do not directly act in the simulation but emit influences that are validated by the decision process.





IRM4S

Michel'07 **Ferber'96**

Multiagent-based Simulation (MABS)

MABS modeling approach – Taxonomy

- **The operational, simulated model can be executed on**
  - Generic multi-agent platforms
    - *Advantage*: the computer scientist knows his environment, i.e. the platform and the related multi-agent model.
    - *Limit*: The platform must be adapted (or not) to support the simulation,
    - *Example*: JASON, JADE (Tapas, PlaSMA), MASH, MADKIT (Turtlekit)
  - Generic simulation platforms
    - *Advantage*: the computer scientist can use the same environment for different design models.
    - *Limit*: a new operational model has to be built for each new simulations.
    - *Example*: MASON, SWARM, GAMA, CORMAS, TURTLEKIT, REPAST, NETLOGO, …
  - Specialized simulation platforms
    - *Advantage*: some parts of the operational model can be already available.
    - *Limit*: adaptation to a new platform.
    - *Example* (traffic simulation platform): Archisim ,MATSim, MITSIMlab, …

Multiagent-based Simulation (MABS)

MABS modeling approach

MABS platforms

MABS discussions

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Numerical Simulation

Conclusion

- **Why use simulations ?**
  - Because the real system cannot be stopped,
  - Because the study of the real system is expensive,
  - Because the understanding of the real system has to be improved,
  - Because the relation between the system and the time has to be study,
  - Because it is less dangerous than manipulate the real system.
- **Why do not use simulations ?**
  - Because the model remains an approximation of the real system,
  - Because the result can be biased by the processing of the model on a computer.

Multiagent-based Simulation (MABS)

Conclusion

- **Advantages**
  - MABS supports multi-level modeling
    - Different models of “individuals”: from simple entities to more complex ones.
    - Different levels of representation: “individuals” and “groups” within an unified conceptual framework.
  - MABS supports modeling of complex systems
    - Structure preserving modeling of the simulated reality,
    - simulation of proactive behaviors,
    - Parallel computations,
    - Dynamic simulation scenarios
- **Limits**
  - Computation costs

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