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Federated Agent Based Modeling and simulation: a new approach to study interdependencies in Critical Infrastructures

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Agenda

- An introduction to critical infrastructures
- Motivations
- Existing approaches
- The simulation approach (in general)
- The federated Agent-based modeling and simulation approach

Critical Infrastructures

- A critical infrastructure is a physical system that, if disrupted, can seriously affect the national security and the economic and social welfare of a nation. Ex.:
  - Power grid
  - Communication (and computer) networks
  - Transportation Network
  - Gas, Oil and water distribution systems
  - Banking and financial systems
- A CI is composed by different components (included humans) dependents on each other
- **CI are intertwined and heavily dependent on each other (interdependent)**

Motivation

- To design security and protection mechanisms for critical infrastructures its fundamental the knowledge of :
  - complex systems behavior,
  - systems interdependencies
  - emergent phenomena originated by systems interactions
- A challenge is to provide formalisms, methodologies and tools to model the complex system composed of critical infrastructures

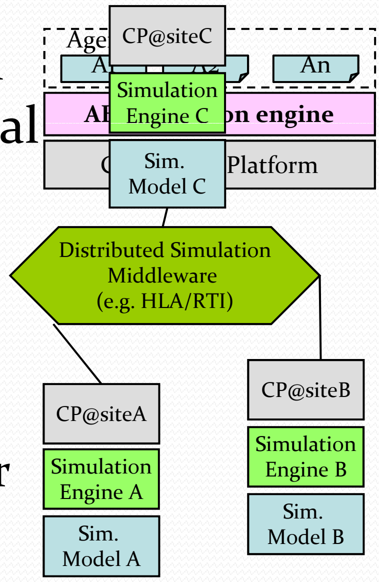
Current approaches

- Macro-analysis approaches (or interdependencies analysis)*
  - Input-output Leontief model, analyze how the inoperability is propagated through interconnected infrastructures
  - Influence model, where each infrastructure is modeled as a Markov chain, whose evolution is influenced not only by its own state, but also by the states of the chain of the neighboring sites
  - Propagation of failure is also studied using Petri nets
- Micro-analysis approach (or systems analysis)
  - Any kind of simulation approach
  - Agent-based modeling and simulation

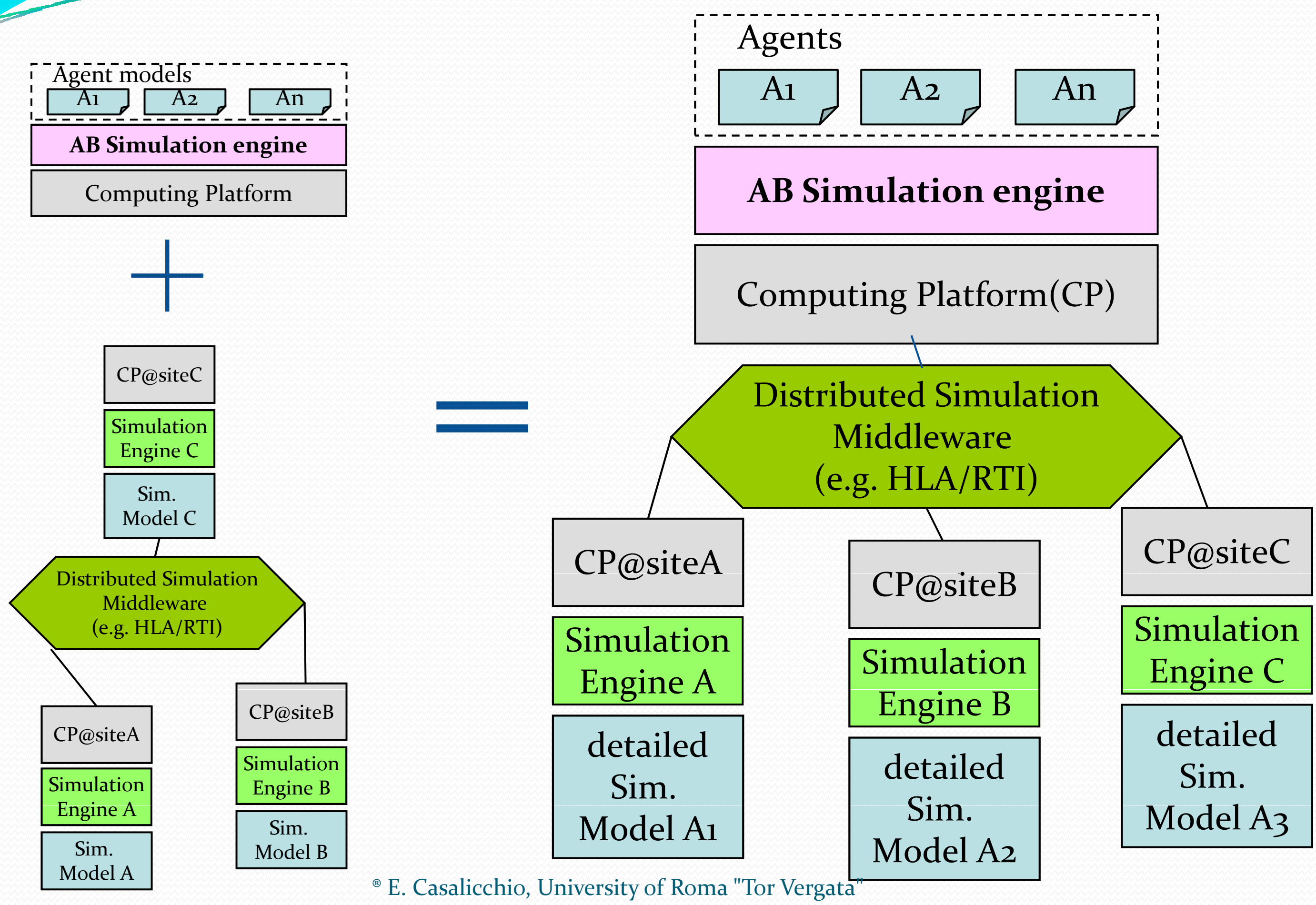
* P.Donzelli, E.Casalicchio, R.Setola, S.Tucci, "Modelling and Simulation of Interdependent Critical Infrastructure: The Road Ahead", Chapter 9 in Communication Network & Complex Systems, Imperial College Press, 2006

What we propose: the Federated ABMS approach

- A new modeling and simulation formalism that exploits the power of both
  - Agent Based Modeling and Simulation (ABMS)
  - Federated simulation
- ABMS use a bottom-up approach to model the whole system starting from its individual parts
- Federated simulation is a technique that allows to
  - reuse existing simulation model
  - distribute the execution of a simulation over a set of computational nodes



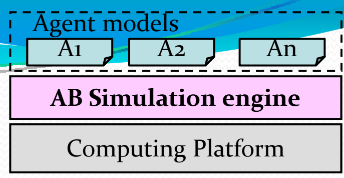
FederatedABMS



Novelty of our approach

- We use ABMS capabilities to give a natural high level description of the infrastructure model and its interdependencies
- We exploit federated simulation capabilities
  - to detail the infrastructures models integrating existing simulation models
  - To use remote resources and distributed computational power
  - To allow remote access to a critical infrastructure simulation center

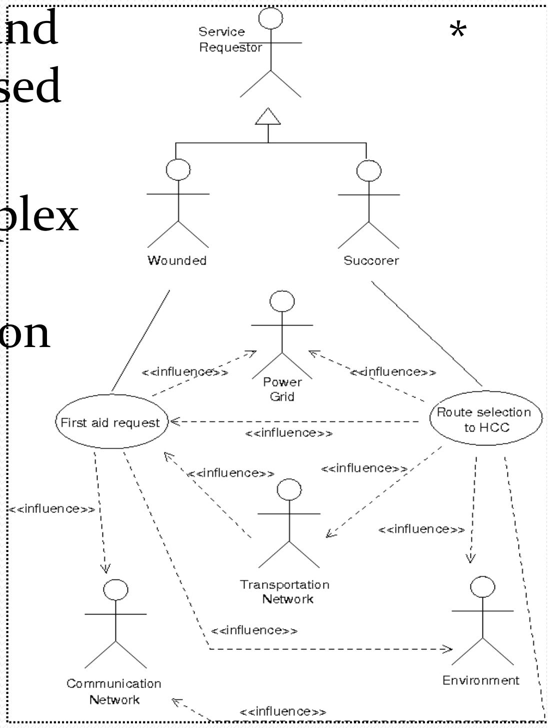
ABMS: more details



- An agent is an entity with a **location**, **capabilities** and **memory**
- **Location** define where it is in a physical or logical space
- What the entity can perform is defined by its **capabilities**:
  - Perception, an agent can modify its internal data representation
  - Behavior, it can modify its environment
  - Intelligent reaction, it can adapt itself to environment's changes
  - Cooperation, it can share knowledge, information and common strategies with other entity
  - Autonomy, it can execute actions without external intervention
- the experience history (for example, overuse or aging) and data defining the entity state represents agent's **memory**

ABMS: advantages

- Natural description of a system.
  - ABM is most natural for describing and simulating a complex system composed of behavioral entities
  - we can embed the model of the complex system into agents and model such system at different levels of abstraction
- Valid support to
  - Conduct what-if analysis
  - study the impact of an unexpected perturbation on the interconnected infrastructures



* V. Cardellini, E. Casalicchio, E. Galli, "Agent-based Modeling of Interdependencies in Critical Infrastructures through UML", Proc of SpringSim /Agent Discrete Simulation 2007, Norfalk, VA, March 2007.

ABMS: advantages (2)

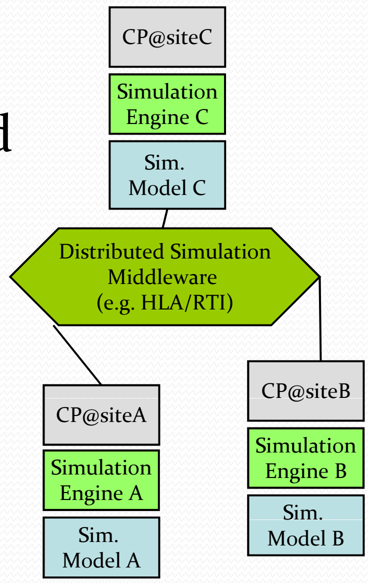
- Questions that we can answer using ABMS
  - What is the failure propagation path from the affected infrastructure to the interdependent ones and its propagation time?
  - What are the points of failure of a system or its parts?
  - What are the direct and side effects of a failure?
  - Can the system react to at certain type of failure and how much time does the reaction take?
  - What is the impact of a miss behavior in a recovery plan?

An open issue

- What are the more appropriate metrics to better highlight the effect of CI interdependencies?
- Strictly connected with the domain under study
- This impose the collection of an huge quantity of data during simulation for post-processing

Federated simulation: Advantages

- Simulation models and software reuse
- Execution of a simulation over a distributed platform (locally or geographically distributed)



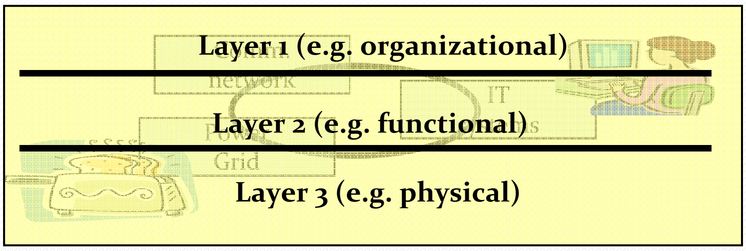
- Development cost reduction
- Knowledge (expertise) and data (workload) sharing

® E. Casalicchio, University of Roma "Tor Vergata"

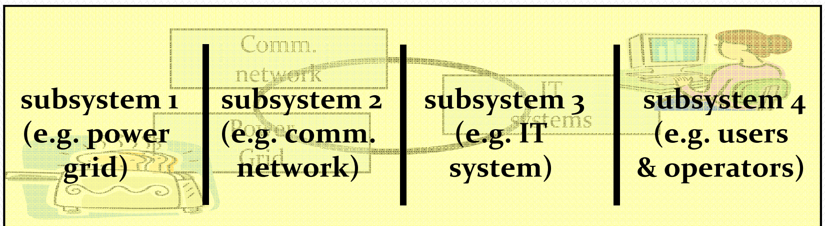
Federated ABMS: the federates boundaries problem

- One of the main issues in designing federated simulation model is
  - *"how to chose the boundaries among federates?"*
- Two approaches: Vertical Partitioning and horizontal partitioning

Vertical boundaries

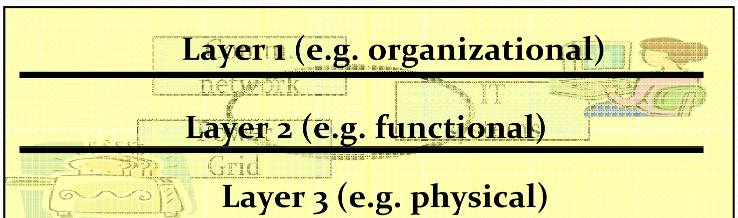


Horizontal boundaries



Federated ABMS: Vertical Partitioning

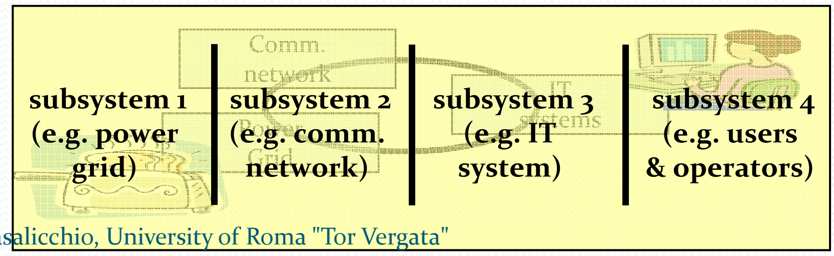
- It models the whole complex system as a set of layers
- E.g.:
  - the organizational layers, which models all the interaction rules among sub-systems;
  - the functional layer, which models all the functionalities exposed by each sub-system;
  - and the physical layer, which models the details of each sub-system
- Each layer is represented by a different model implemented and executed by a specific simulation framework. The different models (federates) are glued together in a federation.



Federated ABMS: Horizontal Partitioning

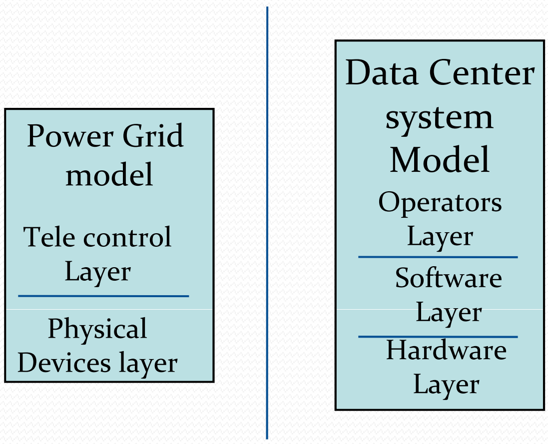
- Horizontal partitioning view the whole complex system as a set of sub-system: each sub-system is modeled and simulated using specialized simulation environments.
- E.g.
  - the power grid,
  - the communication network,
  - the IT system,

  are independent models (federates) glue together in a federation

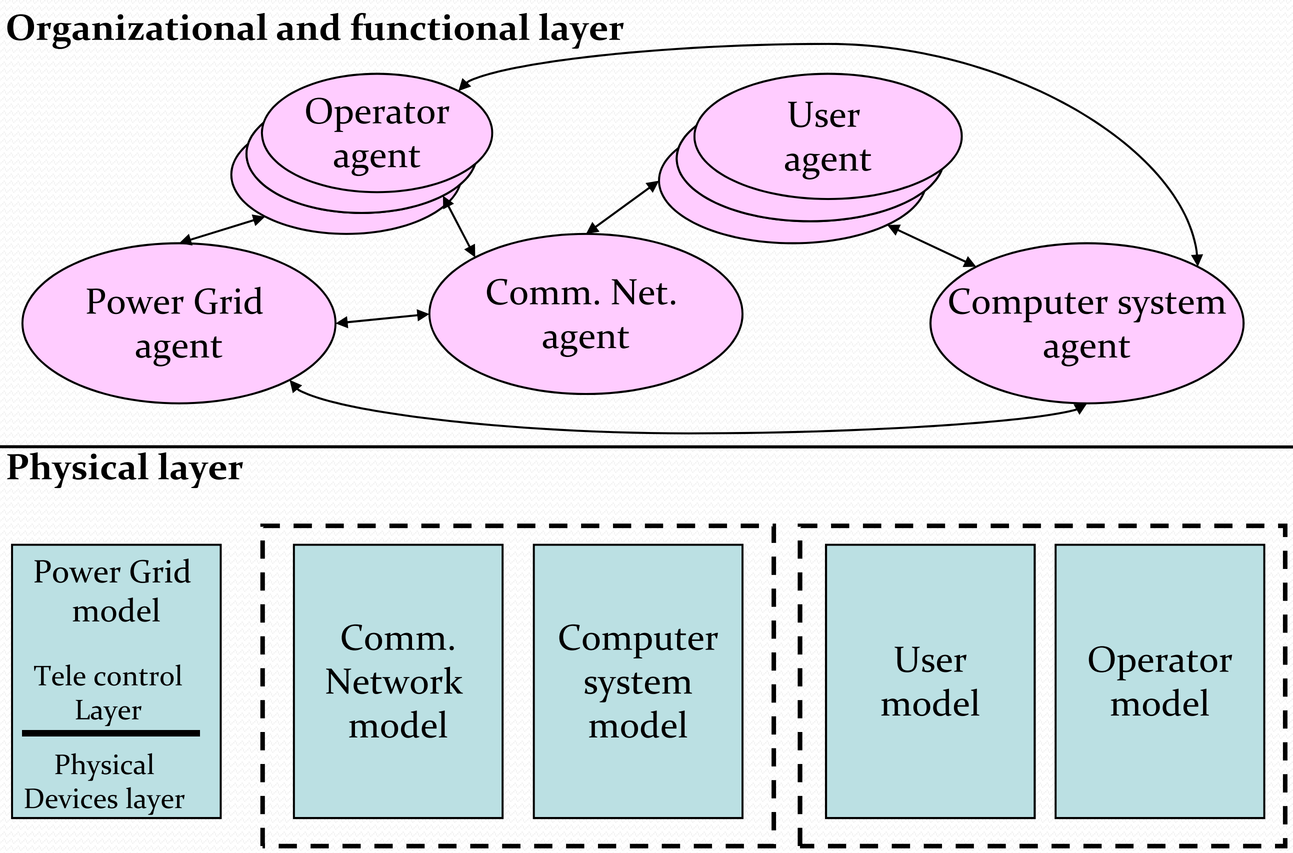


Nesting Vertical and Horizontal partitioning

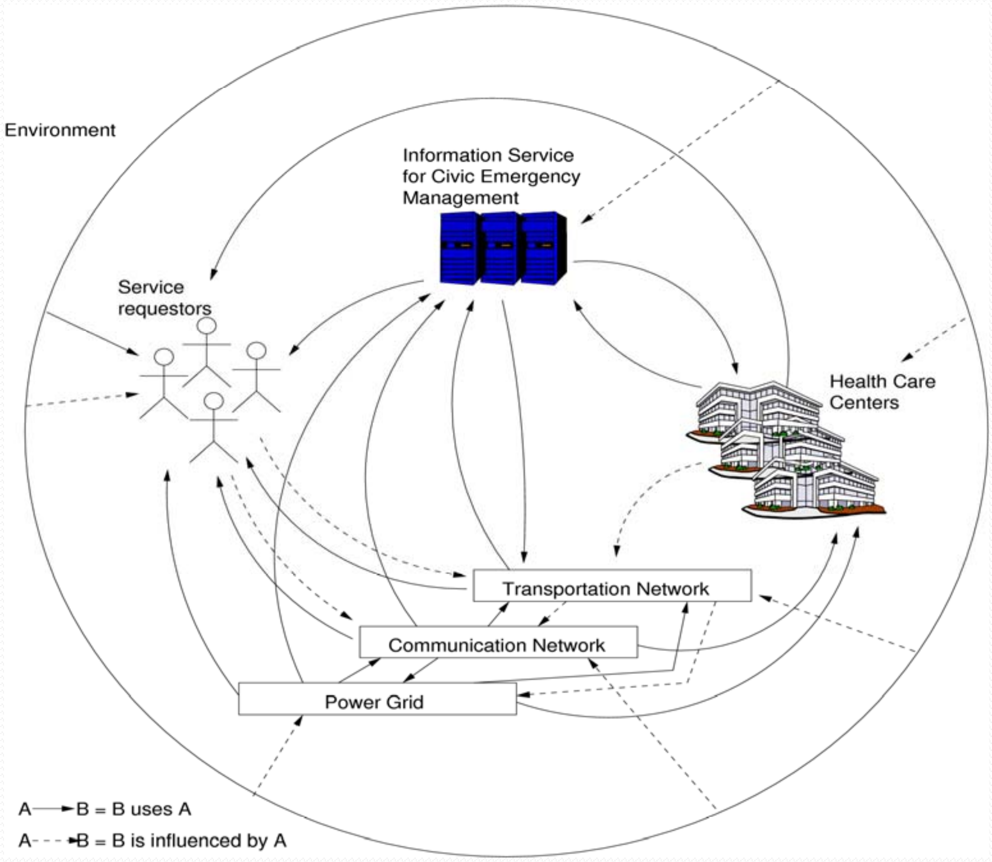
- Models resulting from horizontal partitioning could be vertically partitioned and vice-versa



Federated ABMS methodology



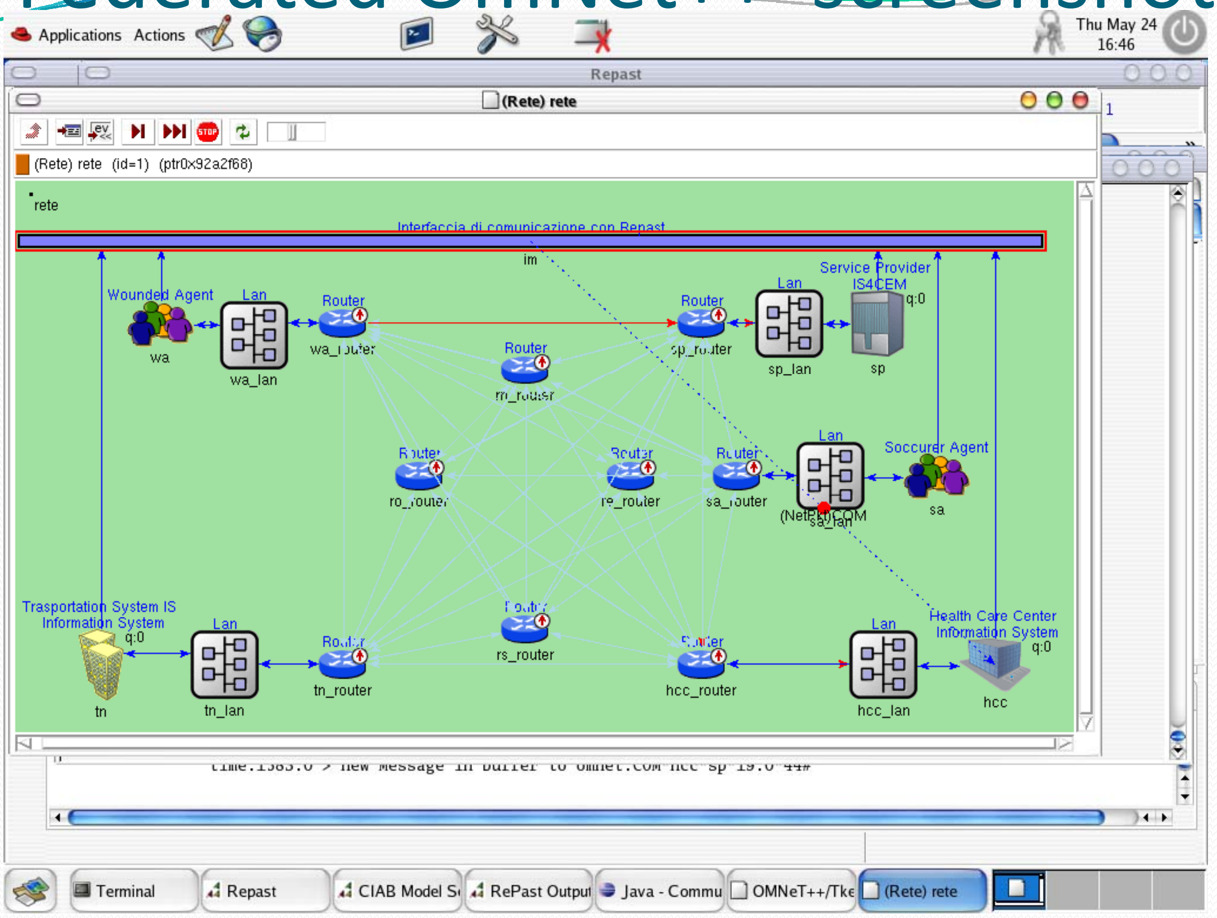
Our case study



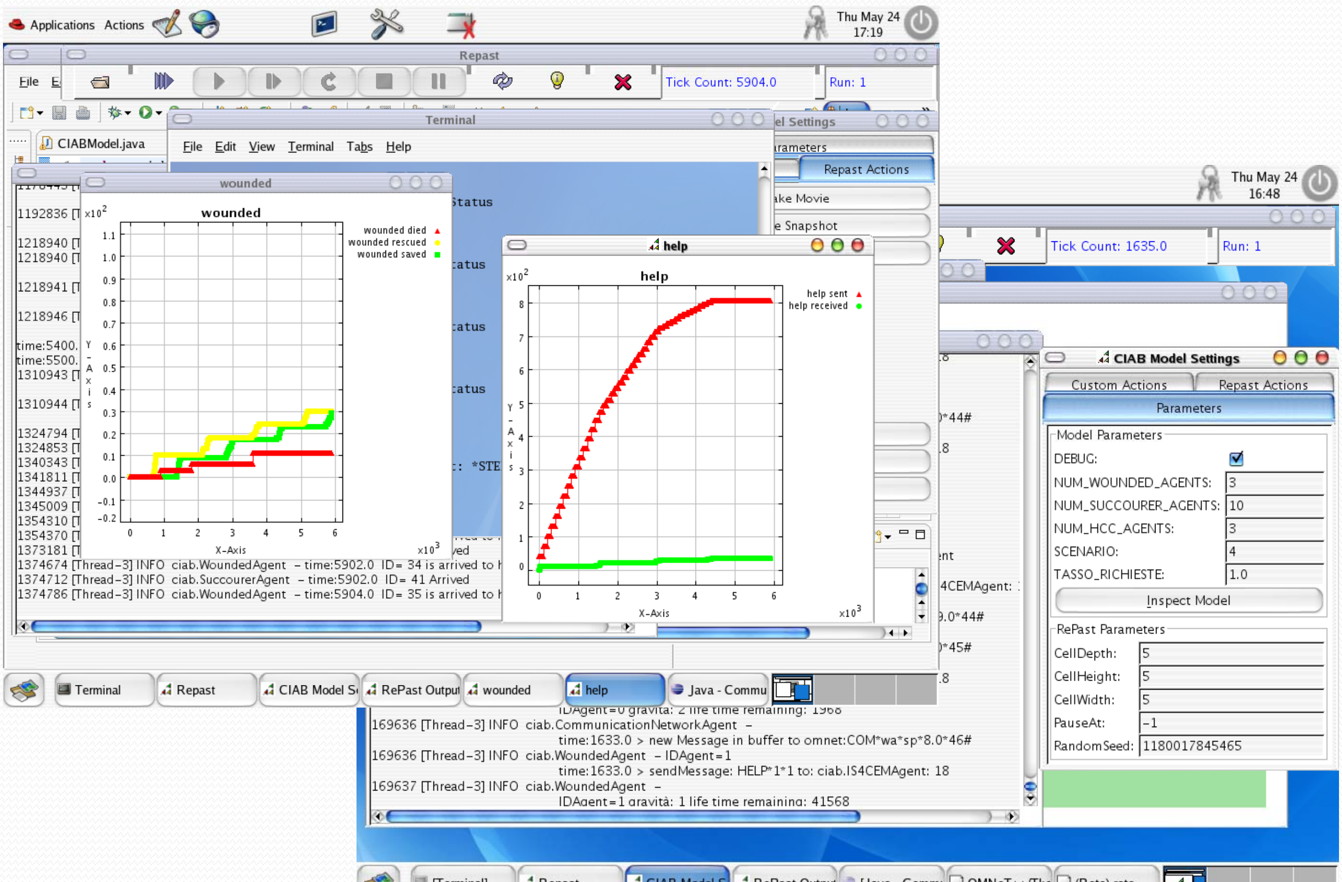
Design and implementation of a Federated ABMS framework

- We have federated
  - an agent based simulation environment (RePast) and
  - a discrete event simulation environment (OmNet++)

Federated OmNet++ screenshots



Federated RePast Screenshots

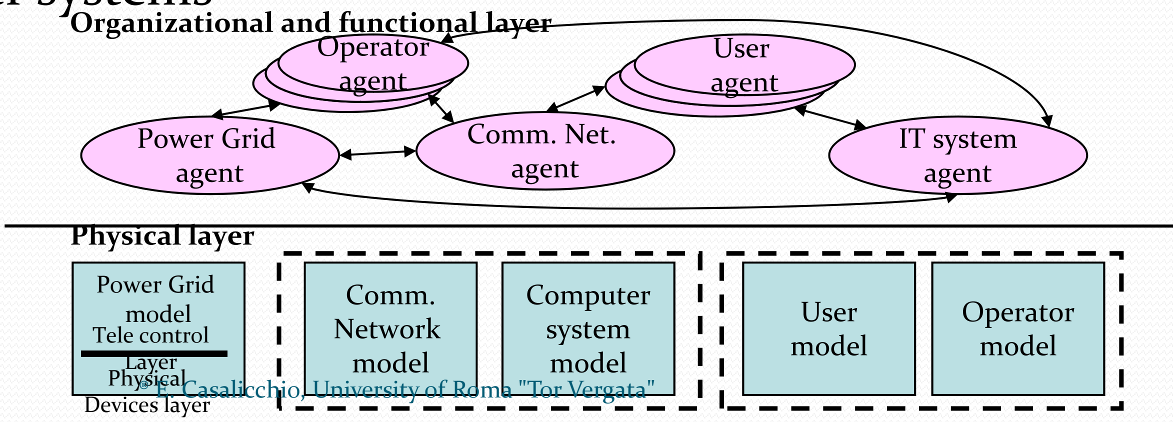


Design and implementation of a Federated ABMS framework (2)

- We have understand that we may integrate
  - Discrete Time Event driven simulation models
  - Time stepped simulation models
  - Any discrete time model
  - Any time independent model or
  - Time dependent model where the transient time to reach the equilibrium is negligible.

Design and implementation of a Federated ABMS framework (2)

- We nested vertical and horizontal partitioning
- We use an agent based model for the organizational and functional layer
  - The interdependencies are modeled at this layer
- We use a discrete event simulation model (QN) to model the behavior of the communication network and computer systems



Implementation issues

- We have implemented our own distributed simulation middleware with the basic functionalities
  - Simulation time management
  - Events and Time synchronization
  - Message exchange

Time management

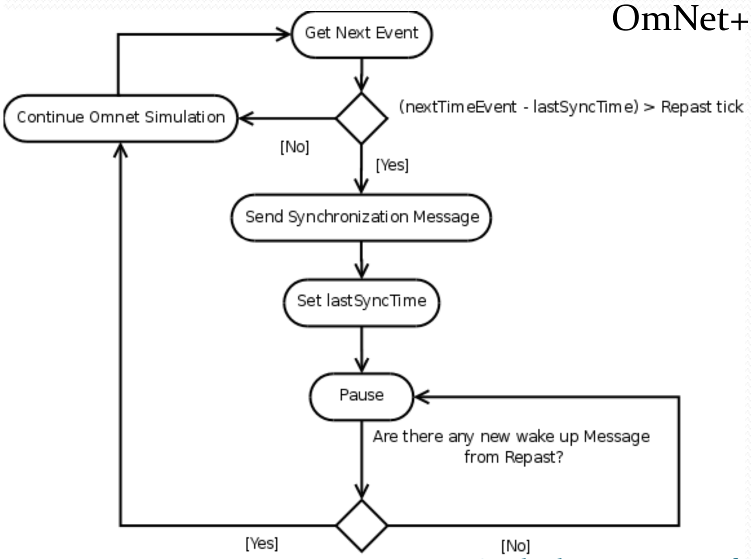
- Two approaches:
  - Optimistic : simulators must provide some way to undo the effect of out-of-order event and return to the state before the inconsistency
  - Conservative: simulators must have some method to determine when events could be correctly processed (not any other earlier events to process)
- We use conservative approach:
  - RePast (time-stepped) is the time manager
  - The time step value is the LBTS

Synchronization algorithm

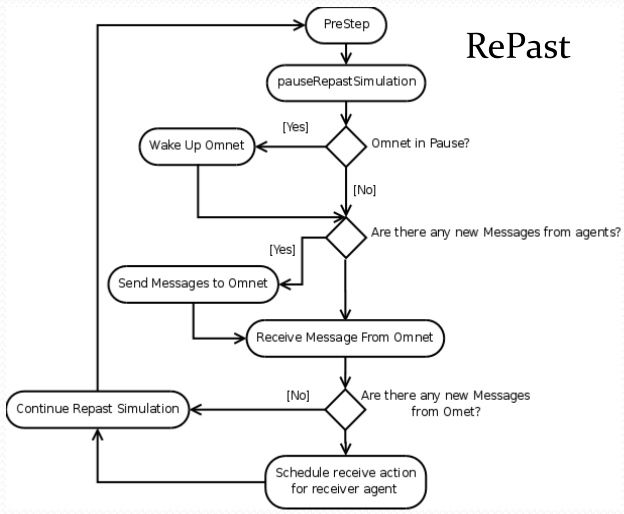
- We have implemented our synchronization algorithm
- Details on

"E.Casalicchio, E.Galli, S.Tucci, Federated Agent-based modeling and simulation approach to study interdependencies in IT critical infrastructure, Proc. Of IEEE DS-RT, Oct. 2007"

OmNet++



RePast



The data exchange model

- During a simulation OMNeT++ and Repast exchange state information and synchronization messages.
- The simulators communicate using sockets
- There are three type of messages:
  - synchronization messages,
  - communication messages and
  - information messages (for runtime management of comm. network and IT system models' parameters)

The interdependencies analysis

We have considered three different scenarios

- **Reference Scenario**: we suppose that the wounded agents generate a burst of help request at the beginning of the simulation.
- **CommNet Scenario**: we add failure and faults in the communication net. Only
- **TranspSys Scenario**: we add traffic congestions only
- **CommNet+TranspSys scenario**

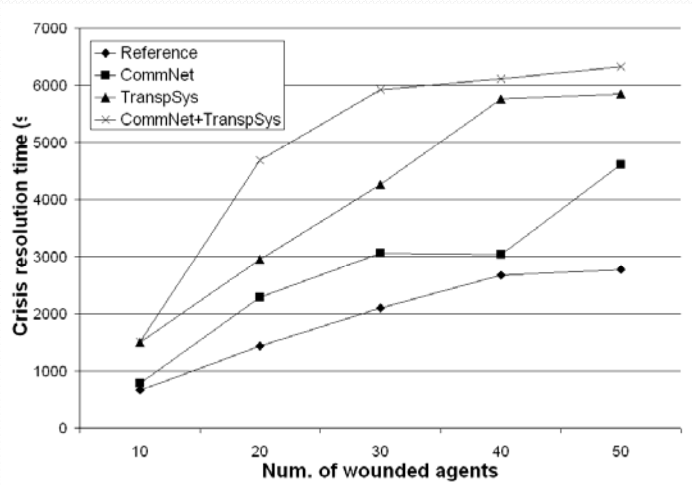
Parameter	Value
Num. of HCCs	3
Num. of soccourer agents	10
Avg. route round trip time (rtt)	5 min.
Avg. route rtt (during congestions)	7-30 min.
Route inter-congestion time	30 min.
Num. of wounded	10 - 50
Node/link mean time to failure	10 min.
Node/link mean recovery time	5 min.

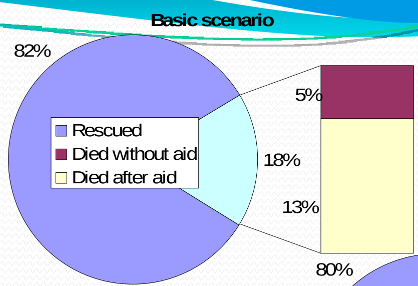
Priority	Percent of wounded agents	Time to live
LOW	40%	12h
MEDIUM	30%	6h
HIGH	20%	30min
VERY HIGH	10%	15min

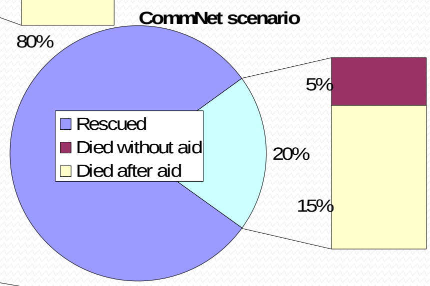
Performance Metrics

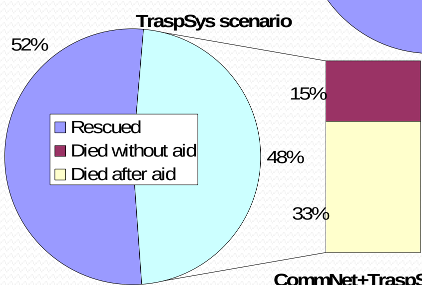
- We have instrumented the simulator to measure
  - high level info., such as the number of died wounded agent,
  - low level info., such as the number of lost packets in the communication network or the IT system nodes utilization
- Some of them (high level) are:
  - Crisis resolution time *T_c* and its downgrade (T_c-T_o)/T_c
  - Number of rescued wounded agents
  - Number of died wounded agents

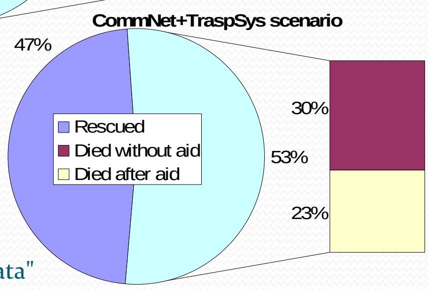
Some results











Conclusions

- We have proposed a novel Federated Agent-based Modeling and Simulation approach
- We have implemented a working prototype and we have proven the validity of our federated approach
- We have understand that we may integrate
  - Discrete Time Event driven simulation models
  - Time stepped simulation models
  - Any discrete time model
  - Any time independent model

Future works

- Short distance goals are:
  - HLA/RTI porting
  - Integration of a more detailed model for power grids (e-agora – load flow power grid simulator)
  - Integration of a more detailed model for humans (fuzzy logic model)
  - Any other model is welcome!!