Multi-level Simulation of the Internet of Things

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joint work with S. Ferretti and V. Ghini

Seminar Slides

These **slides** can be found at the following URL

http://ntu.portazero.it

Outline

- Introduction on the IoT
- A brief introduction to simulation
- Specific challenges in the simulation of the IoT
- Multilevel simulation models / Heterogeneous simulation models
- Case study: smart shires

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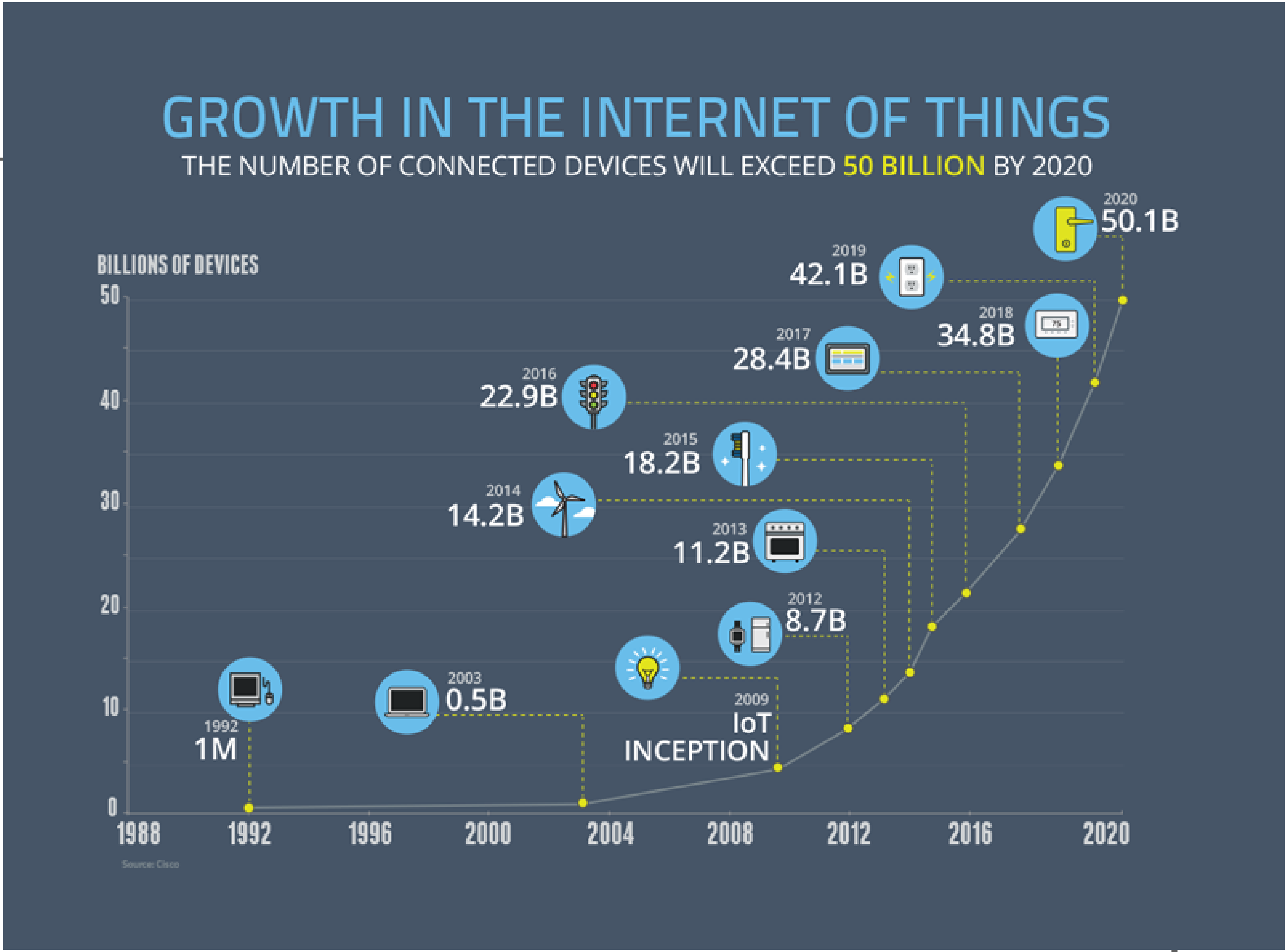
What Is the **Internet of Things**?

«The Internet of Things is the intelligent connectivity of physical devices driving massive gains in efficiency, business growth, and quality of life»

Dave Evans, Cisco



Source: http://www.seediscover.com/behind-the-numbers-growth-in-the-internet-of-things/

Smart City

CONNECTED TRAFFIC SIGNALS
- Reduced congestion
- Improved emergency services response times
- Lower fuel usage

PARKING AND LIGHTING
- Increased efficiency
- Power and cost savings
- New revenue opportunities

CITY SERVICES
- Efficient service delivery
- Increased revenues
- Enhanced environmental monitoring capabilities

Source: M. Kader, Cisco, “IoT (Internet of Things) and Security”

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A Brief Introduction to Simulation

«*A computer simulation is a computation that models the behavior of some real or imagined system over time*»

(R.M. Fujimoto)

Motivations:

- performance evaluation
- study of new solutions
- virtual worlds:
  - online games
  - digital virtual environments

Simulation Paradigms

- **Systems** are becoming more and more **complex**
- A lot of issues on the **performance** of simulation software tools
- Many different **simulation paradigms**, each one with specific **benefits** and **drawbacks**
- There is not the "correct way" of doing simulations, there are many different ways
- **It is really a case-by-case evaluation**

Discrete Event Simulation (**DES**)

- The **state** of the simulated system is represented through a **set of variables**
- The key concept is the "**event**": a **change in the system state** (that occurs at an **instant in time)**
- **Evolution of a modeled system → processing of a chronological sequence of events**
- **DES**: creation, delivery and computation of events
- The **computation** of an event can modify some part of the state and lead to the creation of new events

DES + Single CPU = **Sequential** Simulation

- All the simulation tasks are accomplished by a **single execution unit** (i.e. a CPU and some RAM)
- **PROS**: it is a very simple approach
- **CONS**: there are a few significant limitations
  - the **time required** to complete the simulation run
    - *how fast is a single CPU?*
    - *in some cases results have to be in real time or even faster!*
  - if the model is quite large and detailed the **memory is not sufficient** → some systems can not be modeled
- This approach **does not scale**!

Parallel Discrete Event Simulation (PDES)

- Multiple interconnected Execution Units (EU), that is CPUs or hosts
- Each EU manages **a part of the simulation model**
- Aggregating resources from multiple EUs → **very large and complex models**
- Each EU manages a **local event list**
- Locally generated events may have to be **delivered to remote EUs**

Parallel Discrete Event Simulation (PDES)

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  that is CPUs or ho
- Each EU manages
- Aggregating resou
  large and complex mo
- Each EU manages a **l**   **event list**
- Locally generated events may have to be **delivered to remote EUs**

There is a **synchronization** problem!

Parallel Discrete Event Simulation (PDES)

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- Each EU manages **a part of the simulation model**
- Aggregating resources f ltiple EUs → **very lar**
- Eac
- Loc ve to be **de**

"Concurrent" events
can be executed
in parallel → **speedup!**

Parallel Discrete Event Simulation (PDES)

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- Each EU manages
- Locally generate **delivered to remo**

The model has to be **partitioned** in Logical Processes (**LP**s)

This is not easy…

The **Partitioning** of PADS

- Aspects to be considered:
  - **minimization** of **network communication**
  - **load balancing** of both **computation** and **communication** in the execution architecture
- A few issues:
  - **background load** in the execution architecture
  - **unpredictable**/**unbalanced** model behavior
  - **faults** in communications and execution architecture
  - **metrics** (e.g. execution time, resources cost, power cost)

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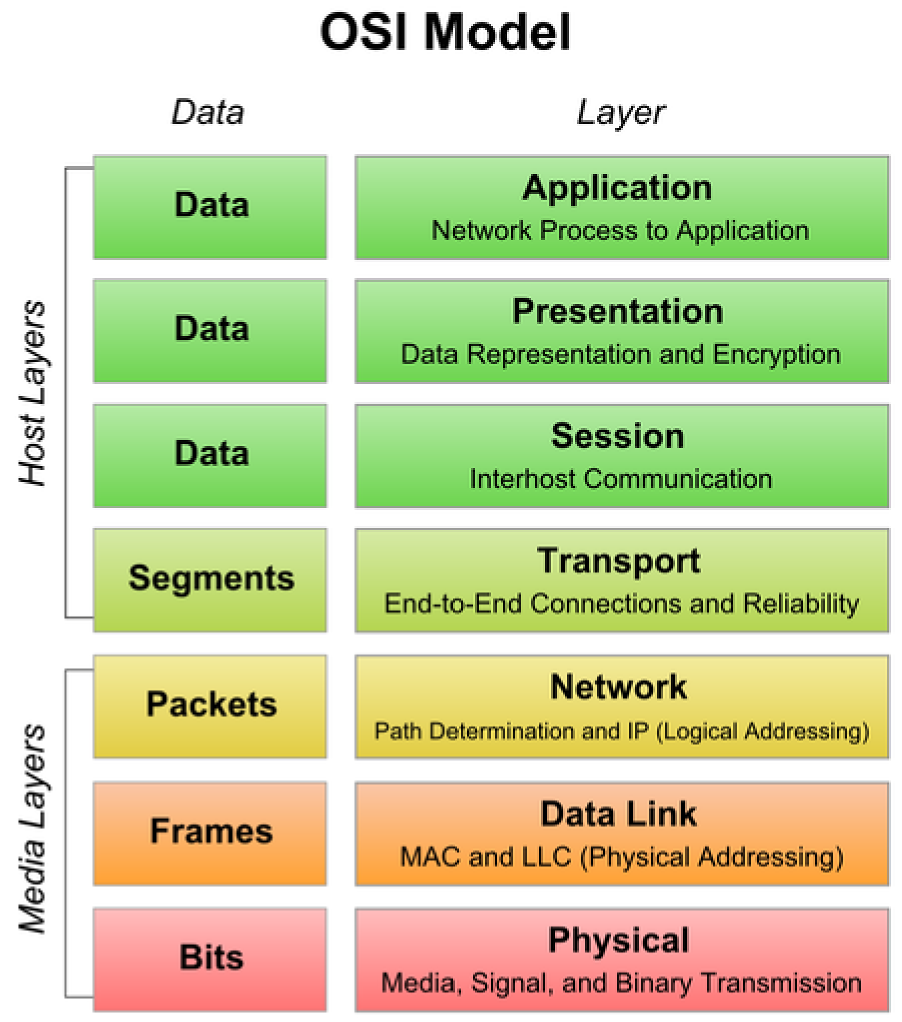
Scalability

- Even a small partition of the IoT is a huge number of devices
  - i.e. of nodes to be simulated
- The goal is to design scalable distributed systems embodying IoT
  - to do it, we need scalable simulators
    - number of simulated entities
    - wide range of scenarios
  - simulation allows forecasting, proactive management, what-if analysis

Simulation of **IoT Models**

What is the "appropriate" **level of detail** for IoT simulations?

- very detailed → **huge overhead**
- few details → **oversimplified → wrong results**



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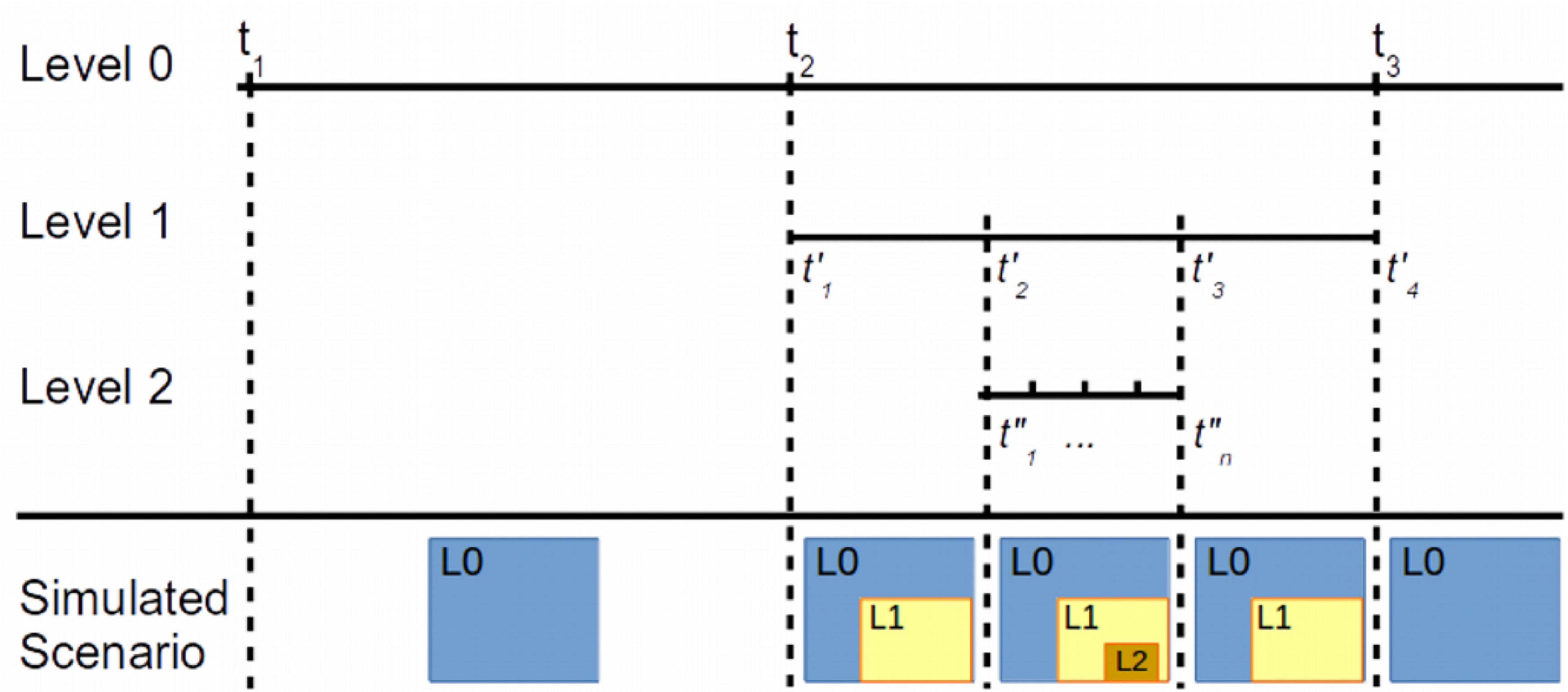
Simulation of IoT Models

- Both **sequential** and **PADS** are **unable to handle IoT models**
- We need a **more flexible approach**
- **Heterogeneous** simulation models
- The **"complexity" must be restricted** to some parts of the model

Multi-level Simulation Models



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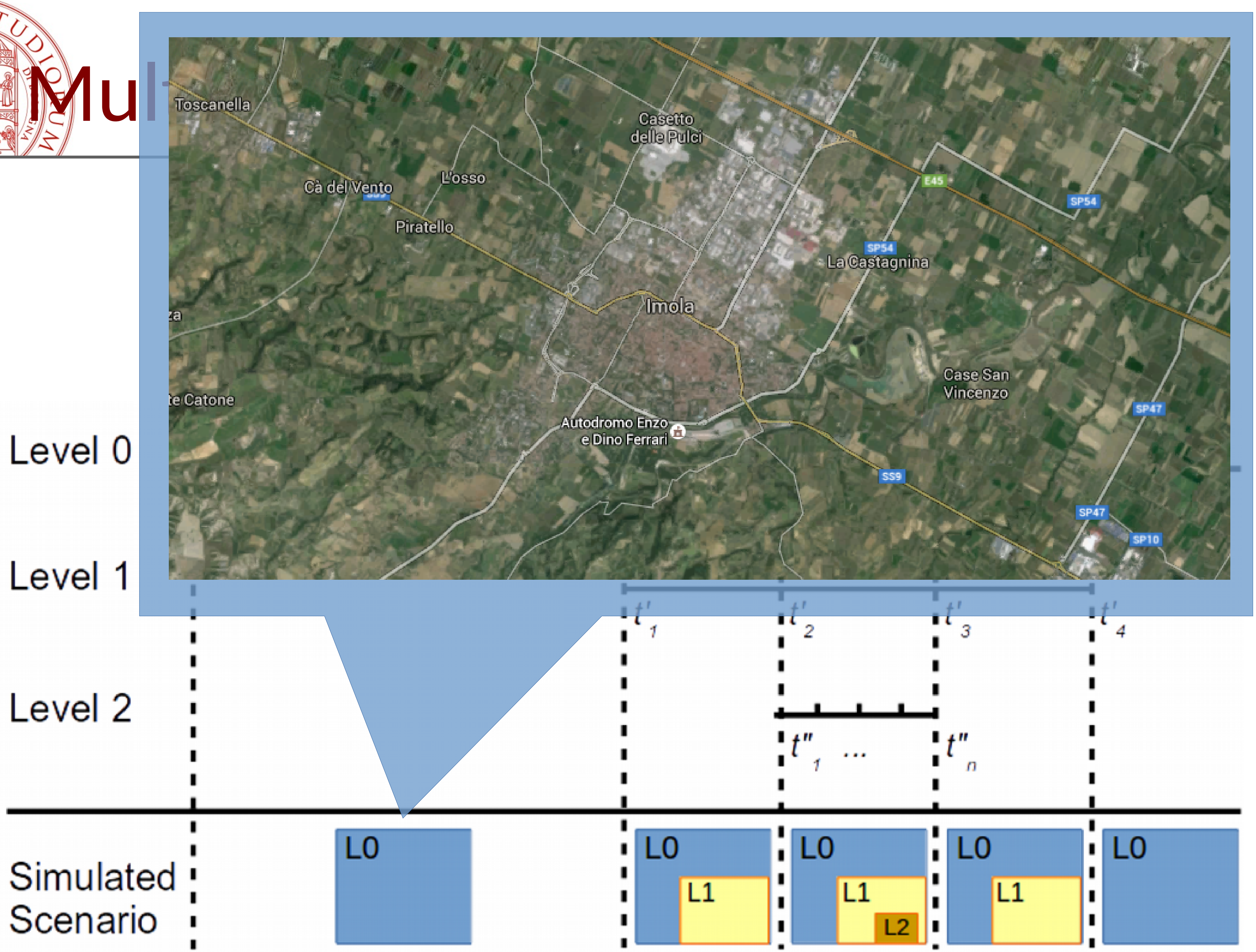

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Cà del Vento
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SP54
La Castagnina
Imola
Case San Vincenzo
Autodromo Enzo e Dino Ferrari
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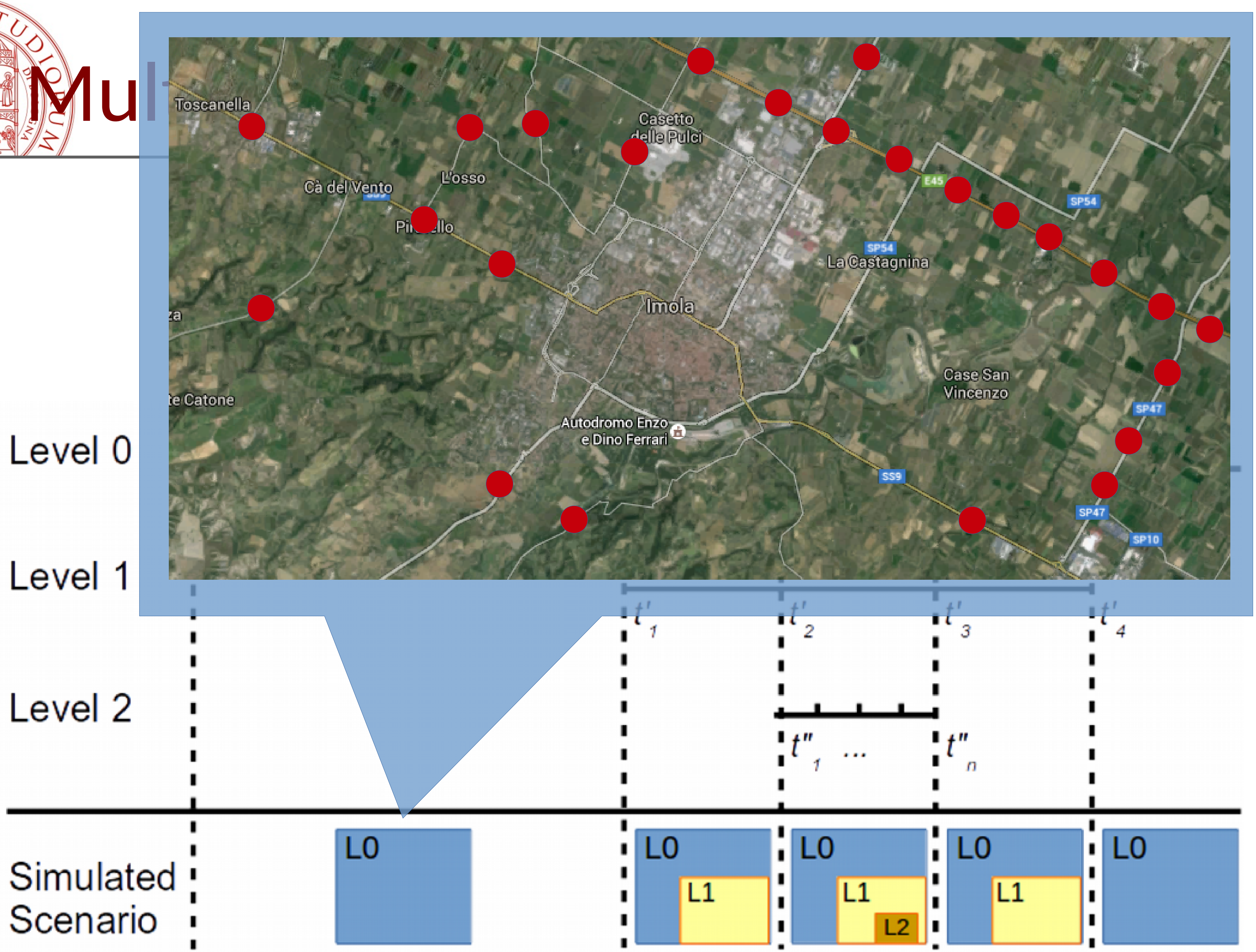
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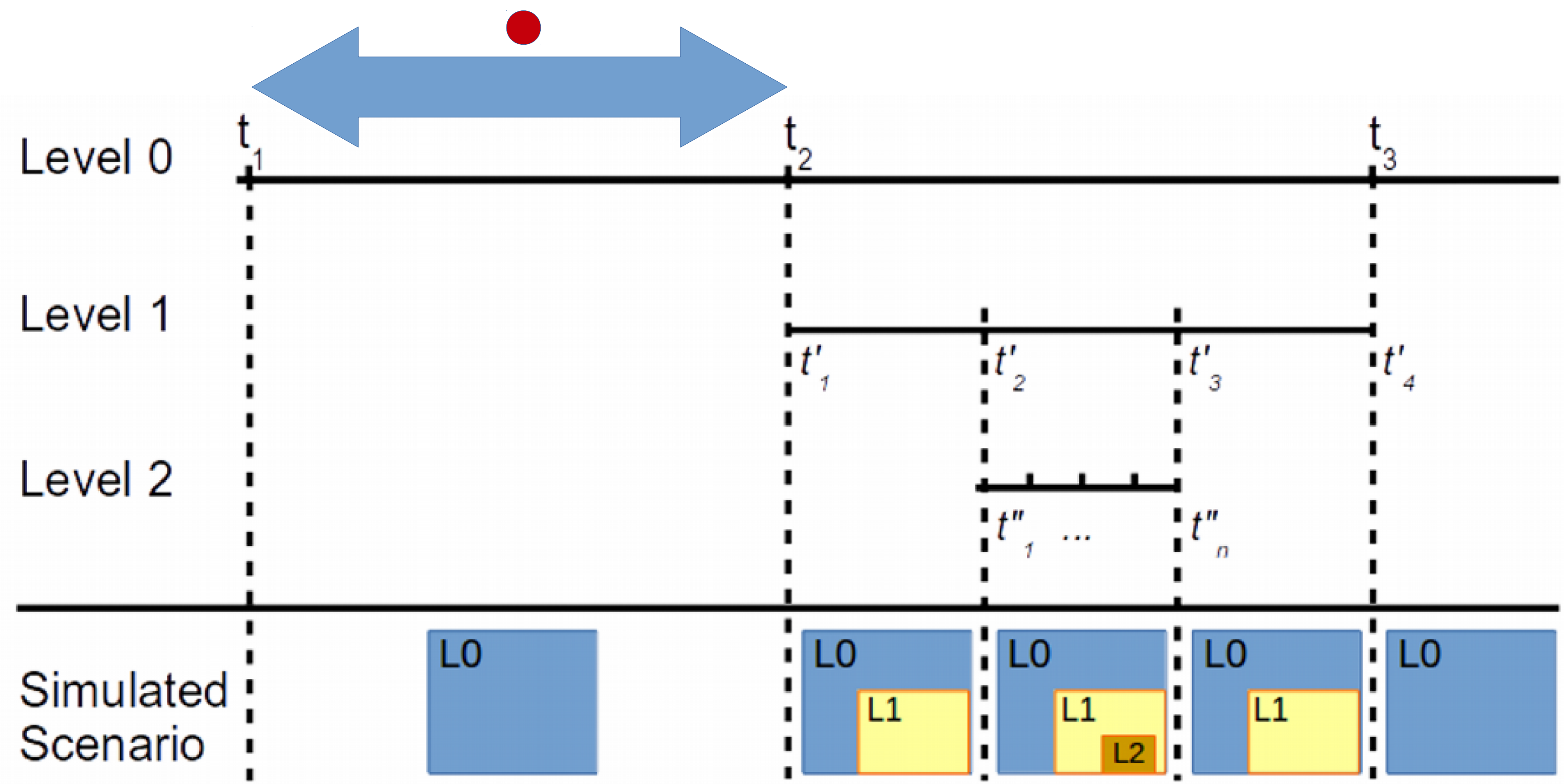

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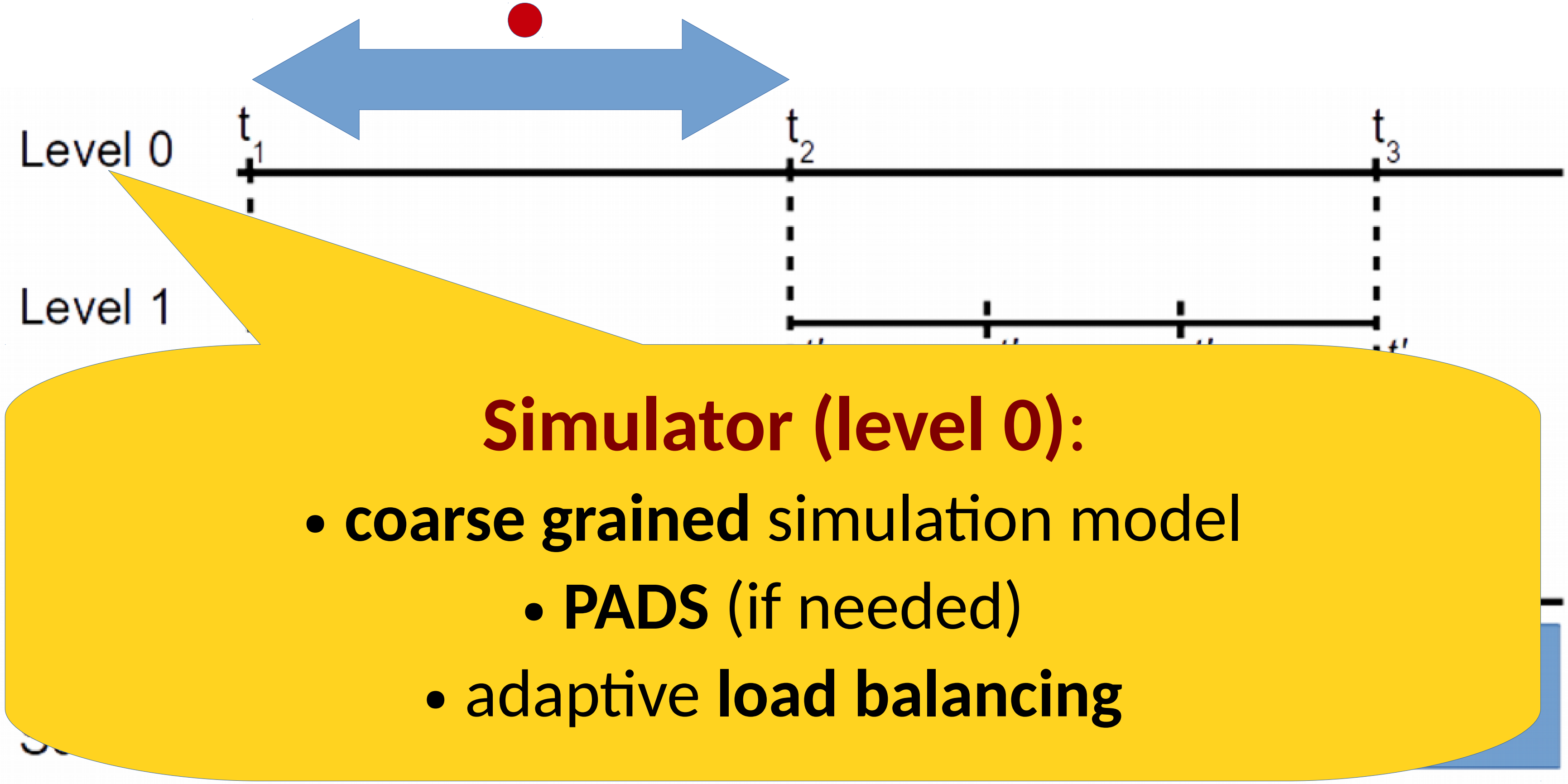

Simulator (level 0):

- **coarse grained** simulation model
- **PADS** (if needed)
- adaptive **load balancing**

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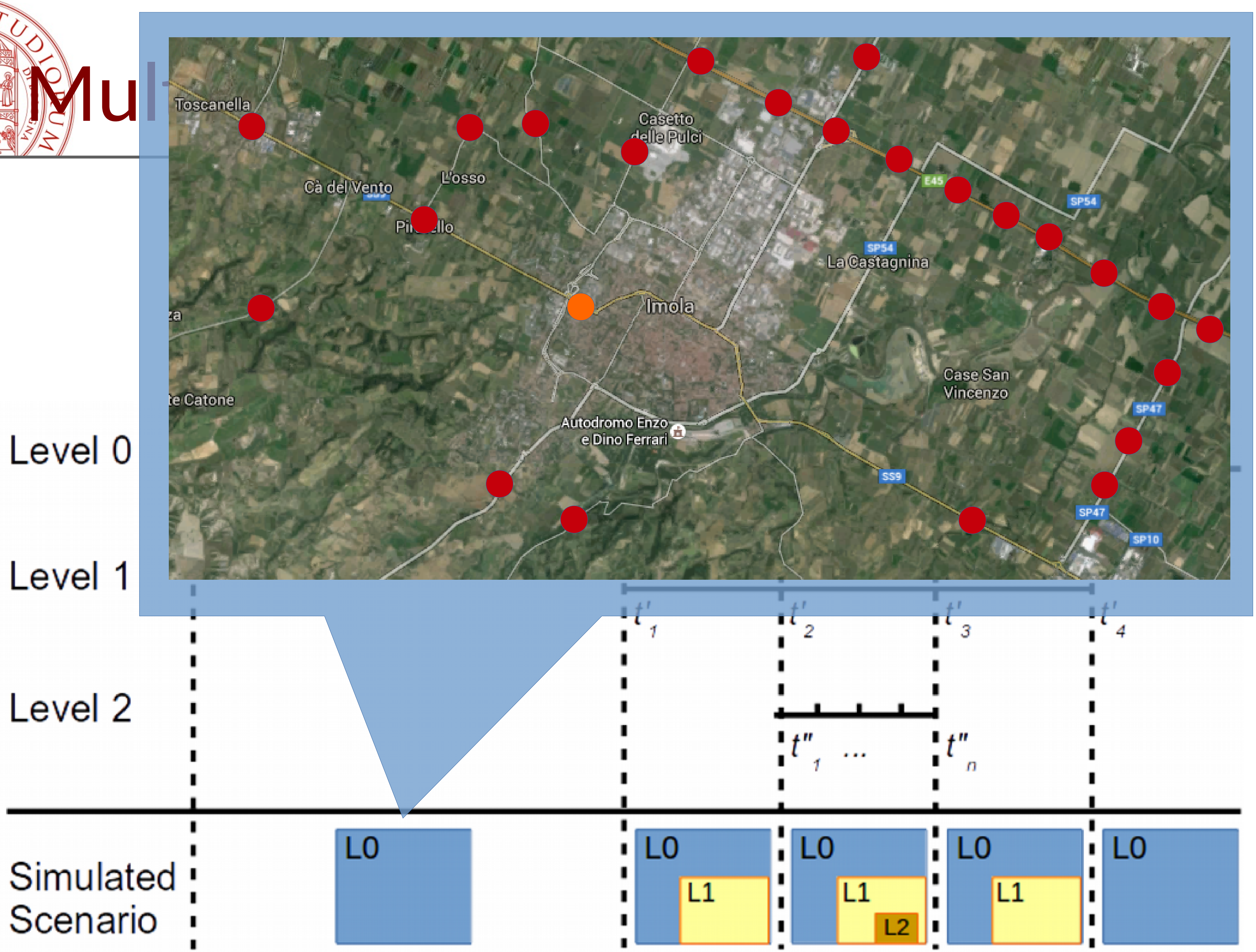
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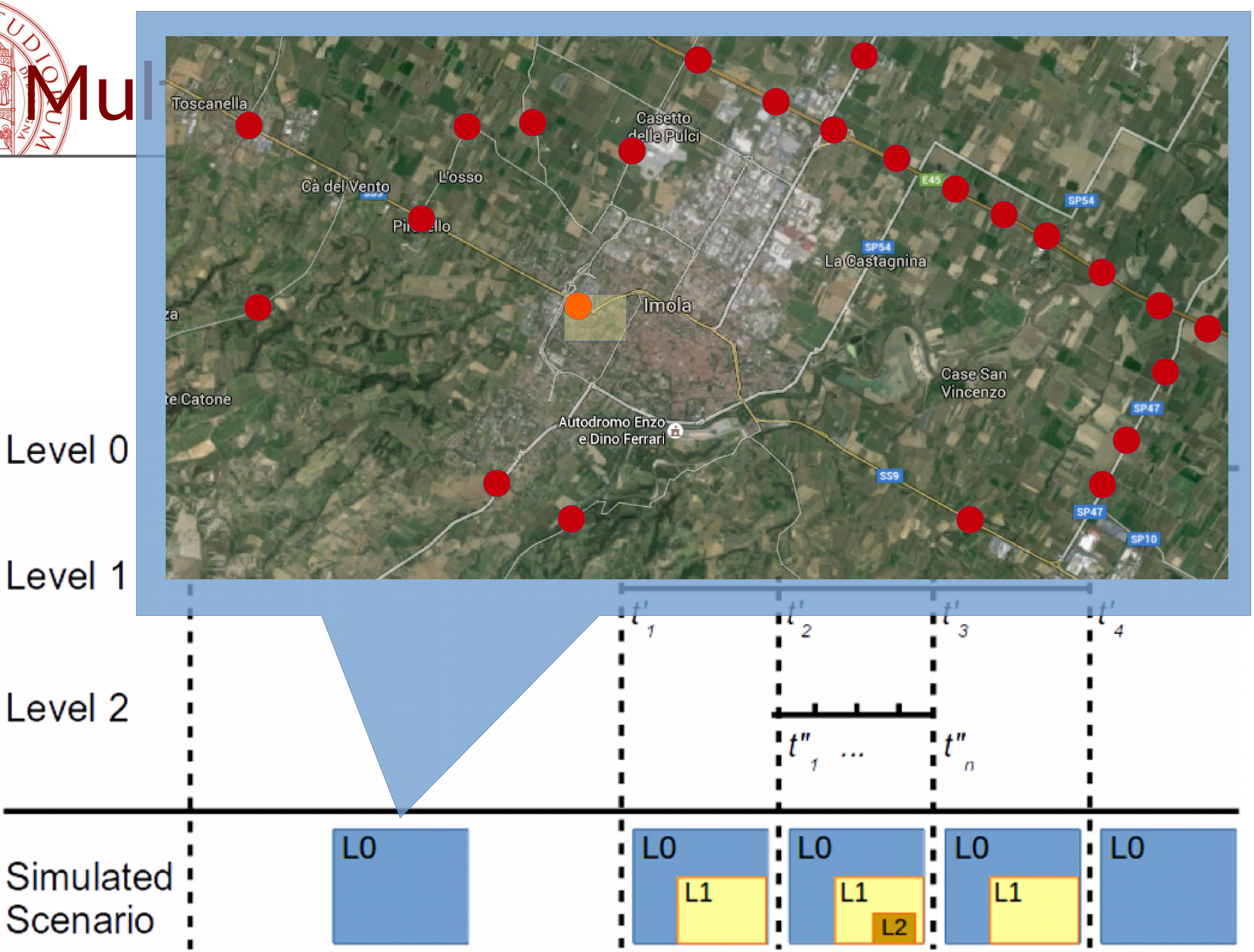

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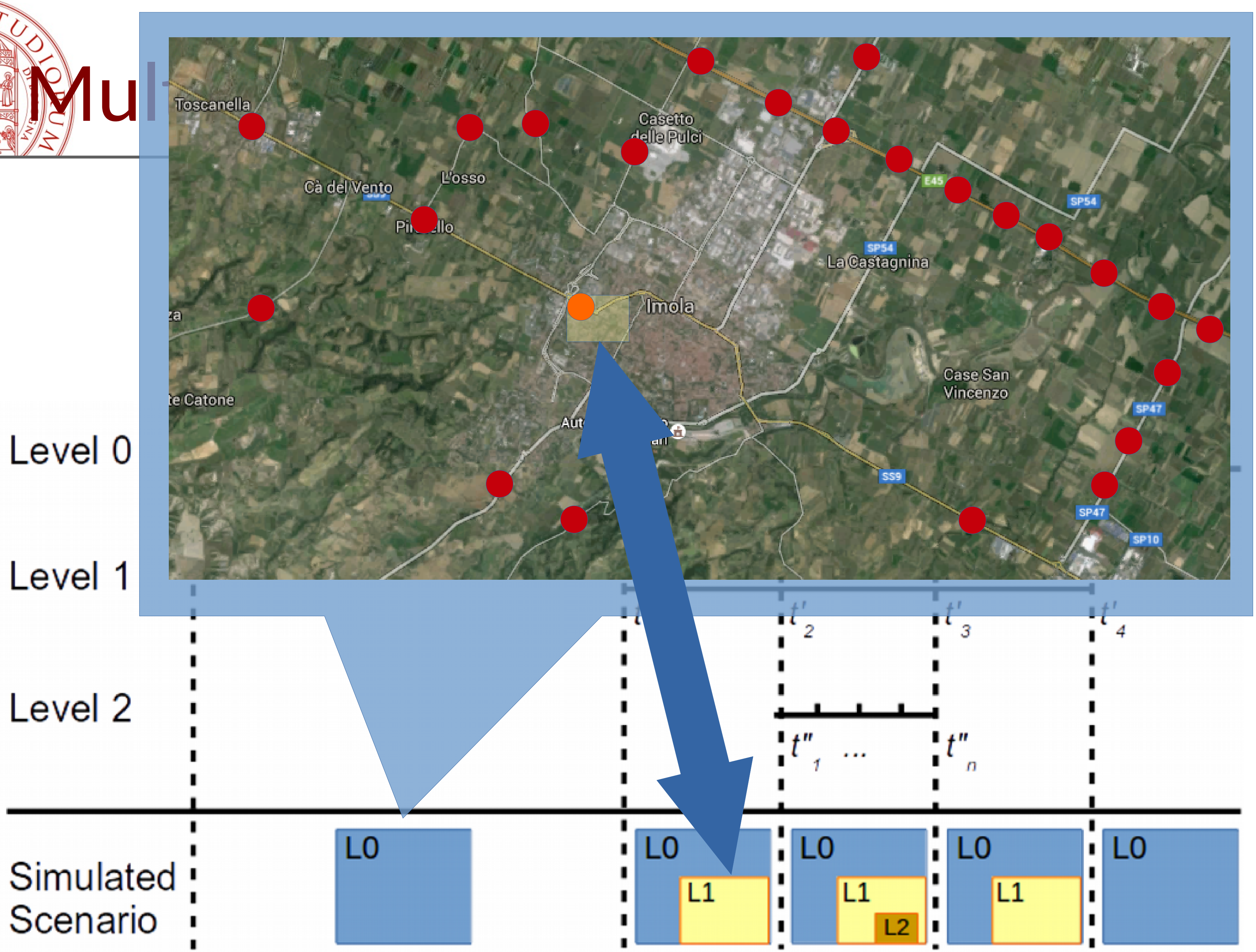

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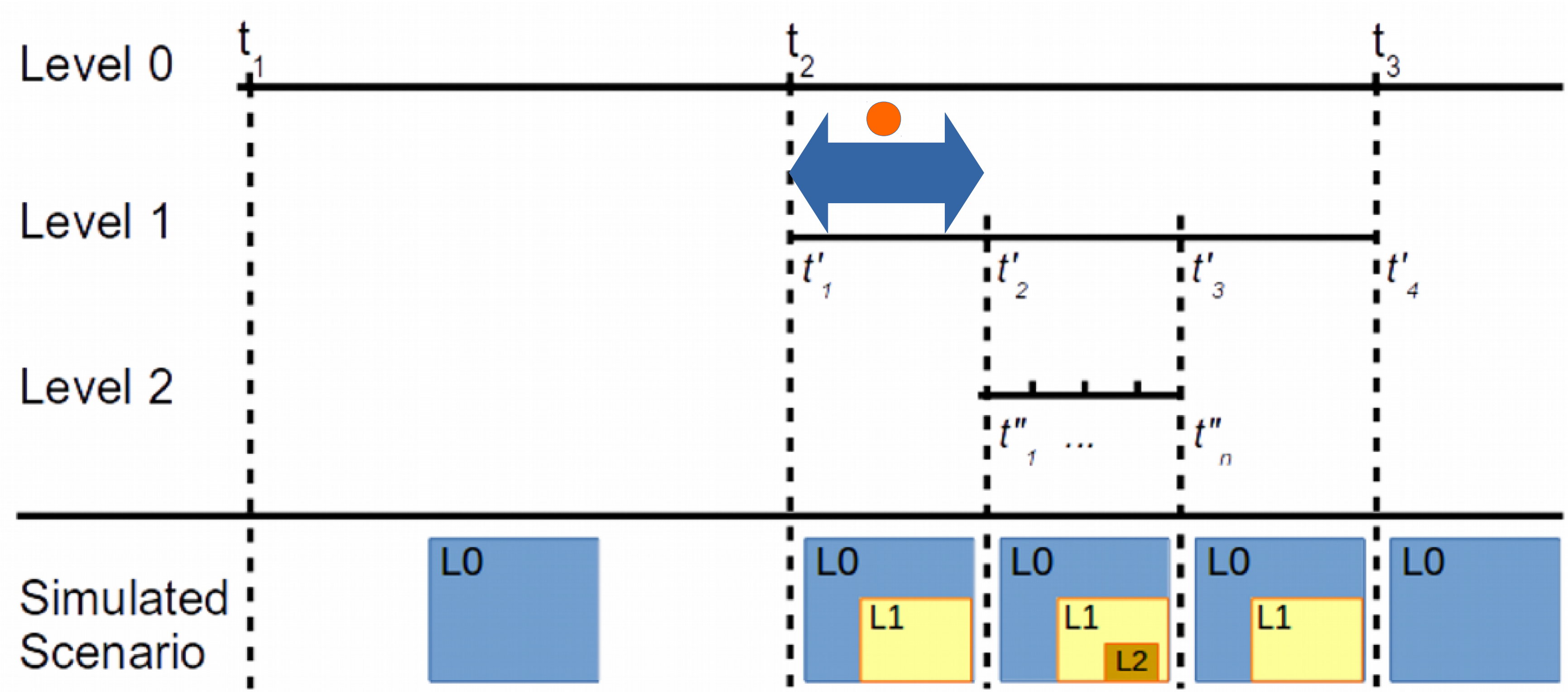
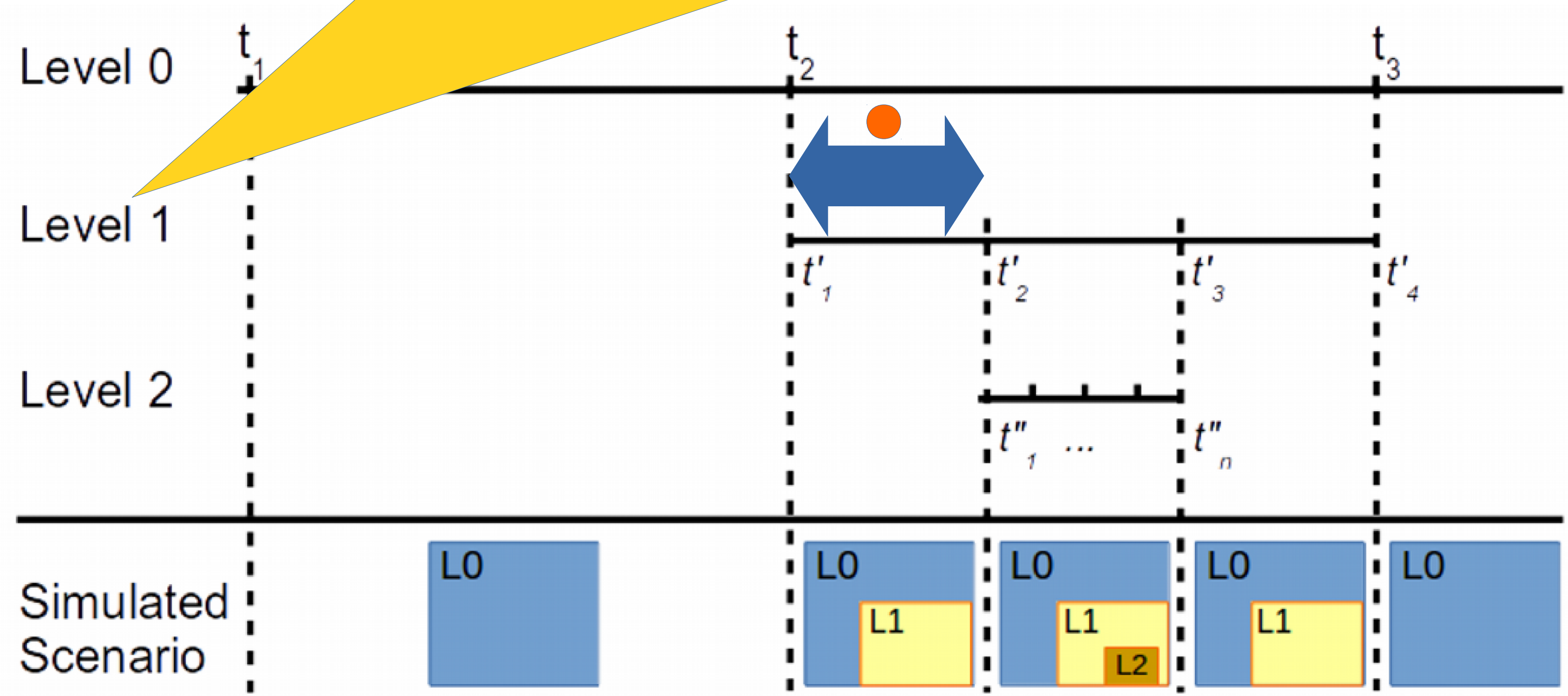
Multi-level Simulation Models



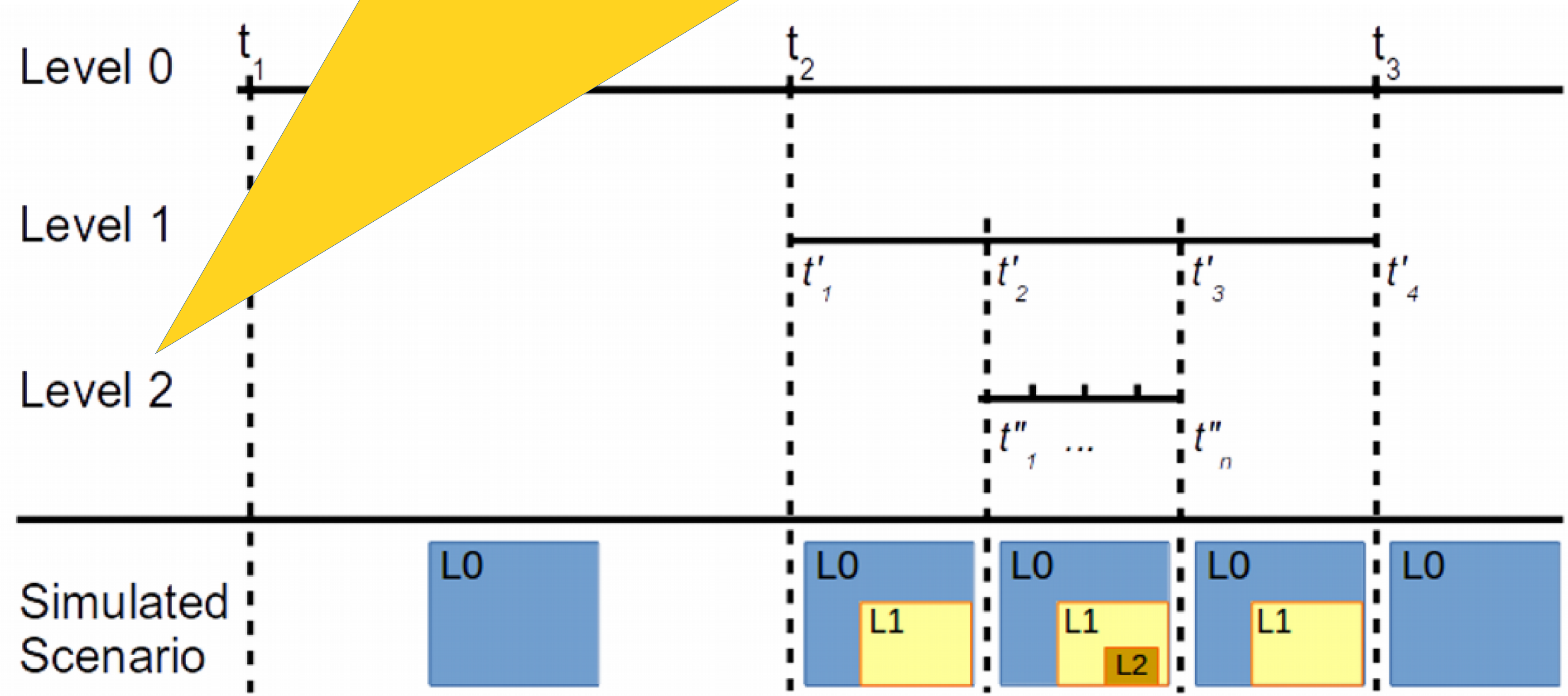
Simulator (level 1):

- **fine grained** simulation model
- **sequential** or **PADS**
- **domain specific** simulator



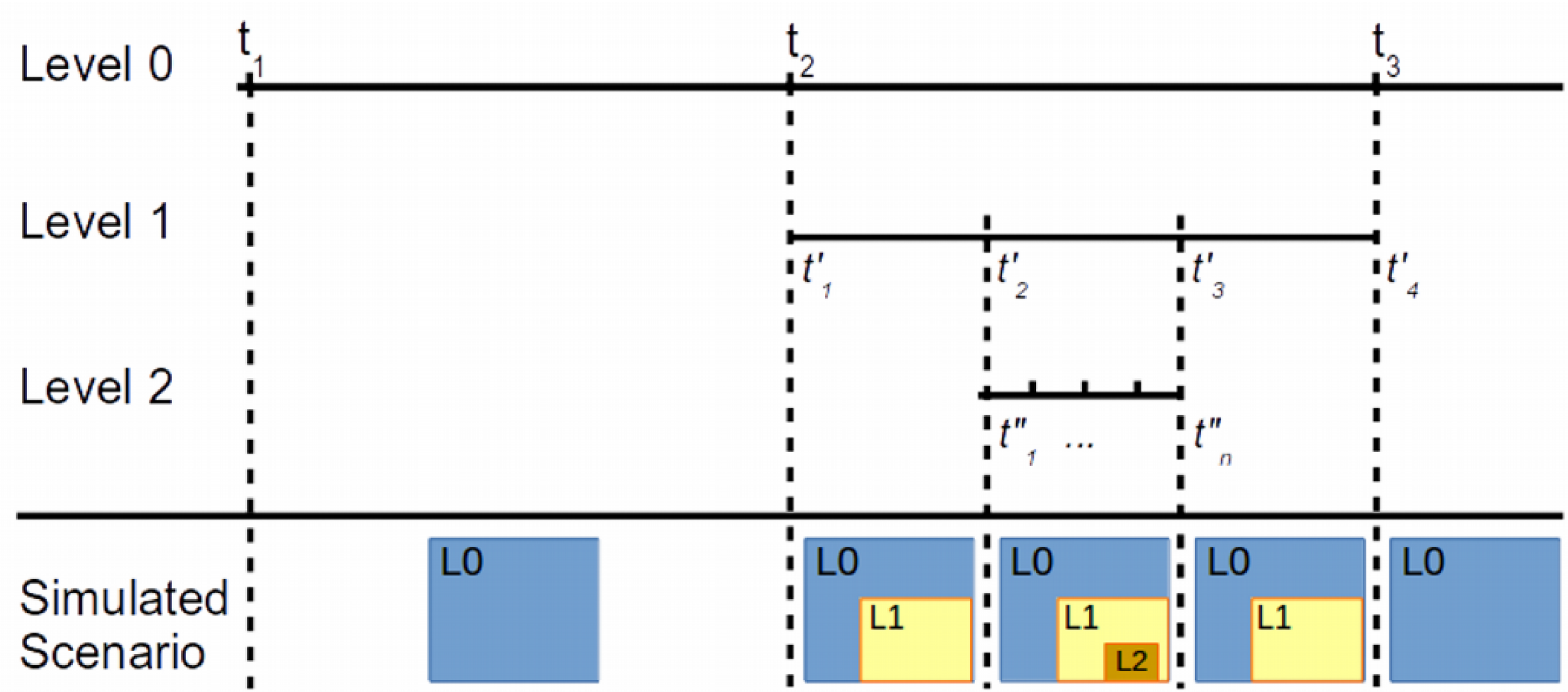
Simulator (level 2):

- more and more **detailed**… (if needed)



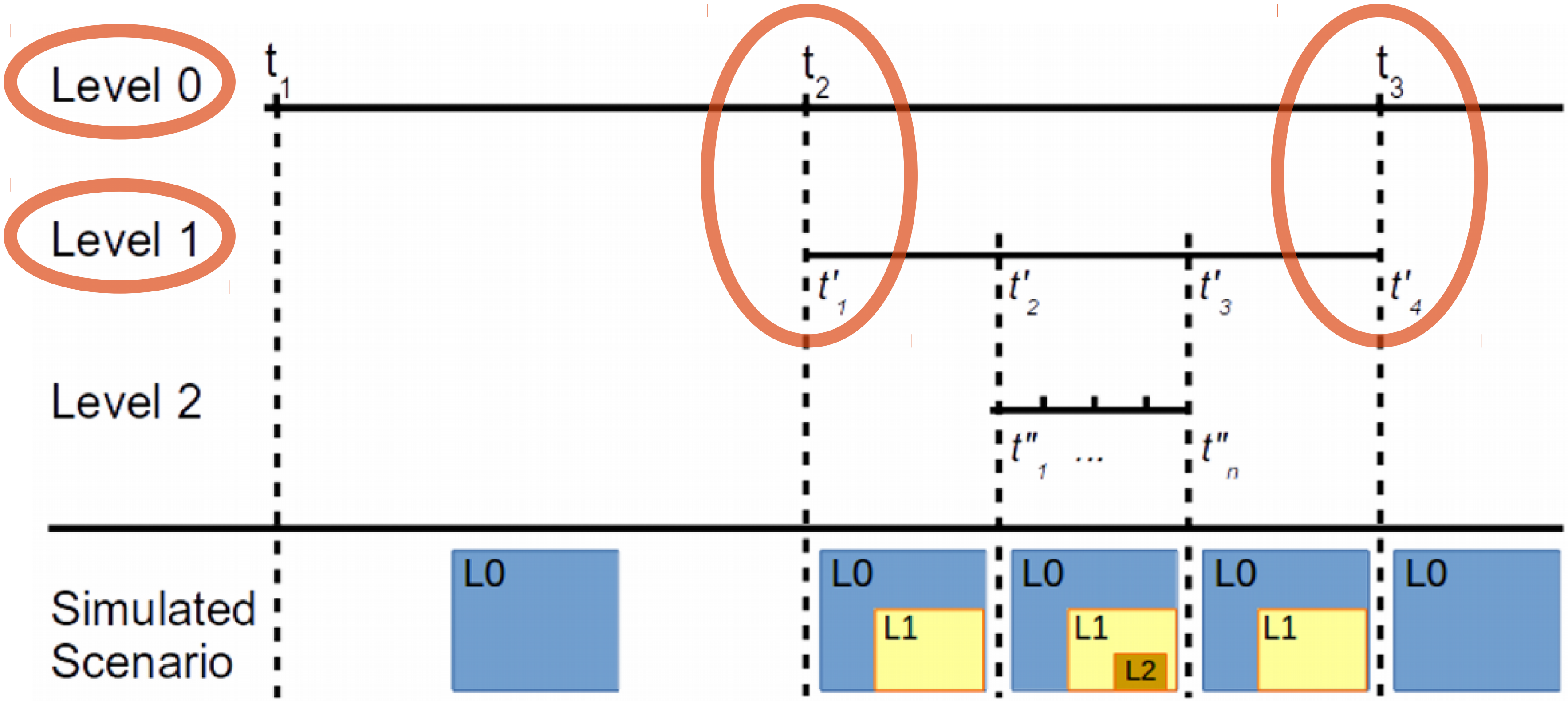
Multi-level Simulation Models

Synchronization and **Interoperability**



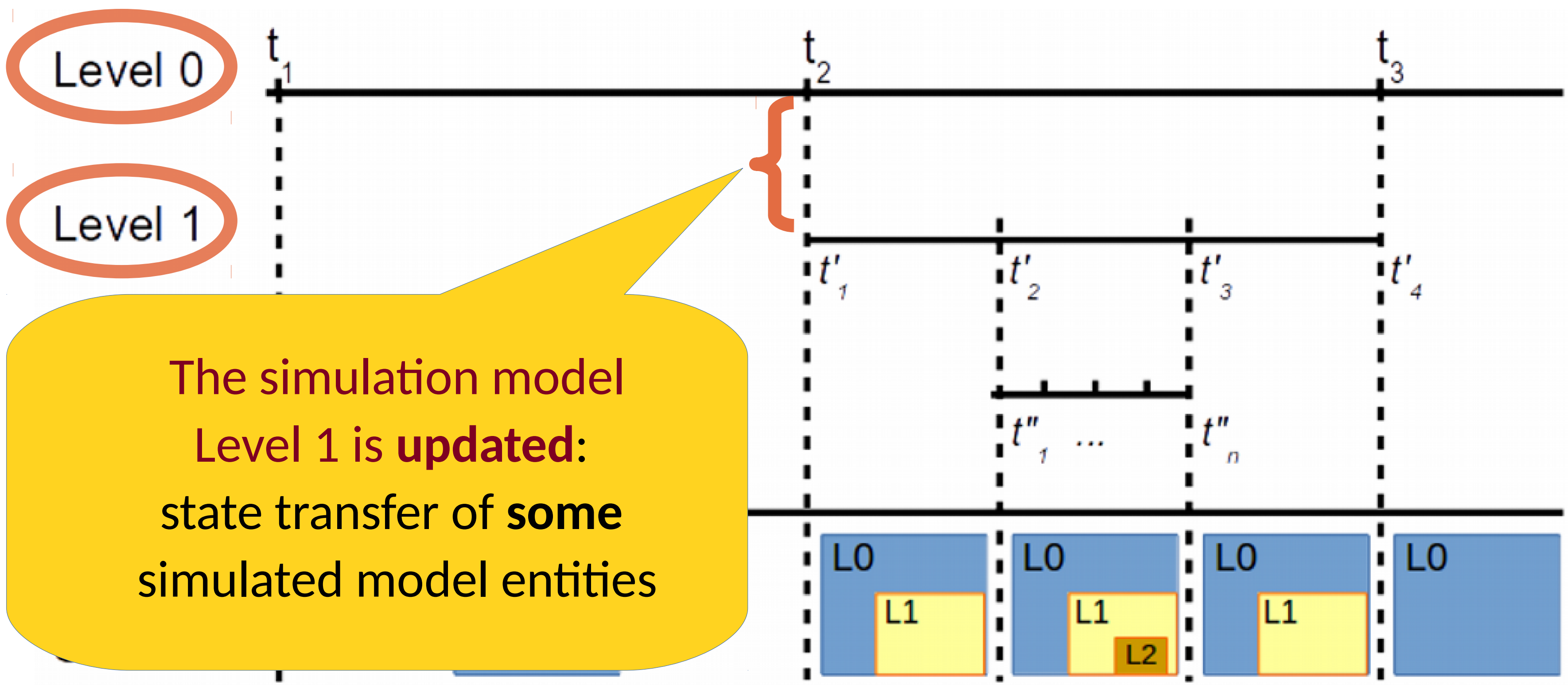
Multi-level Simulation Models

Synchronization: at level 0 timesteps



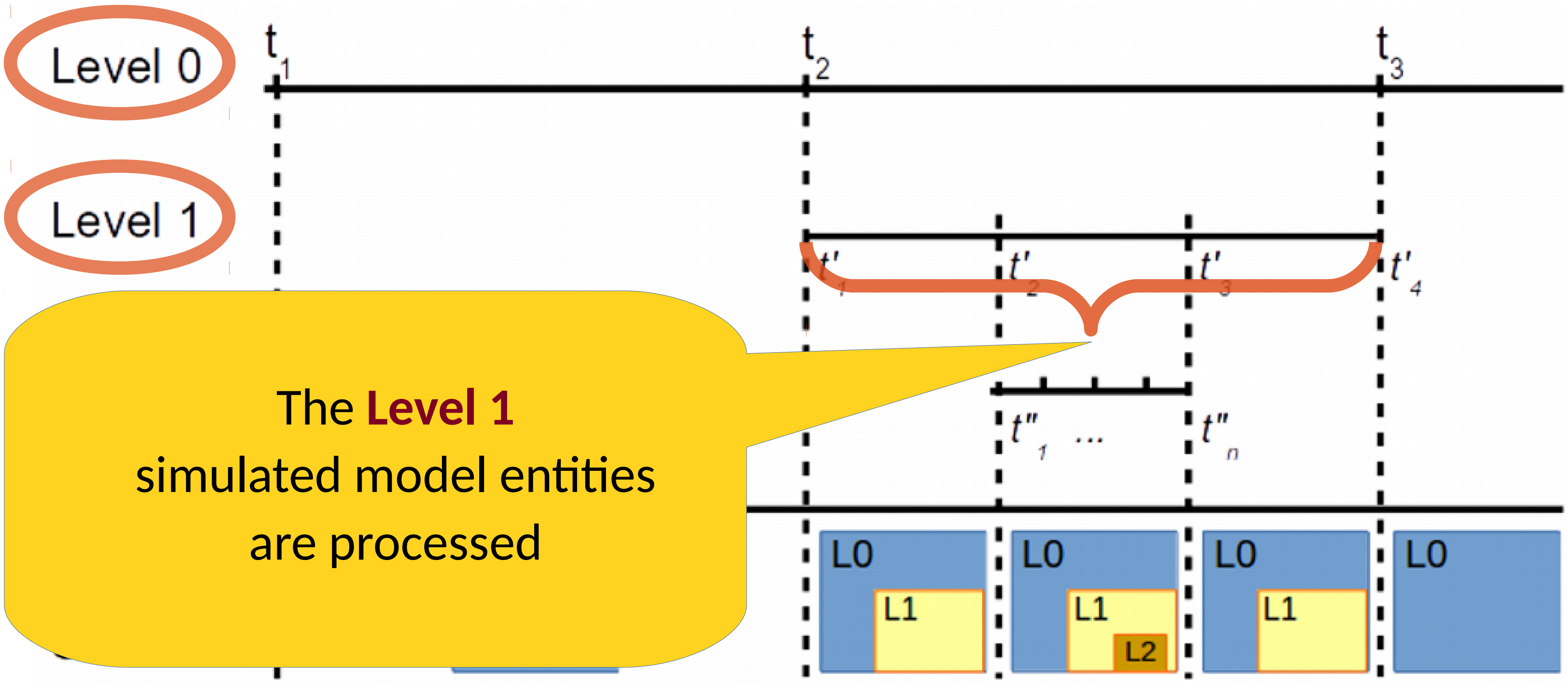
Multi-level Simulation Models

Interoperability



The simulation model Level 1 is **updated**: state transfer of **some** simulated model entities

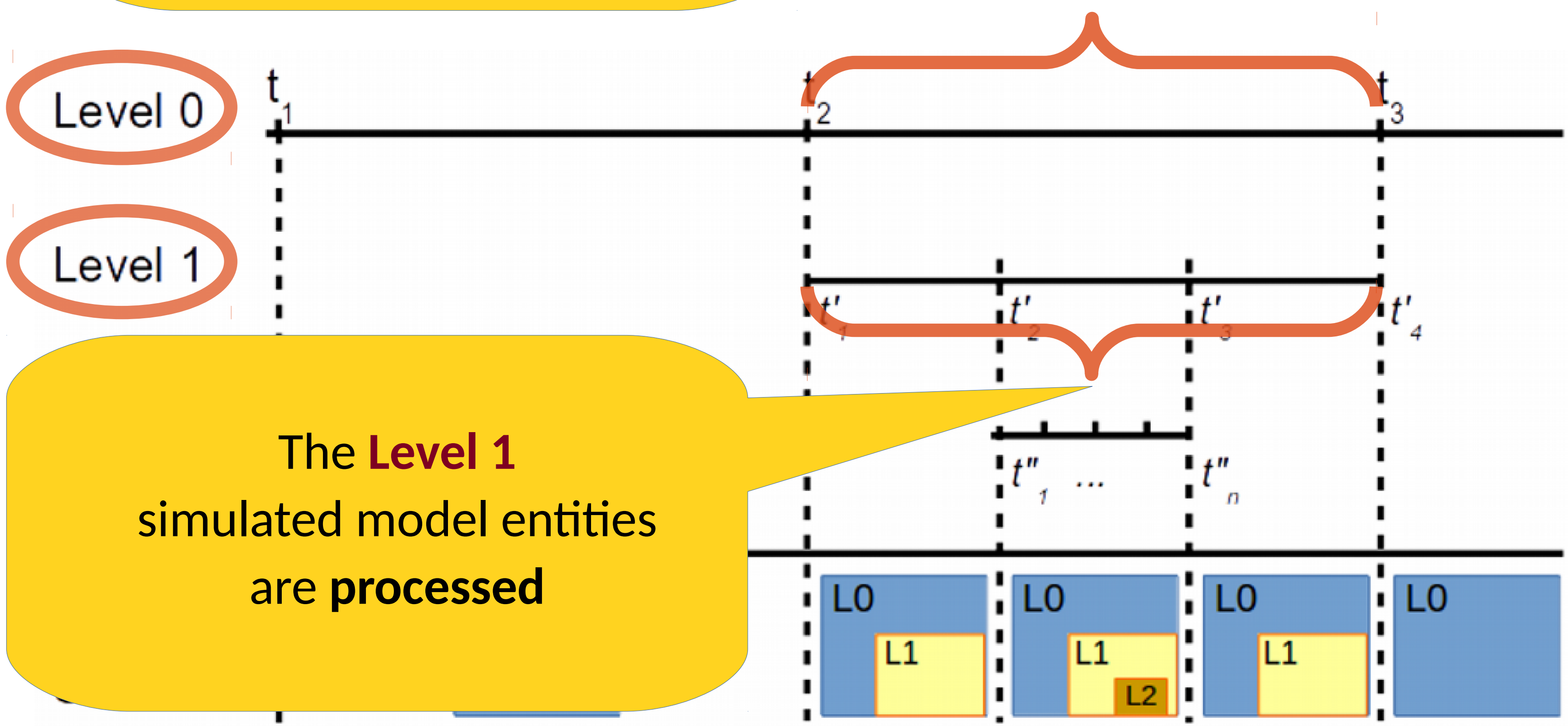
Multi-level Simulation Models



The **Level 1**
simulated model entities
are processed

lation Models

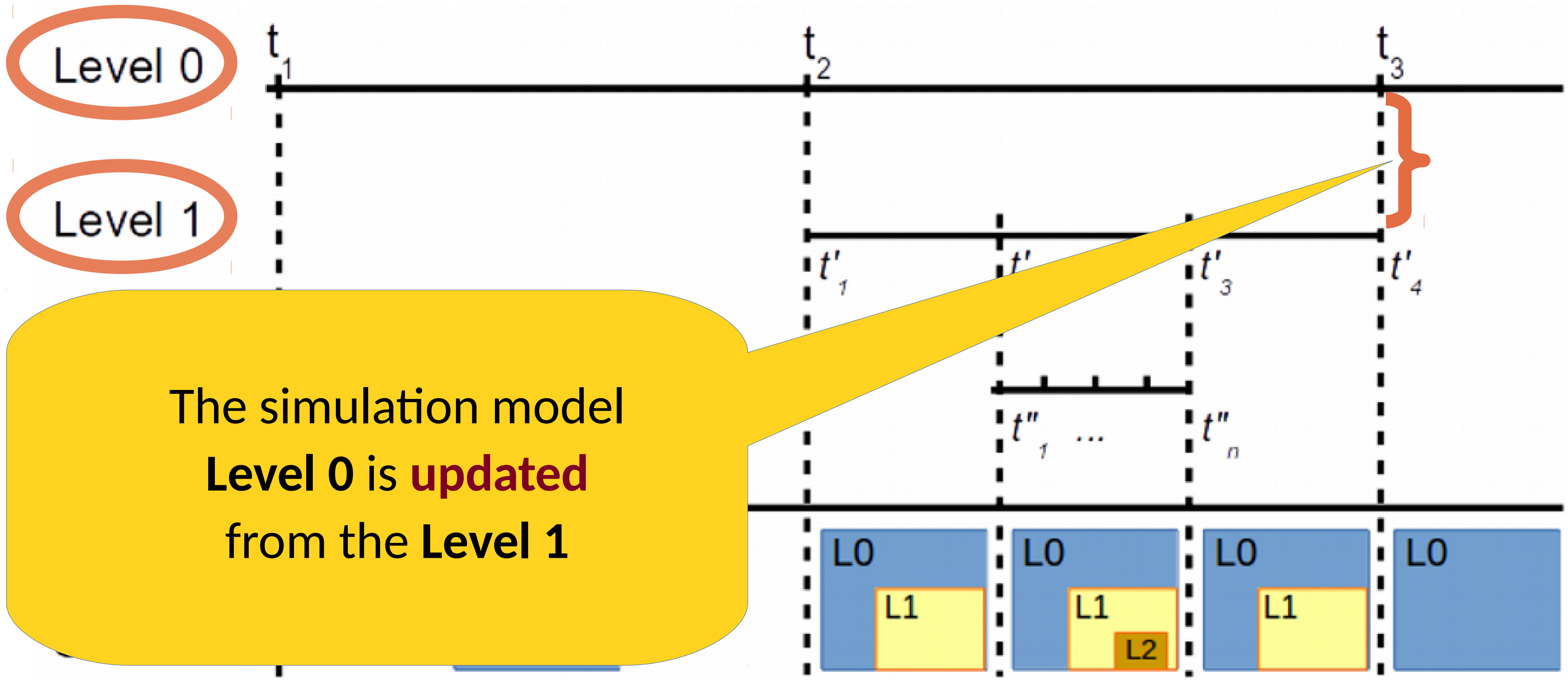
All the remaining
Level 0
simulated model entities
are **processed**



The **Level 1**
simulated model entities
are **processed**

Multi-level Simulation Models

Interoperability



The simulation model **Level 0** is **updated** from the **Level 1**

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Smart Cities

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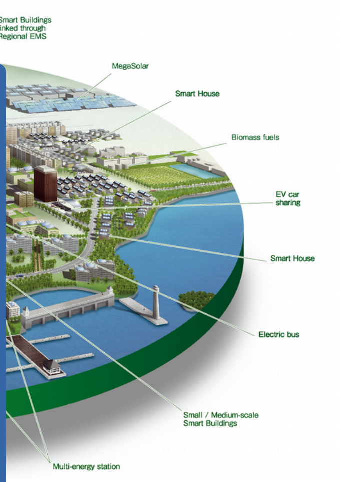
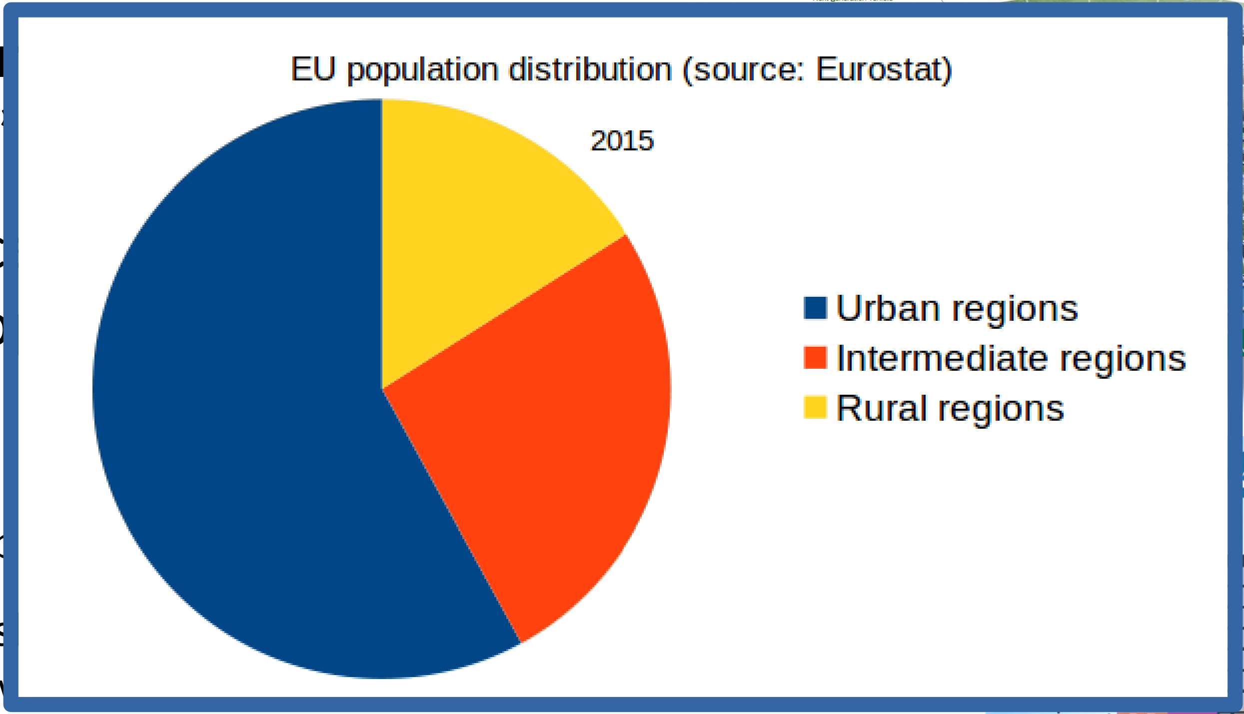


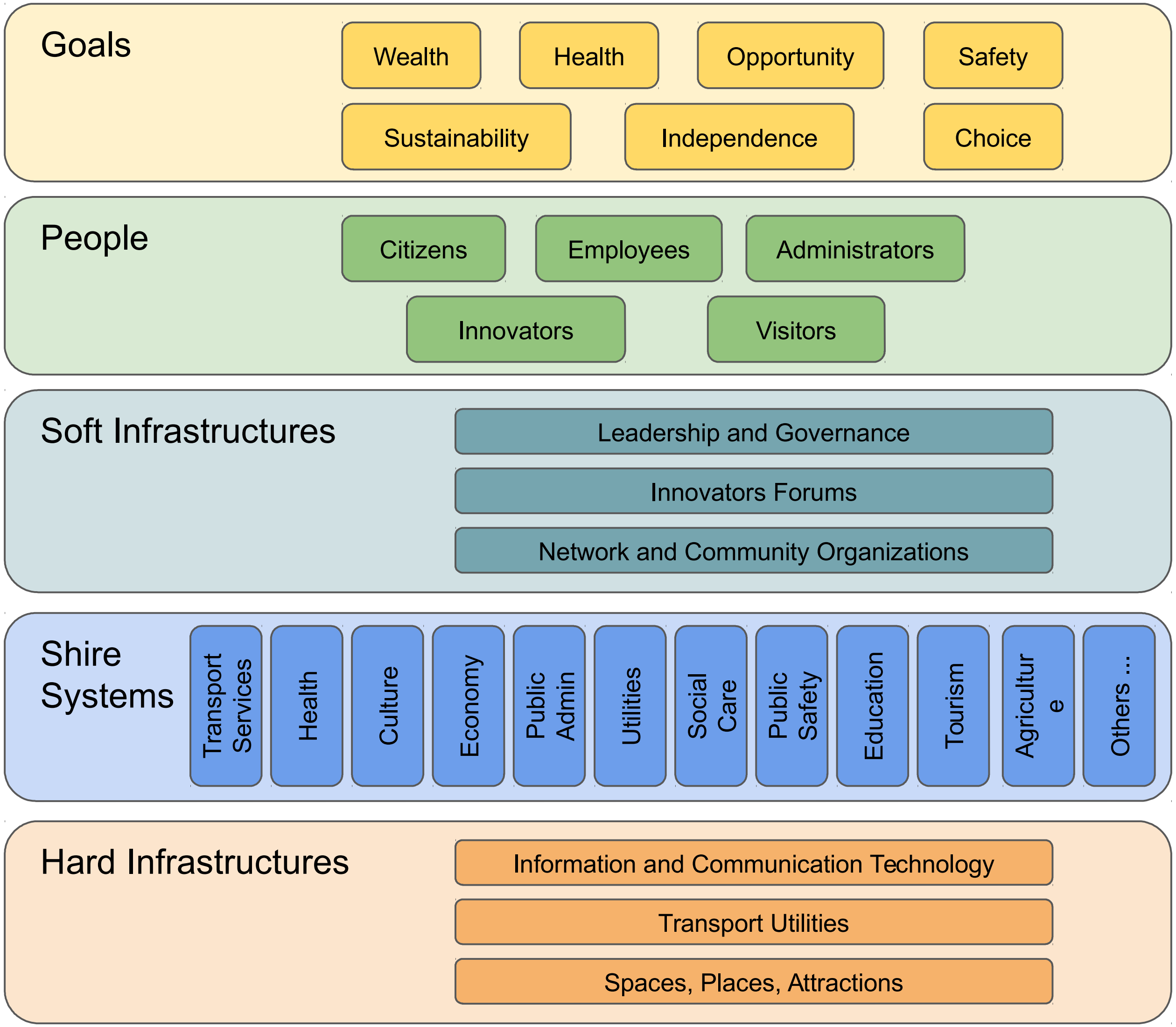


What about decentralized areas?

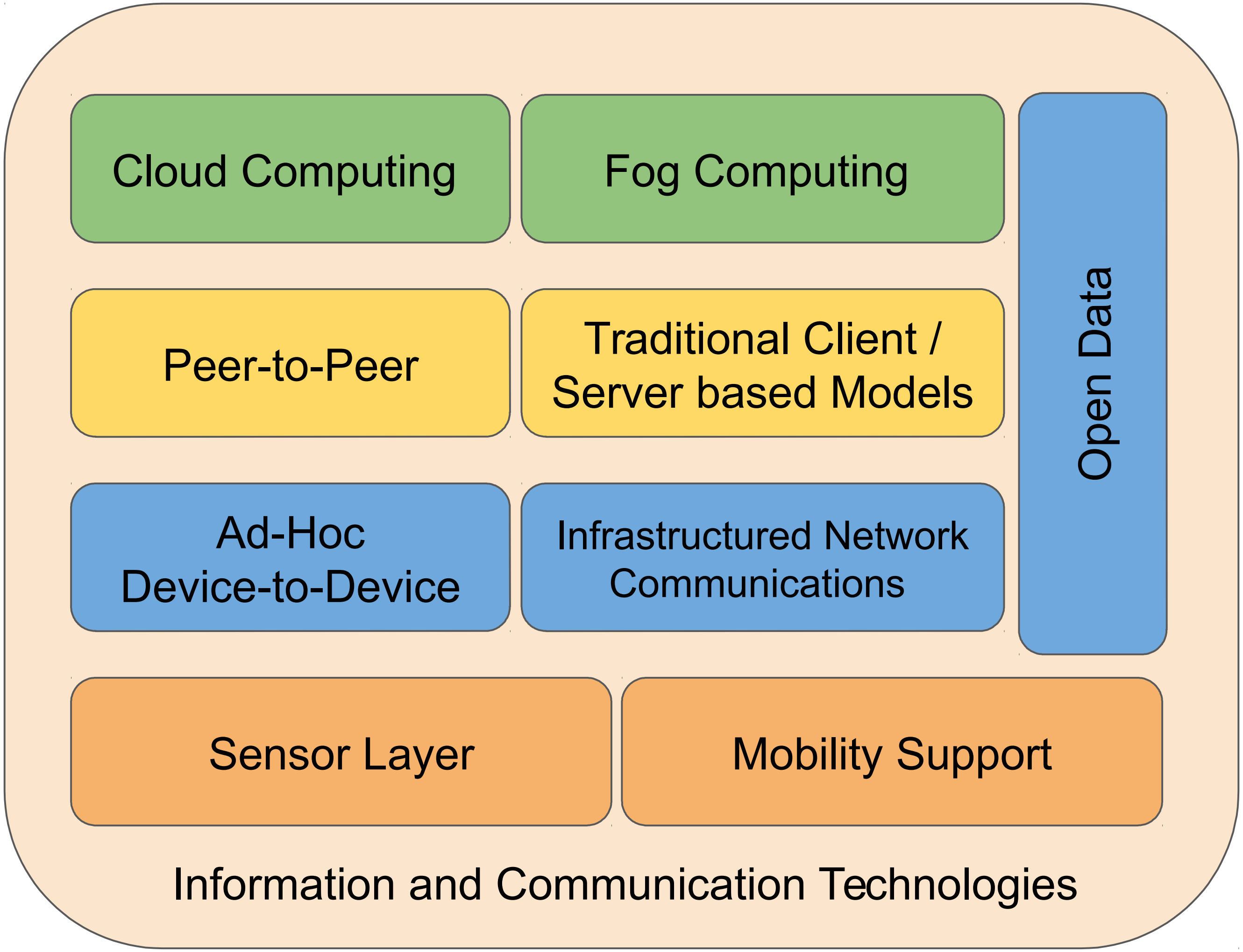
Shires aren't Cities

- **Goals**:
  - promote the underestimated potential (tourism, healthy lifestyle, products, …)
  - reduce technological gaps with cities
- **Not** possible to implement (costly) smart cities services to make them work in a country territory
- Need for adaptive, self-configuring and cheap solutions
  - **not** dependent to the presence of a classic networking infrastructure
  - opportunistic and dynamic solutions

Components of the Architecture



Information and Communication Technologies



Smart Market

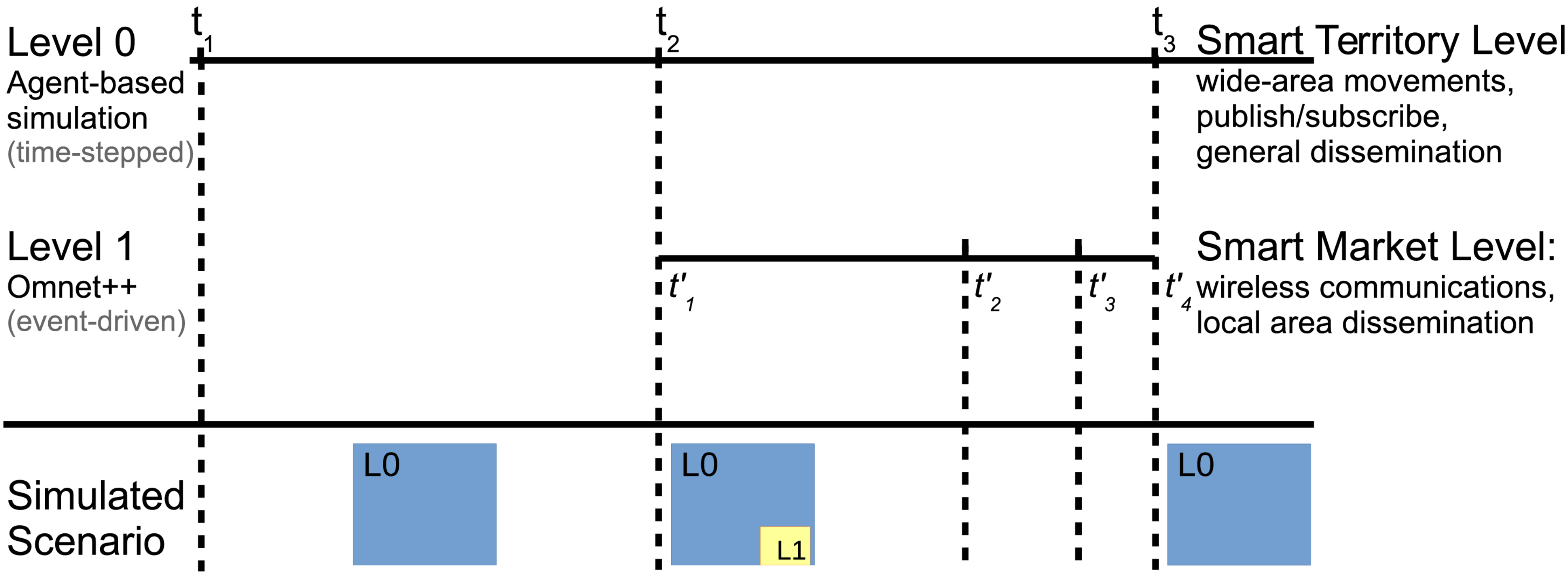
Smart Market Services

- Publish/Subscribe
  - consumers subscribe to the availability of a certain product
  - producers notify upon availability
    - they might indicate small markets where users can find them
- Proximity-based applications (on the fly information)
  - guidance
  - advertisement for similar products of interest
  - services for people with disabilities

Smart Market Simulation

- Multi-level simulation
  - scalability
  - different levels of granularity
    - publish/subscribe, wide area movements, general dissemination → **coarse grained**
    - smart market interactions, local interactions, net configuration → **finer grained**

Multi-level Simulation



Level 0: Agent-based Simulator

- Based on the GAIA/ARTÌS simulation middleware
- Time-stepped, agent based simulator
- ARTÌS permits seamless sequential/parallel/distributed execution of large scale simulation models
  - shared memory, TCP/IP, MPI
  - time-stepped, conservative, optimistic synchronization
- GAIA framework
  - provides high level application program interfaces
  - implements communication and computational load-balancing strategies, based on the **adaptive partitioning** of the simulation model

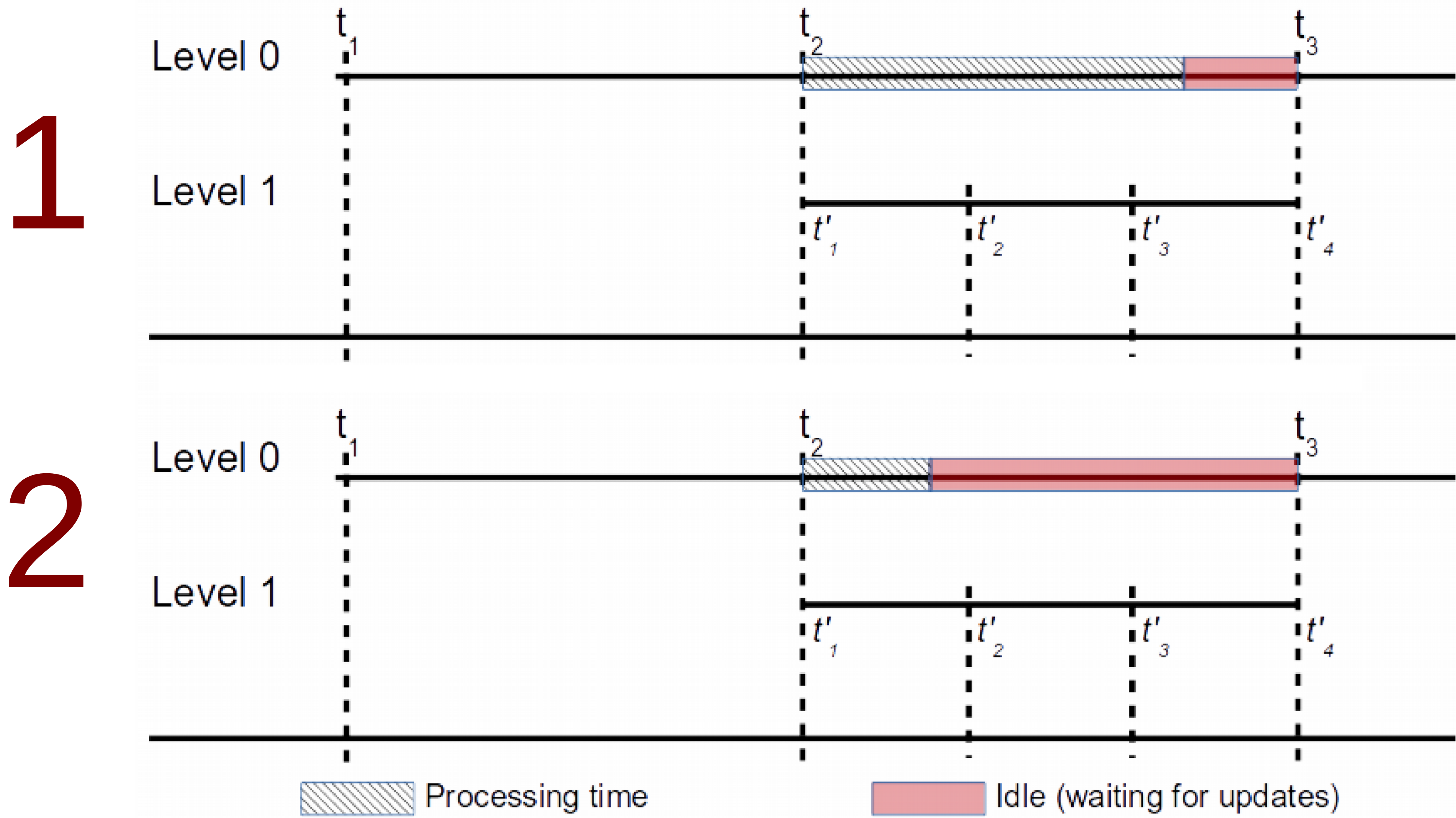
Level 1: Omnet++

- Omnet++ v. 4.4.1 + INET framework v. 2.3.0
- Event-driven simulator
- Grid of fixed nodes representing the market sellers
- MANET: DYMOUM routing protocol
- N mobile nodes representing pedestrian users
  - they move at walking speed
- Mobile client broadcasts messages looking for the identifier of the specific seller
- Seller replies with his geographical position
- Mobile user moves towards his destination

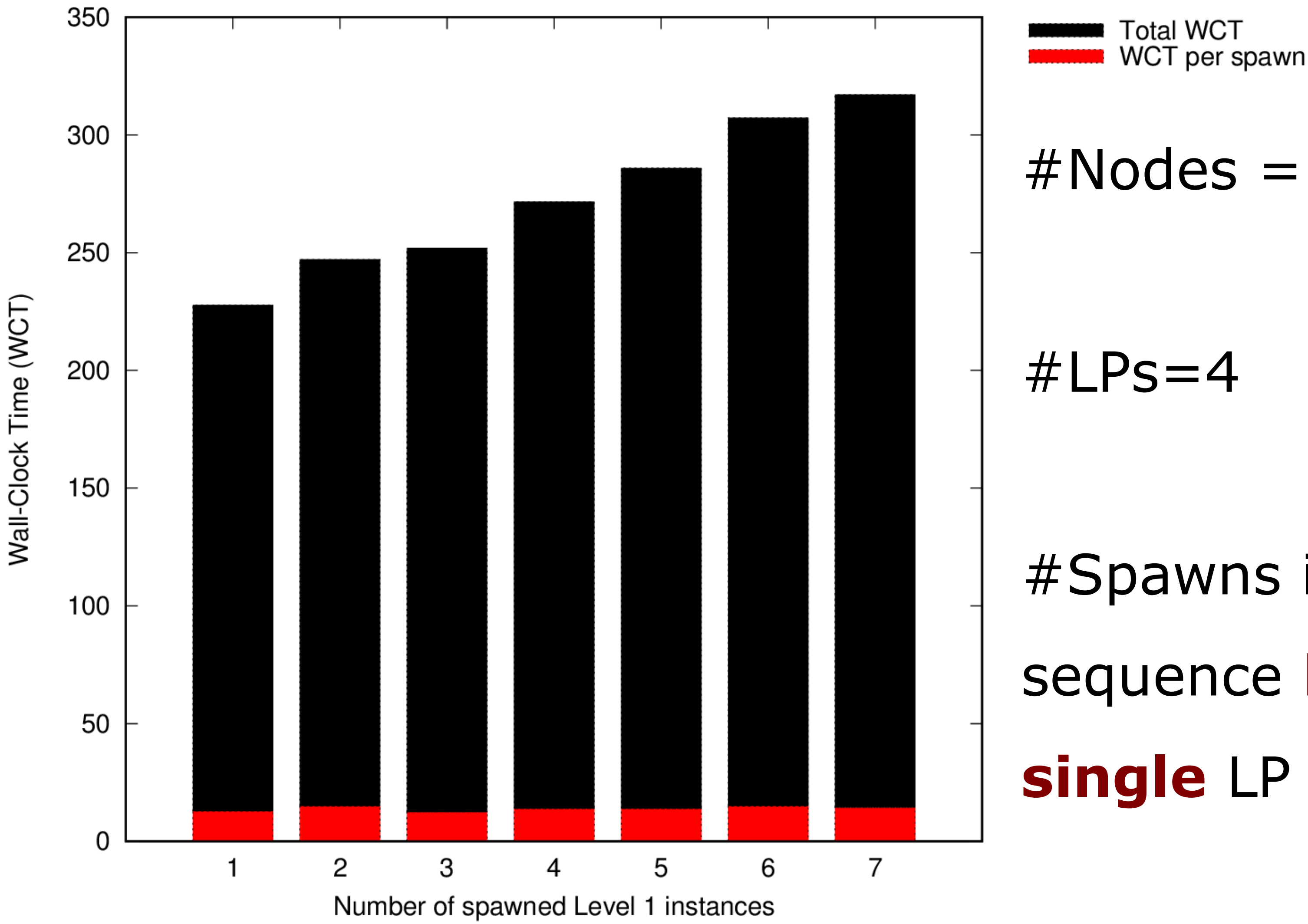
Interoperability of Simulators

- The two simulators communicate through a TCP connection
- Messages:
  - Data:
    - input
    - configuration parameters
    - output
  - Level 0 → Level 1:
    - "continue the simulation" or "end of simulation" commands
    - sent at the end of each level 0 timestep

Performance Evaluation



Performance Evaluation

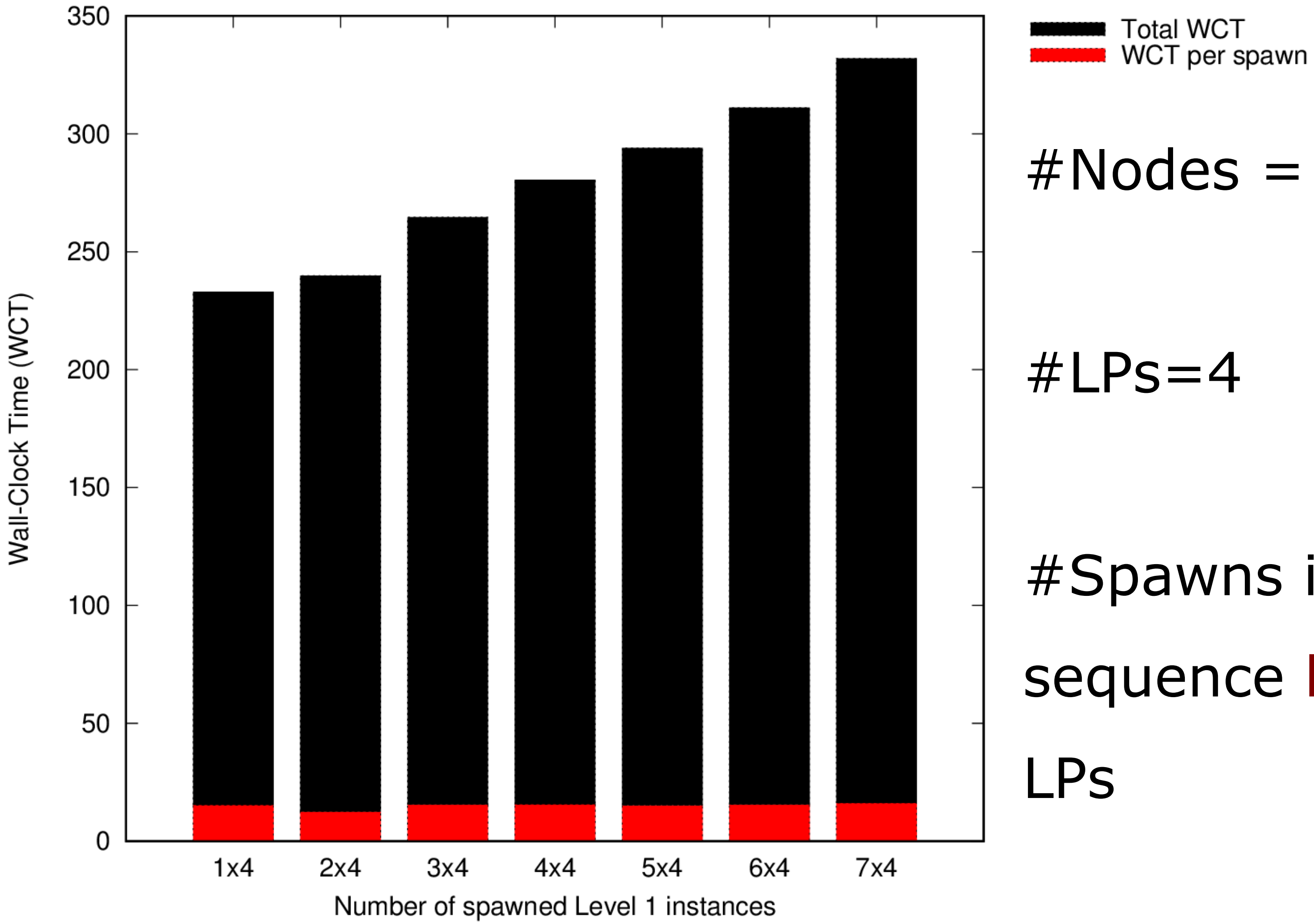


#Nodes = 4000

#LPs=4

#Spawns in sequence **by a single** LP

Performance Evaluation



#Nodes = 4000

#LPs=4

#Spawns in sequence **by all** LPs

Further Information

Gabriele D'Angelo, Stefano Ferretti, Vittorio Ghini

Simulation of the Internet of Things

Proceedings of the International Conference on High Performance Computing and Simulation (HPCS 2016). Innsbruck, Austria, July 2016

A **draft version** of this paper is freely available at the following link:

- https://arxiv.org/abs/1605.04876

The **ARTÌS** middleware and the **GAIA** framework can be downloaded from:

- http://pads.cs.unibo.it

Gabriele D'Angelo

- E-mail: <g.dangelo@unibo.it>
- http://www.cs.unibo.it/gdangelo/

Related Work

Gabriele D'Angelo

The Simulation Model Partitioning Problem: an Adaptive Solution Based on Self-Clustering

Simulation Modelling Practice and Theory, Elsevier, vol. 70

pdf

Stefano Ferretti, Gabriele D'Angelo

Smart Shires: The Revenge of Countrysides

IEEE Symposium on Computers and Communications (ISCC 2016)

pdf

Stefano Ferretti, Gabriele D'Angelo

Smart Multihoming in Smart Shires: Mobility and Communication Management for Smart Services in Countrysides

IEEE Symposium on Computers and Communications (ISCC 2016)

pdf

Gabriele D'Angelo, Moreno Marzolla

New Trends in Parallel and Distributed Simulation: from Many-cores to Cloud Computing

Simulation Modelling Practice and Theory, Elsevier, vol. 49

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