Simulation of the Internet of Things

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Tutorial Material and Extra Info

These **slides**, the **tutorial paper** and some

extra information can be found on the web page:

http://iot.portazero.it

Outline

- Introduction on IoT
- A brief simulation introduction
- Specific challenges in the simulation of IoT
- Multilevel simulation models / Heterogeneous simulation models
- Visionary: simulation of the IoT using the IoT
- Case study: smart shires
- Simulation tools: a very small review
- Demo: using a parallel/distributed simulation tool for modelling a massively populated IoT

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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

What Is the Internet of Things?

Kevin Ashton coined ***"Internet of Things"*** phrase to describe a system where the Internet is connected to the physical world via ubiquitous sensors

About IoT

- *A Reference Architecture for the Internet of Things.* WSO2 white paper
- *Learning Internet of Things.* Peter Waher, Packt
- Surveys
  - *Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications*. Al-Fuqaha, A.; Guizani, M.; Mohammadi, M.; Aledhari, M.; Ayyash, M., Communications Surveys & Tutorials, IEEE (Volume:17 , Issue: 4), 2015
  - *The Internet of Things: A survey.* Luigi Atzoria, Antonio Ierab, Giacomo Morabito, Computer Networks. Volume 54, Issue 15, 28 October 2010, Pages 2787–2805

Relationship to the Internet of Everything (IoE)

People
Connecting People in More Relevant, Valuable Ways

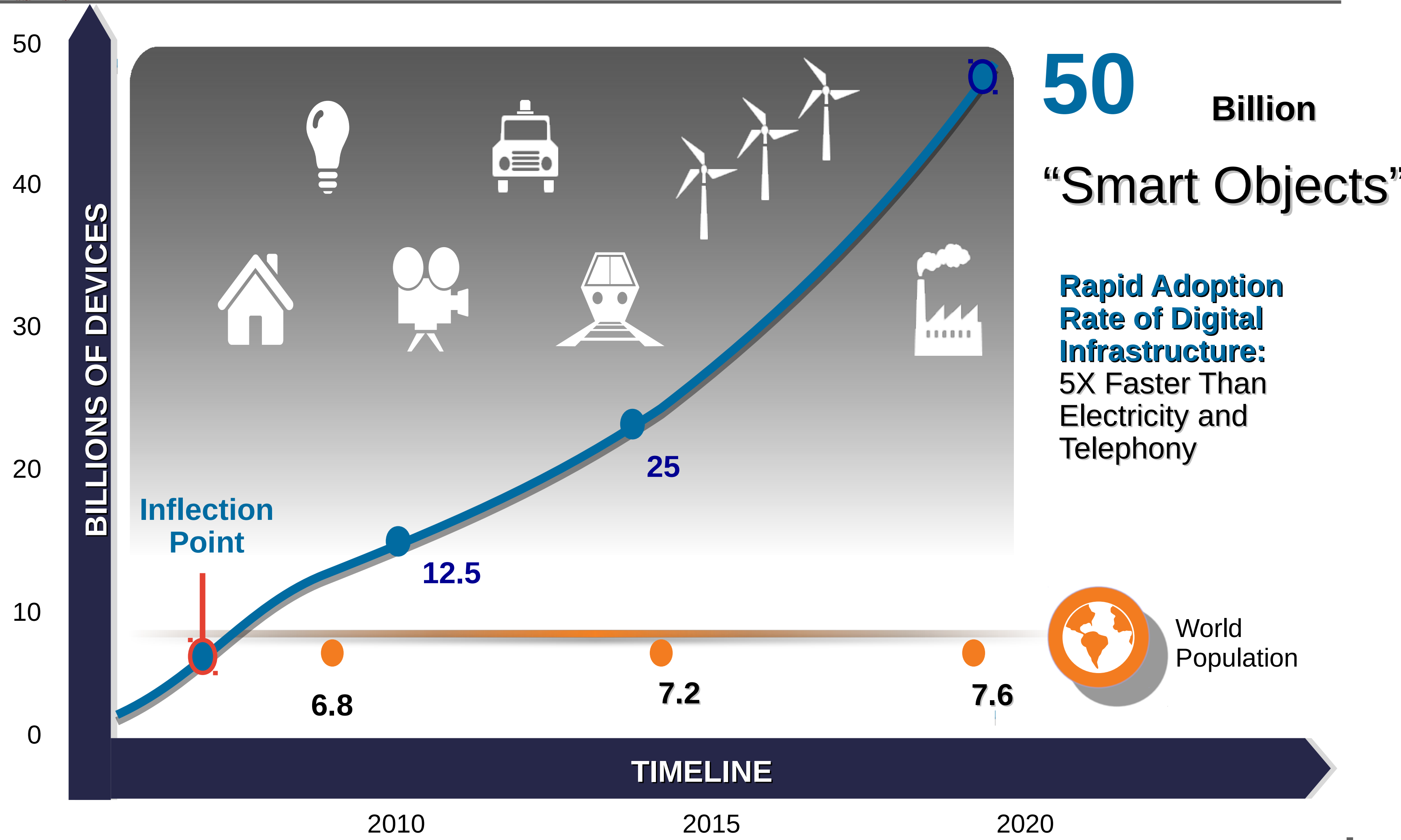
Process
Delivering the Right Information to the Right Person (or Machine) at the Right Time

Data
Leveraging Data into More Useful Information for Decision Making

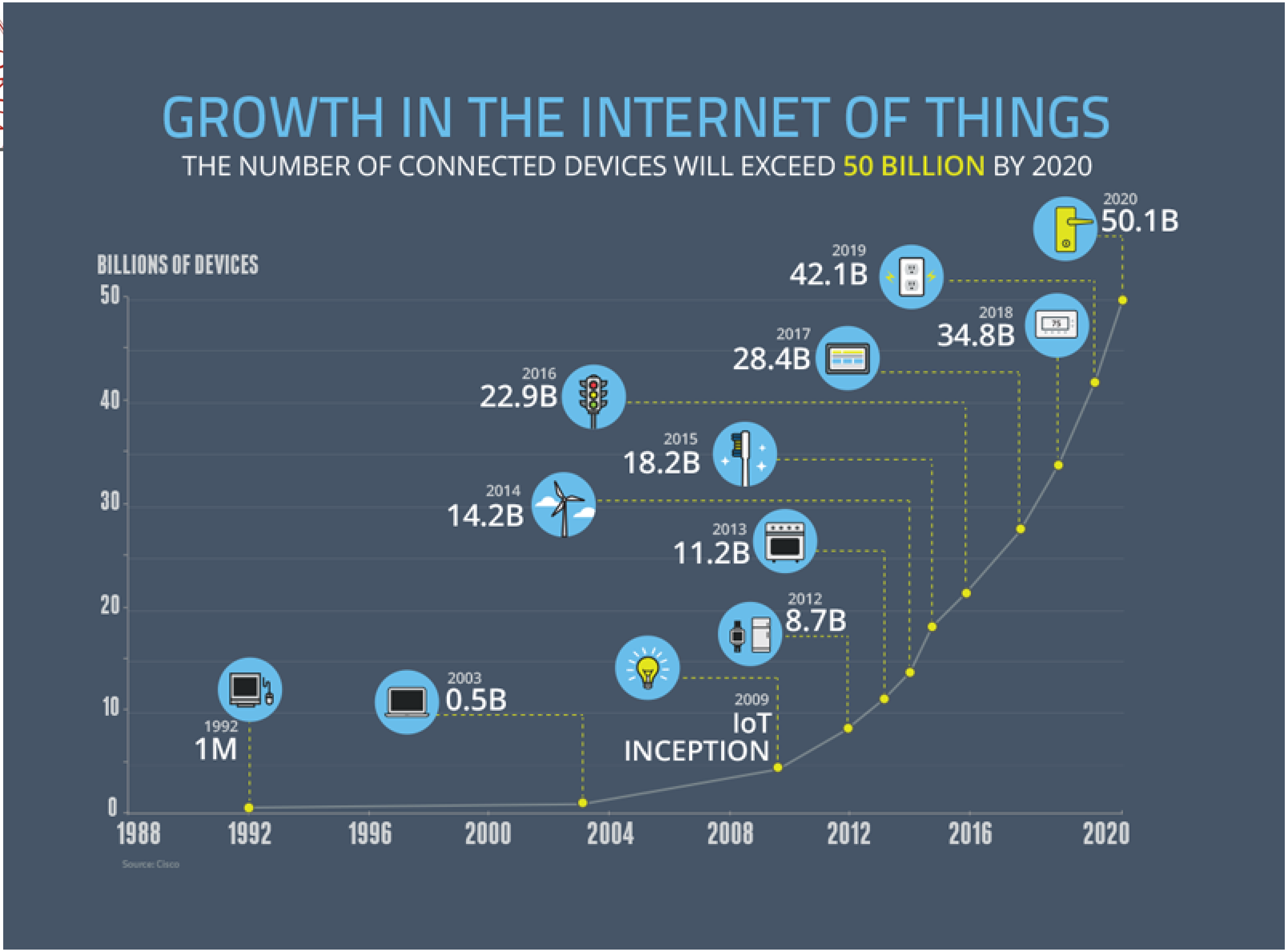
Things
Physical Devices and Objects Connected to the Internet and Each Other for Intelligent Decision Making

Source: Cisco

IoT Is Here Now – and Growing!



Source: Cisco IBSG, 2011

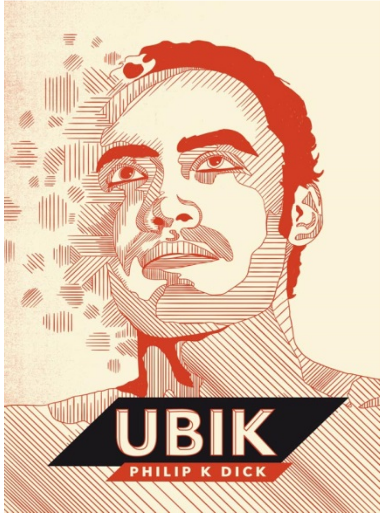


Source: http://www.seediscover.com/behind-the-numbers-growth-in-the-internet-of-things/

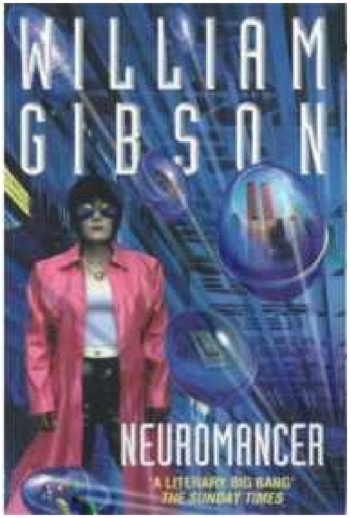
How Ubiquitous?

Gartner: «IoT installed base will grow to ***26 billion units*** by 2020». ***That number might be too low***

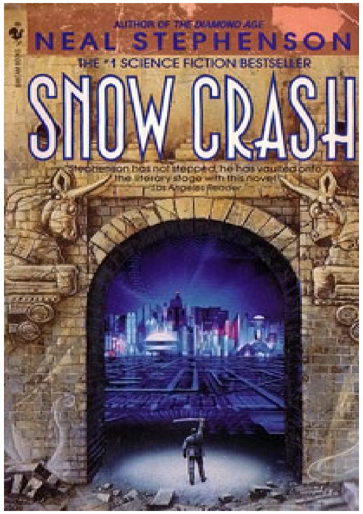
Every mobile
Every auto



Every door
Every room



Every part, on every parts list



Every sensor in every device …
in every bed, chair or bracelet ...
in every home, office, building or hospital room …
in every city and village ...
on Earth ...

Source: Nasir Memon, New York University

Connected Rail Operations

PASSENGER SECURITY
- In-station and onboard safety
- Visibility into key events

ROUTE OPTIMIZATION
- Enhanced Customer Service
- Increased efficiency
- Collision avoidance
- Fuel savings

CRITICAL SENSING
- Transform “data” to “actionable intelligence”
- Proactive maintenance
- Accident avoidance

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

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

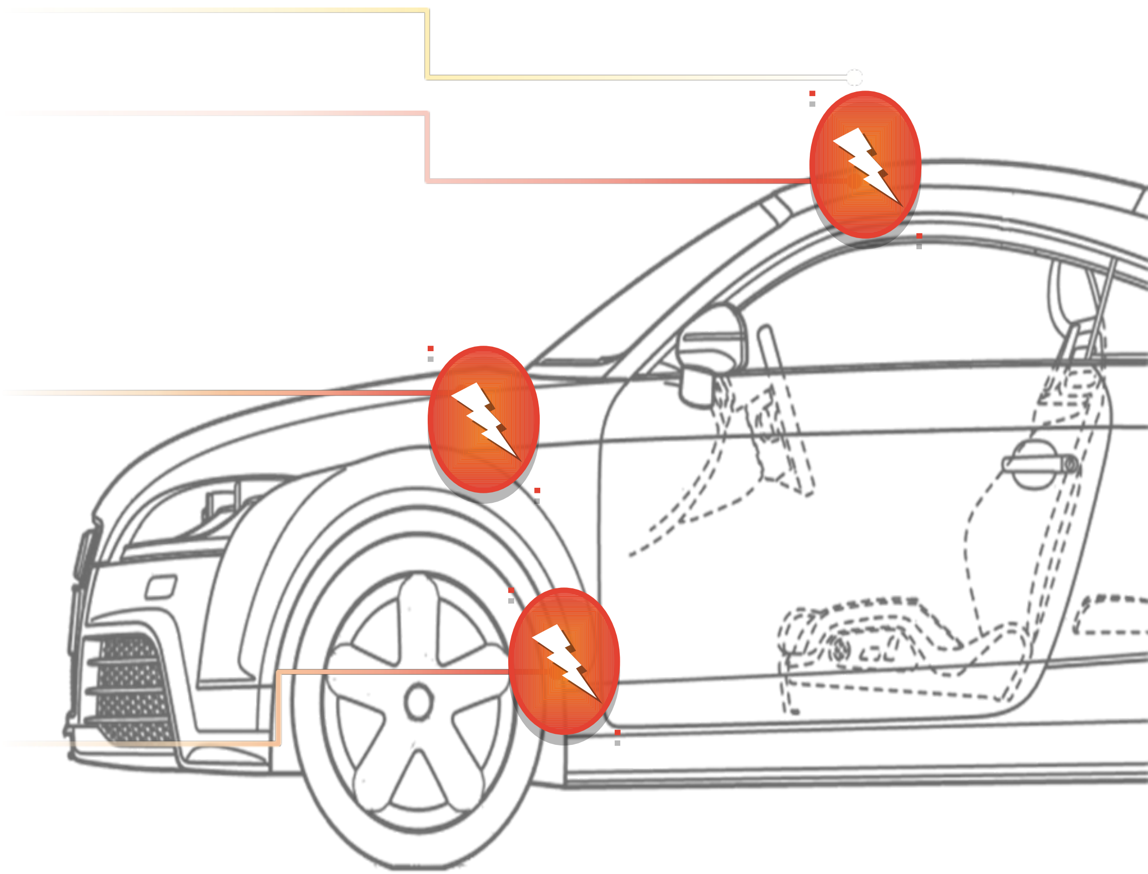
Source: M. Kader, Cisco, “IoT (Internet of Things) and Security”

The Connected Car

WIRELESS ROUTER
- Online entertainment
- Mapping, dynamic re-routing, safety and security

CONNECTED SENSORS
- Transform “data” to “actionable intelligence”
- Enable proactive maintenance
- Collision avoidance
- Fuel efficiency

URBAN CONNECTIVITY
- Reduced congestion
- Increased efficiency
- Safety (hazard avoidance)



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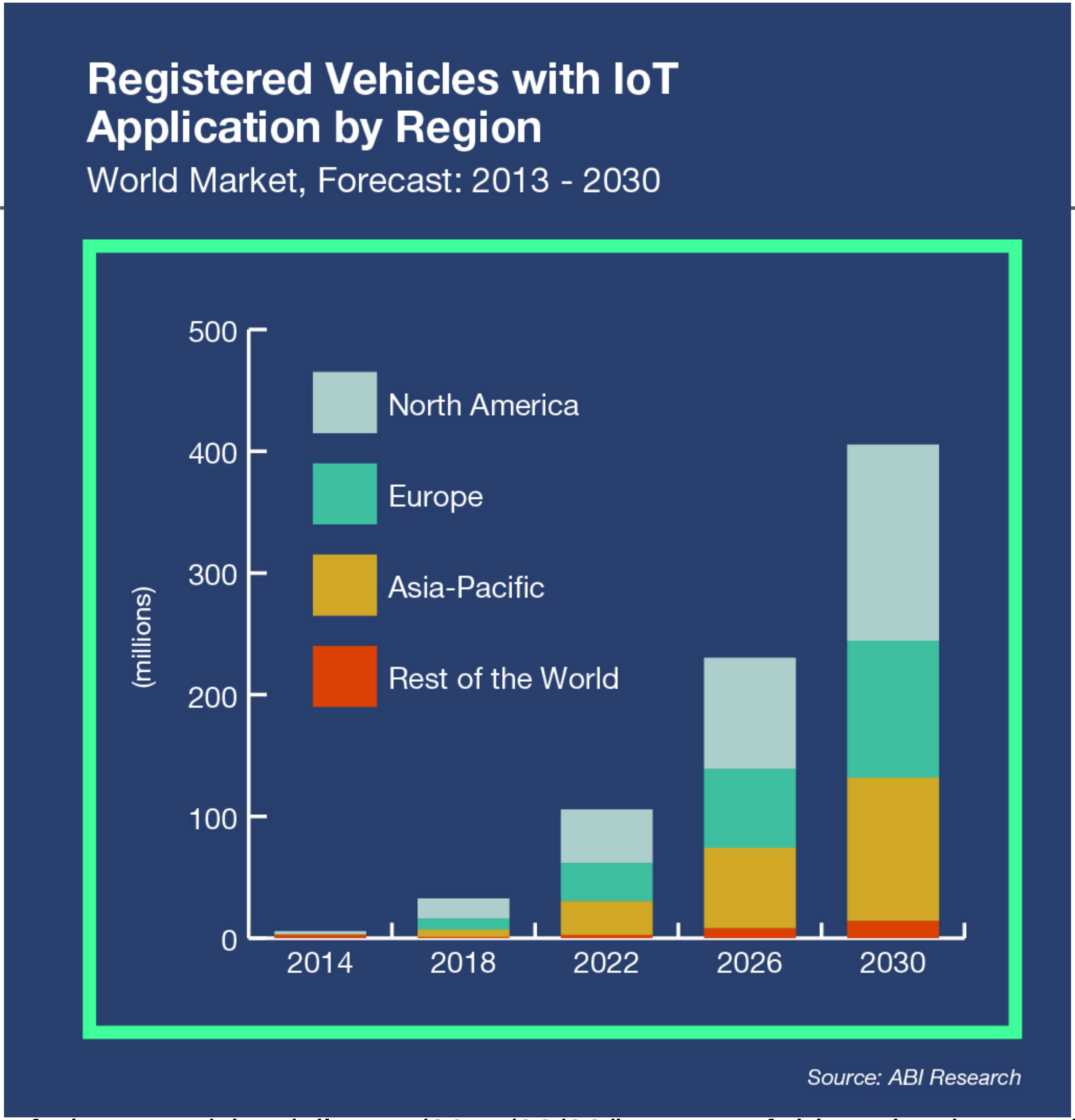
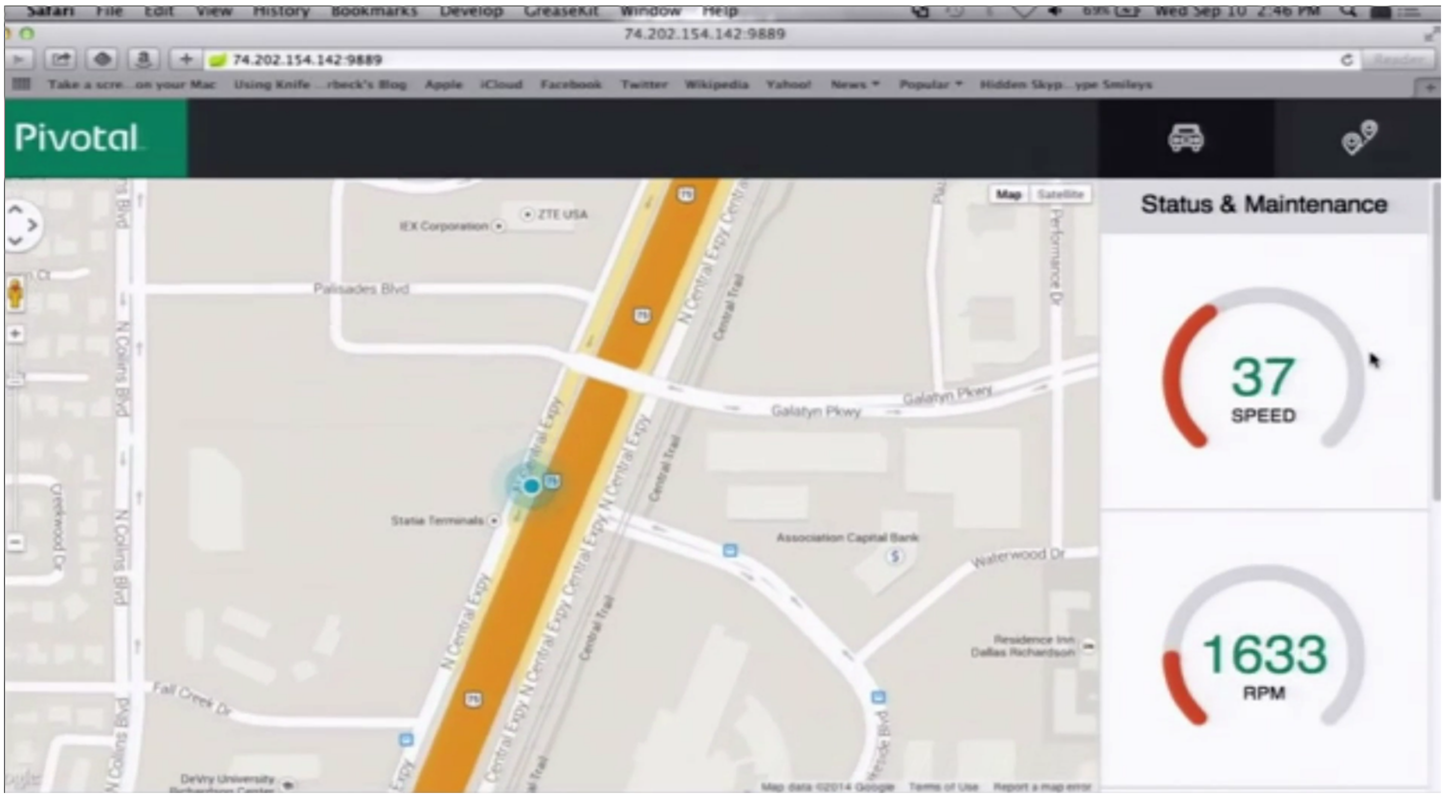


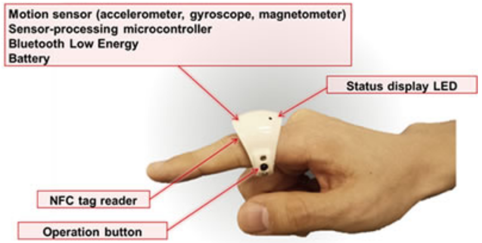
Source: http://www.forbes.com/sites/gilpress/2014/08/22/internet-of-things-by-the-numbers-market-estimates-and-forecasts/#5bdc25022dc9

The Connected Car



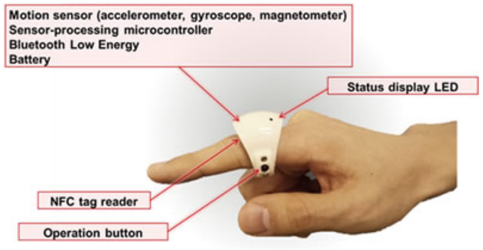
Snippet from
https://www.youtube.com/watch?v=cejQ46IQpUI

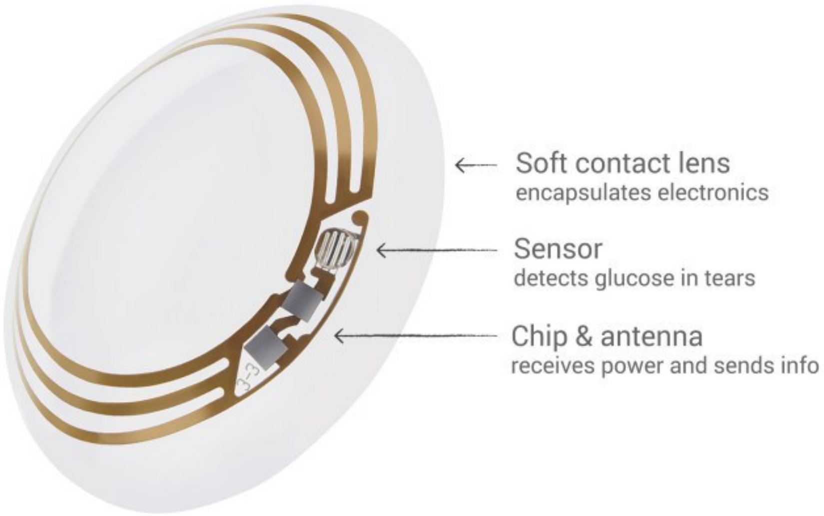
Personal devices and wearables



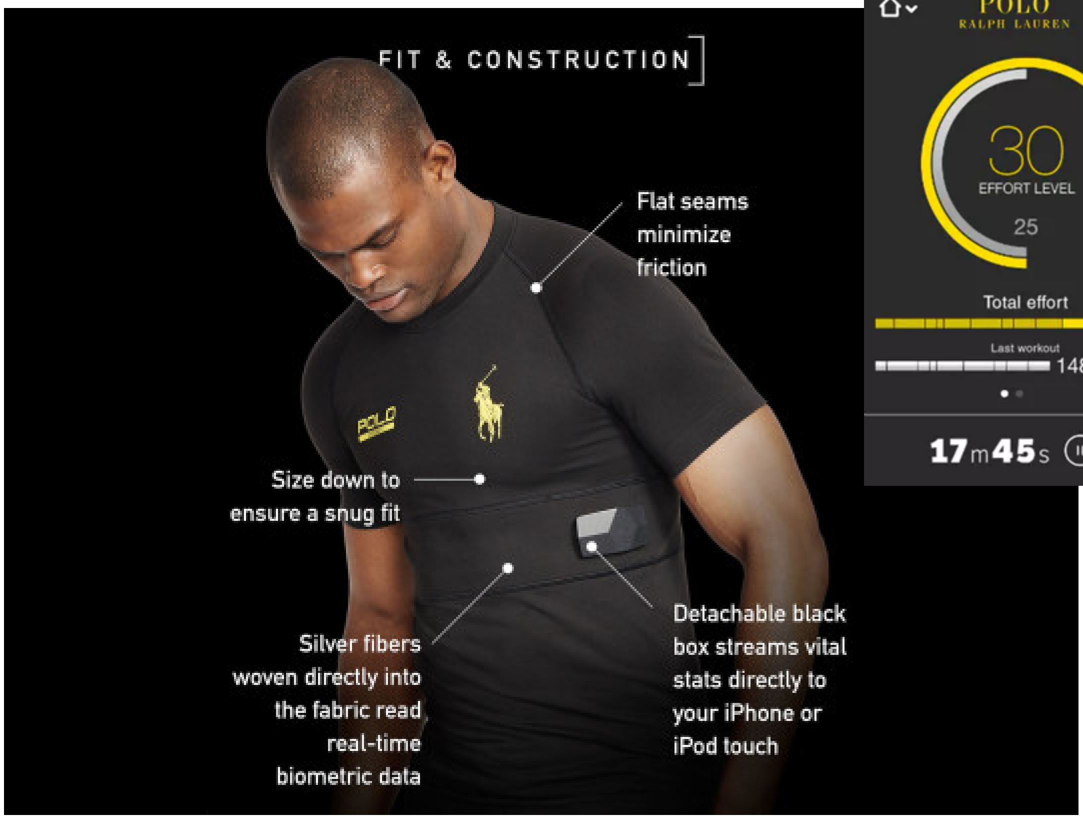
Personal devices and wearables

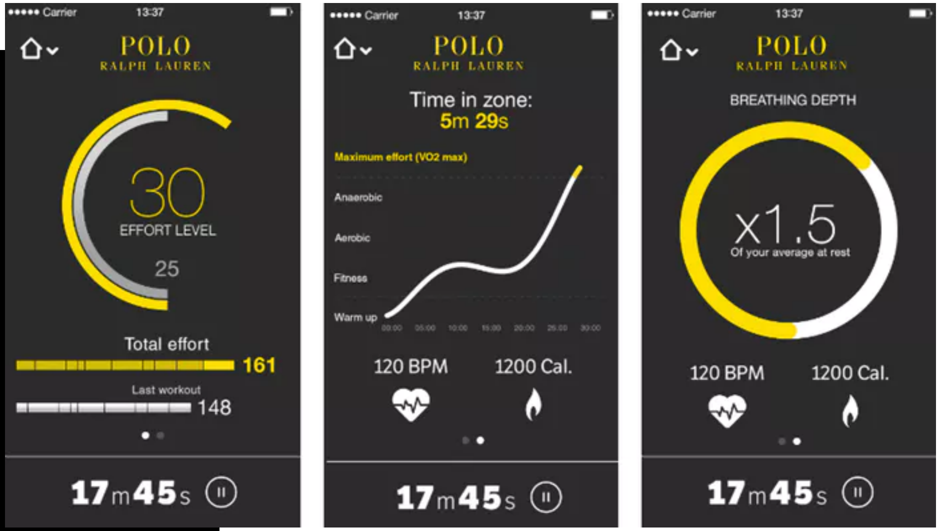
Wearables for user sensing





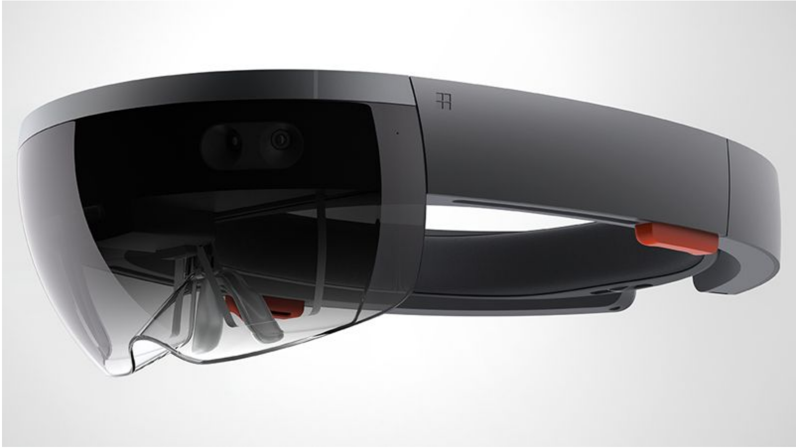
Wearables for user sensing





Wearables for user sensing

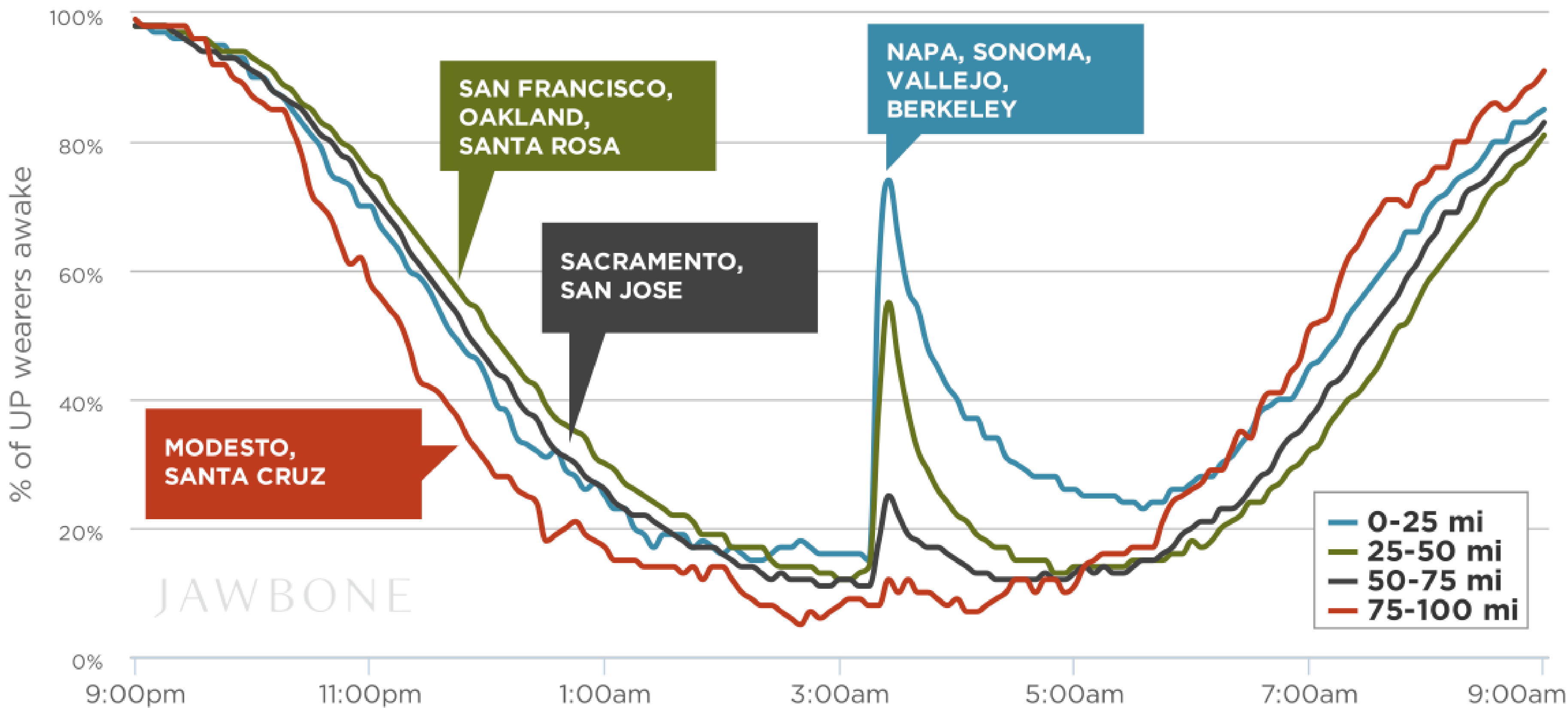
Wearables for environment sensing



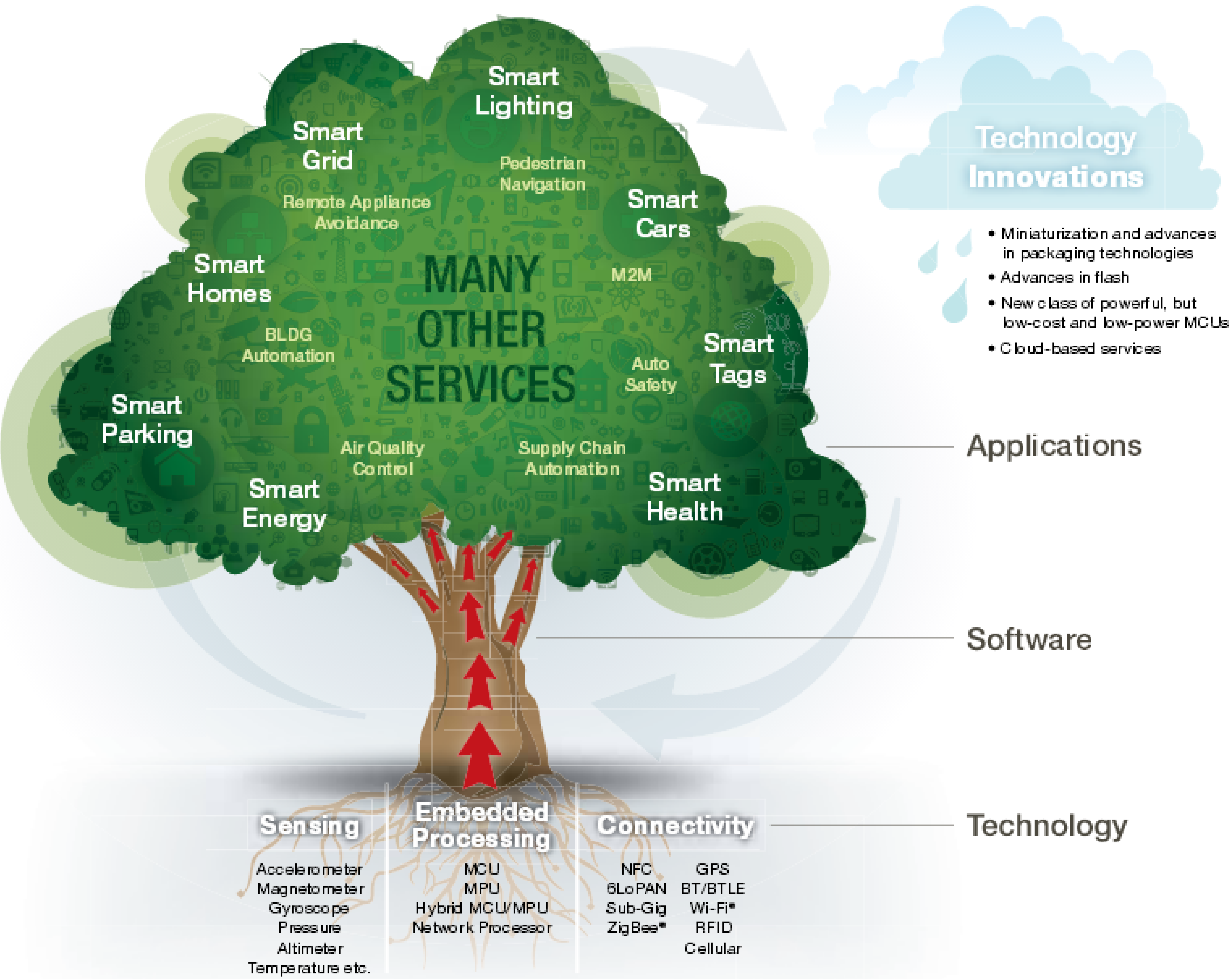
Wearables for environment sensing

Apps sensing you and your activity

User data analysis



The IoT: Different Services, Technologies, Meanings for Everyone



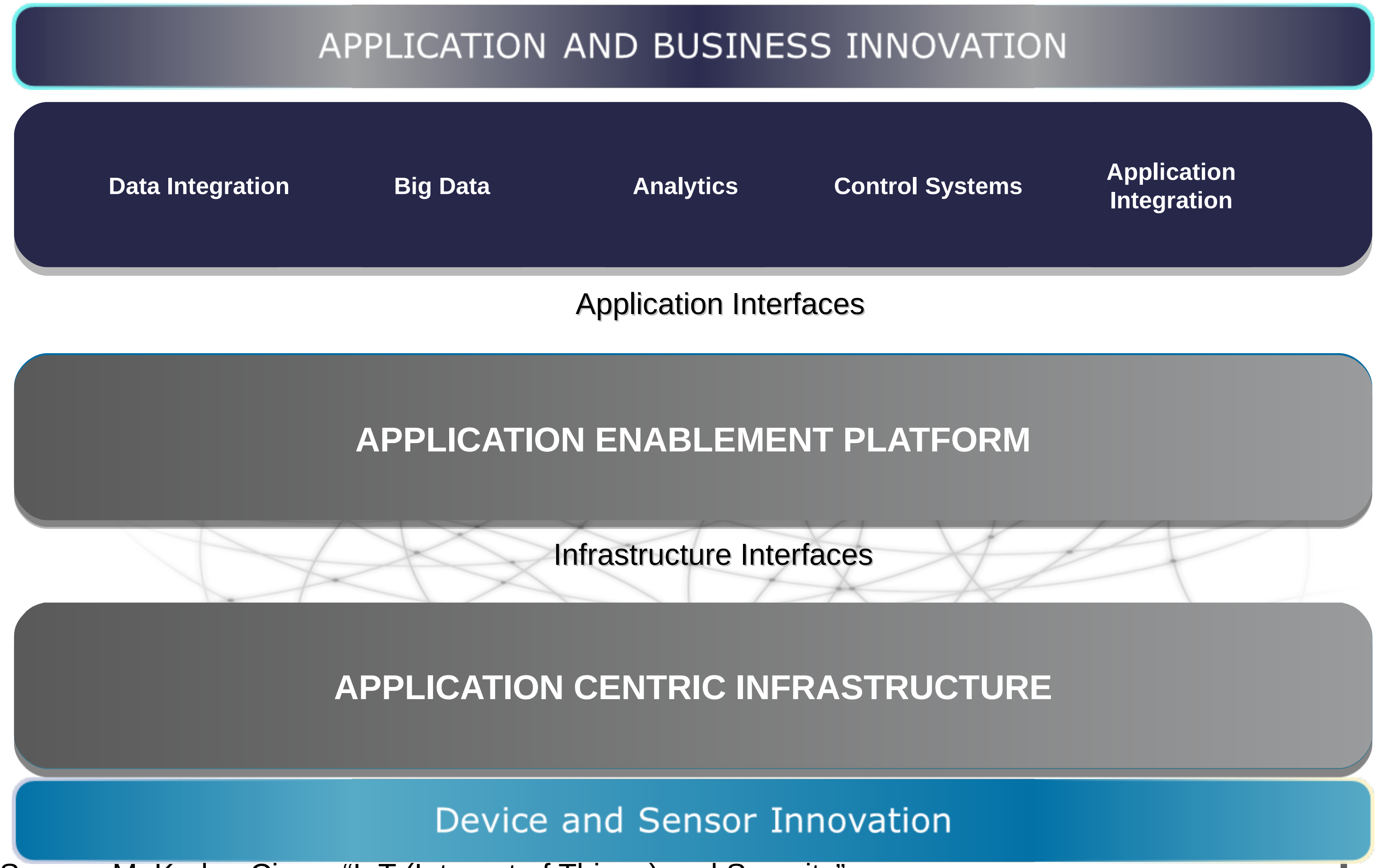
Source: K. Karimi, G. Atkinson, “What the Internet of Things needs to become a reality”

Internet of Things

The Internet of Things (IoT) is generating an unprecedented volume and variety of data

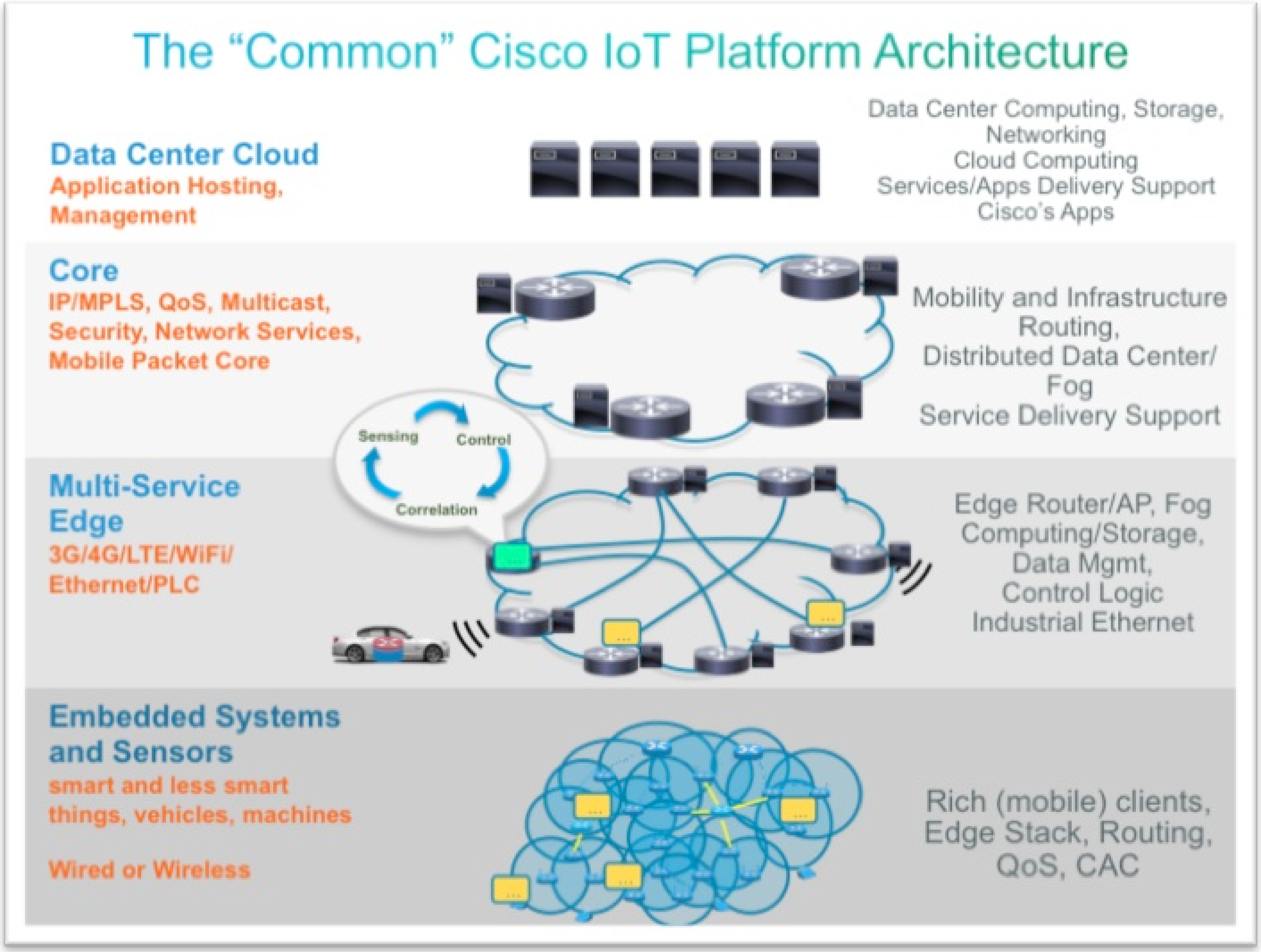
IoT devices generate data constantly and often analysis must be very rapid

… But It Also Adds Complexity



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

Multi-level Architecture



Multi-level Architecture (simplified)

Cloud – *hundreds*

Fog – *thousands*






Things – *millions (billions)*





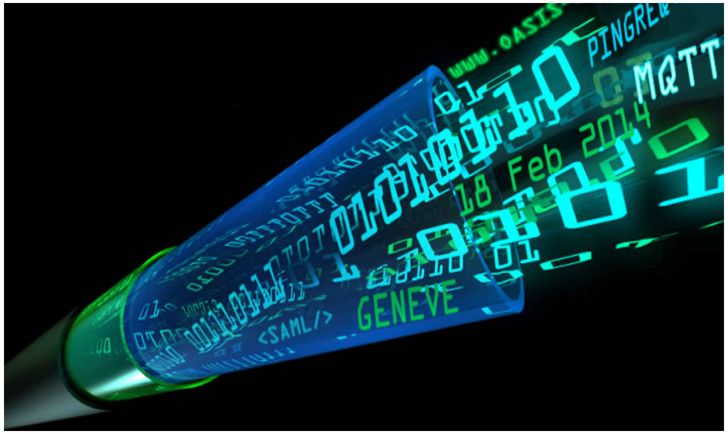





Open Protocols

Current Internet and software methods are highly modular (APIs), highly distributed (Cloud) and "loosely coupled" (SOA). In today's systems, *every LEGO brick comes from a different source* – and they all still must snap together.

This requires ***open, rapid and safe*** development methods.

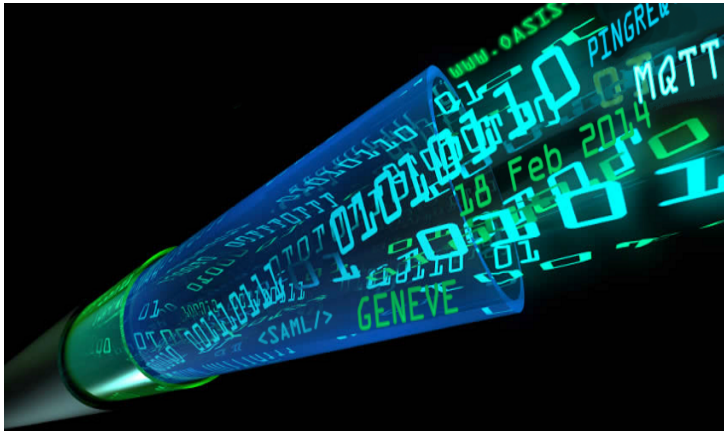


Source: C. Cosgrove-Sacks, “Open protocols for an open, interoperable internet of things”

Open Protocols

Current Internet and software methods are highly modular (APIs), highly distributed (Cloud) and "loosely coupled"

Simulating all this requires taking into considerations many factors, several level of details, without introducing (in many cases) over-simplifications



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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

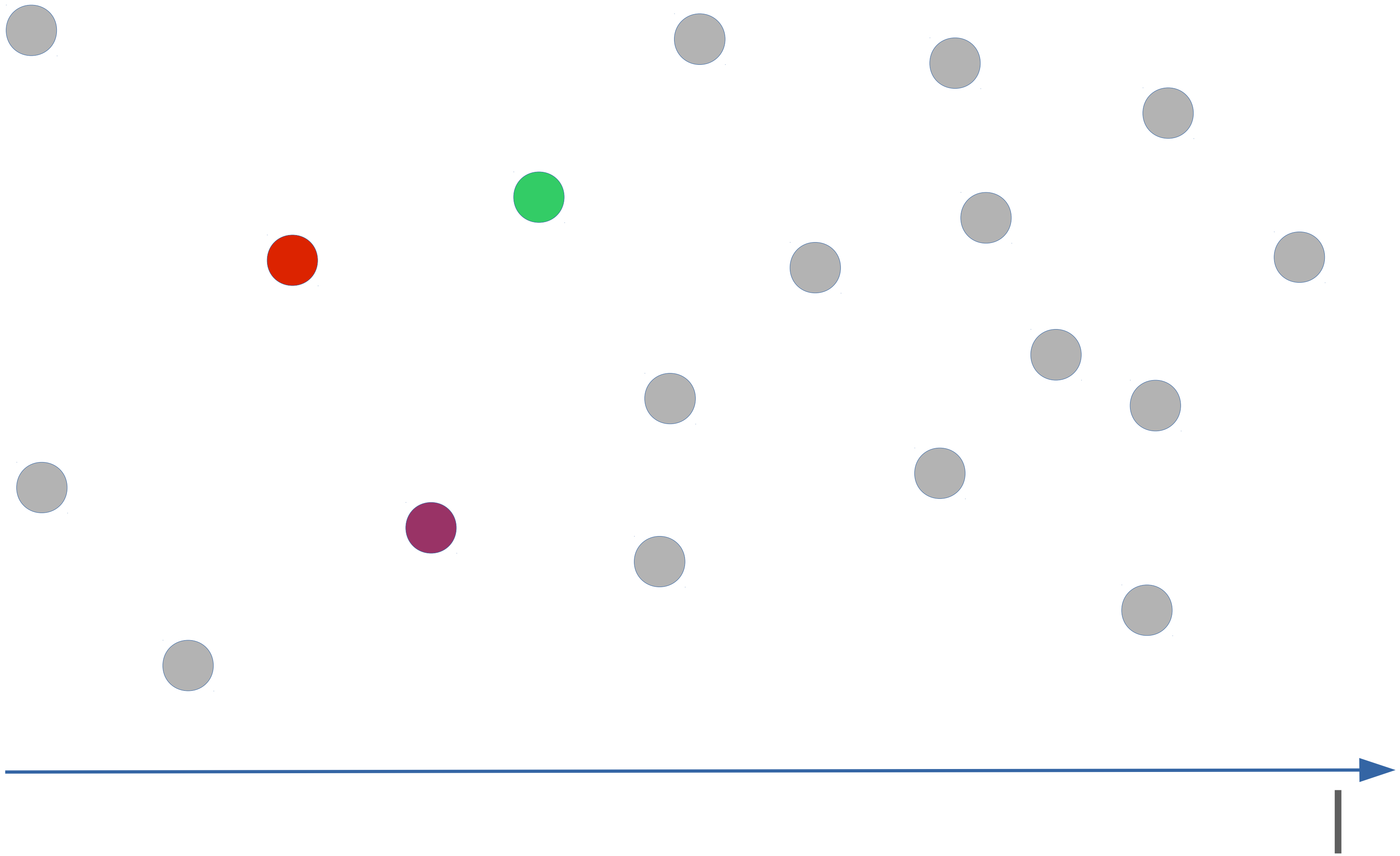
Simulation Paradigms

- **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**)

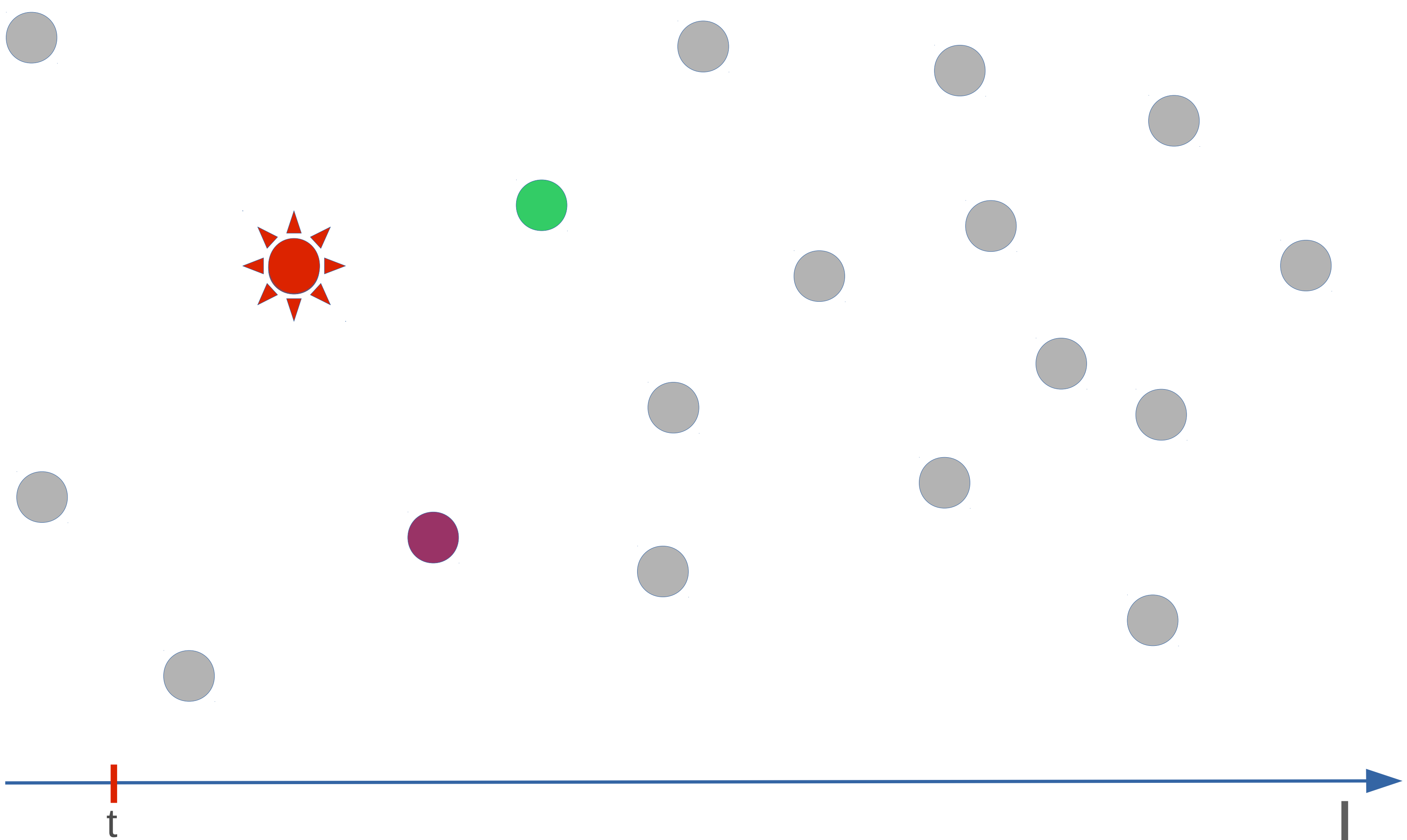
- The **state** of the simulated system is represented through a **set of variables**
- The key concept is the "**event**": a **change in the system state** (that occurs at an **instant in time**)
- **Evolution of a modeled system → processing of a chronological sequence of events**
- **DES**: creation, 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: A Simple Example



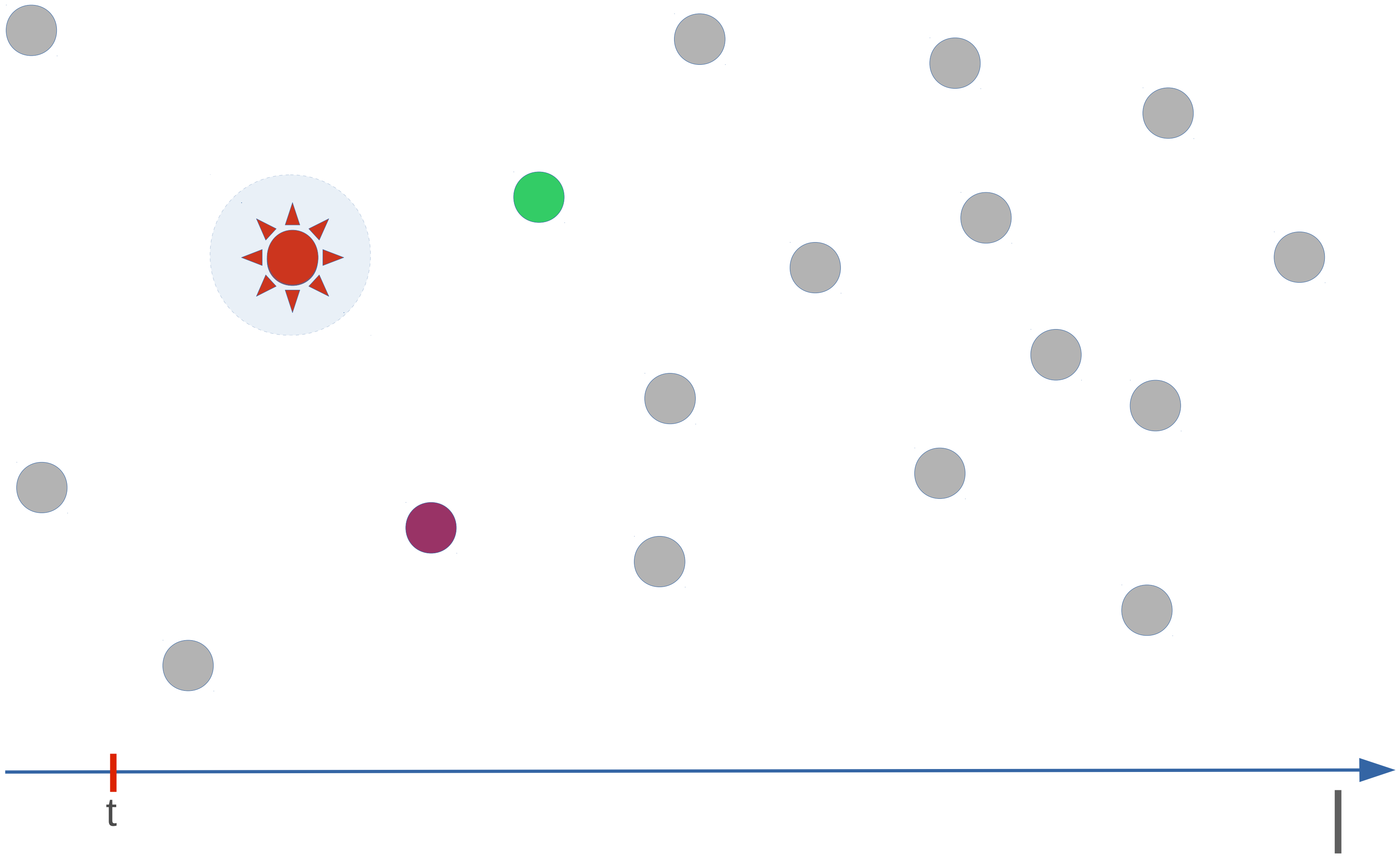
1) A set of mobile wireless hosts

DES: A Simple Example



2) At time t the red node starts transmitting

DES: A Simple Example



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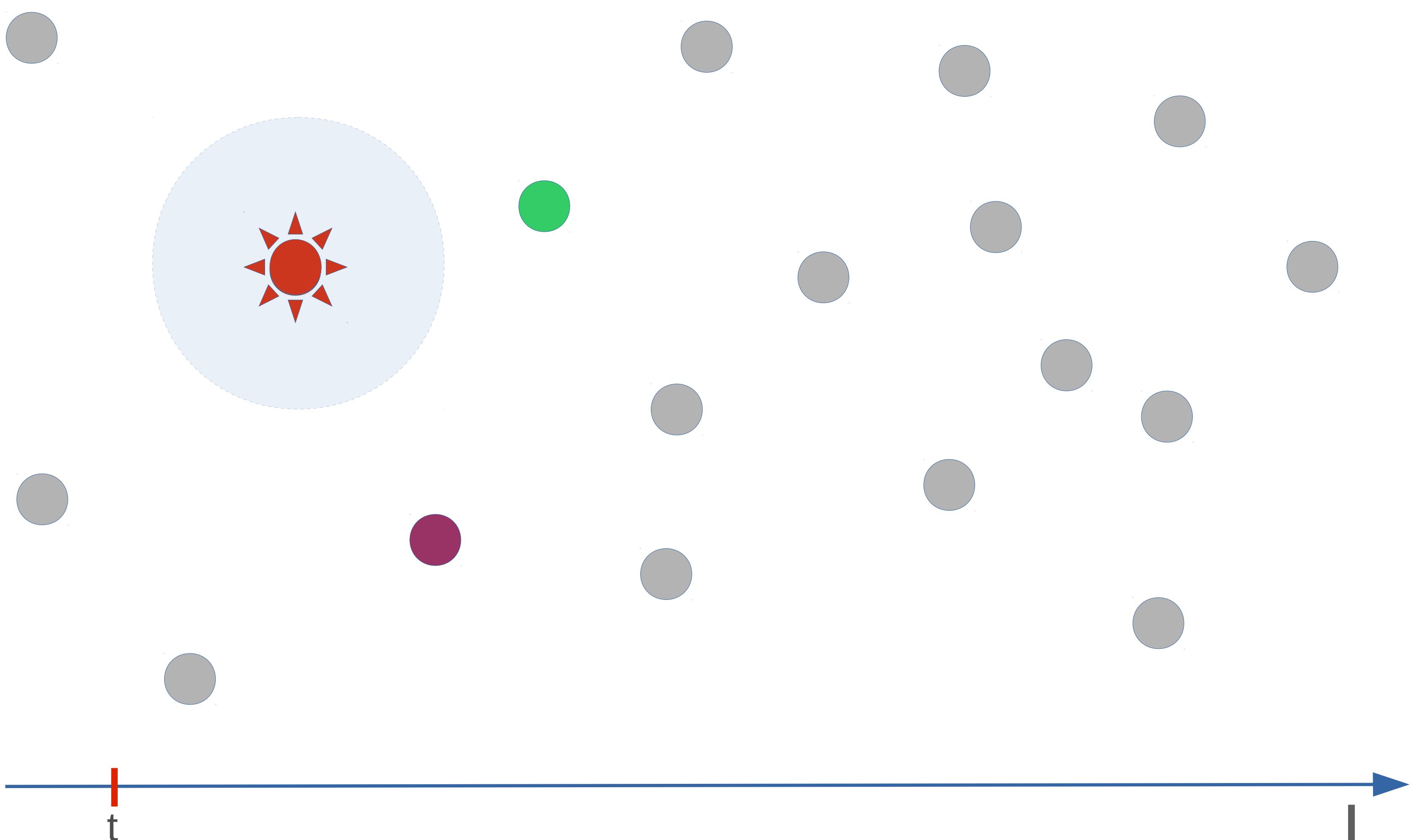
DES: A Simple Example



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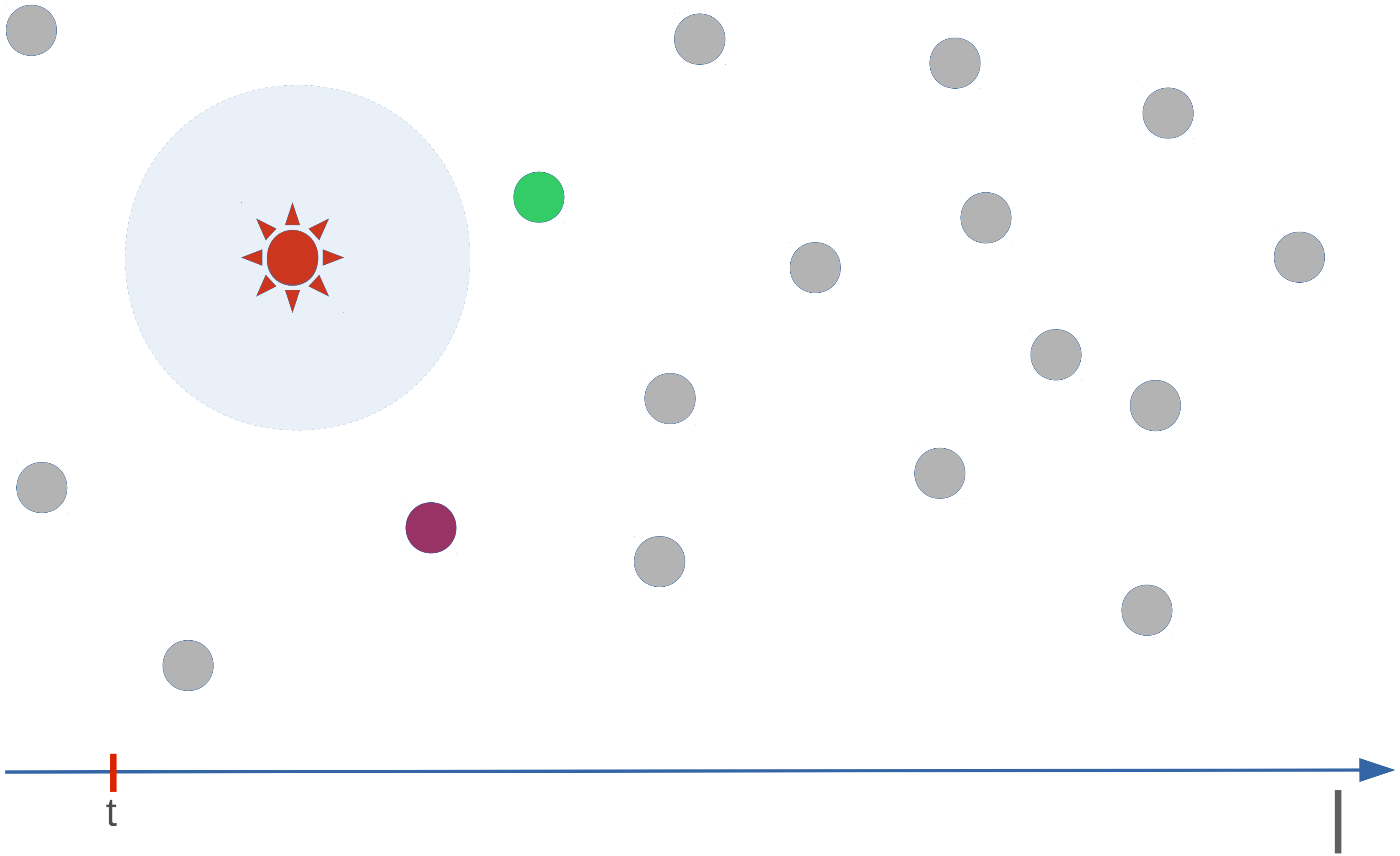
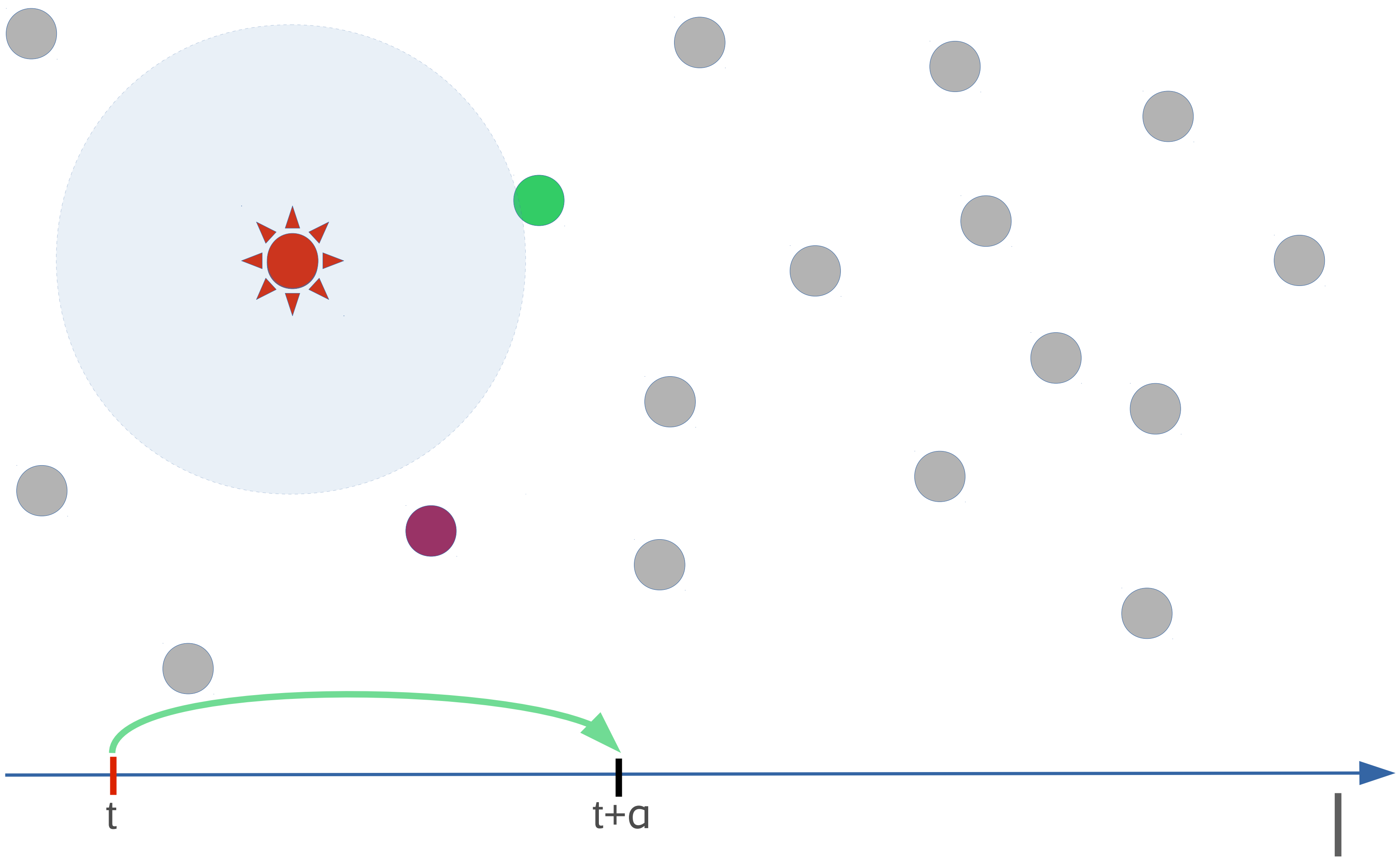
DES: A Simple Example



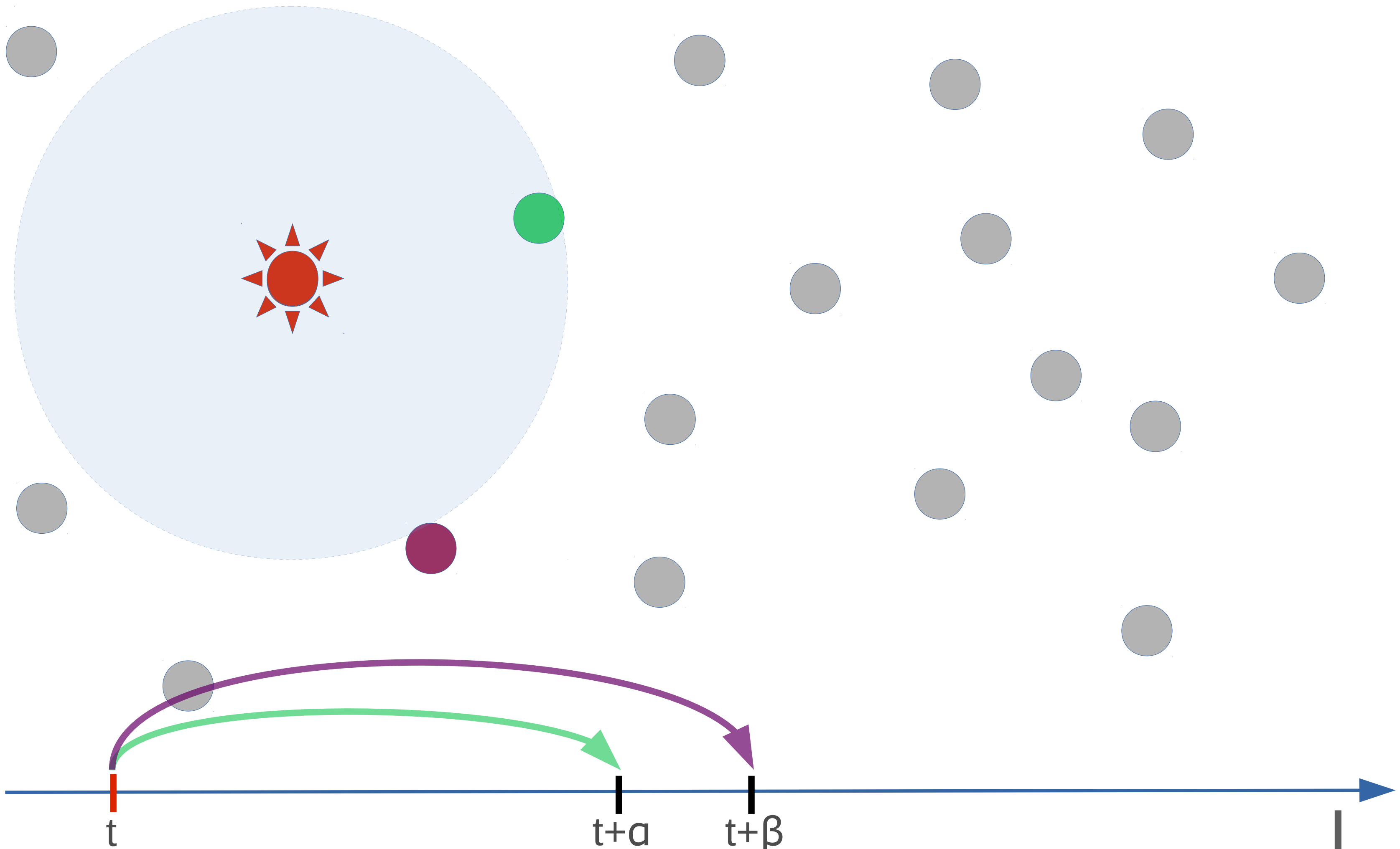
2) *At time t the red node starts transmitting*

DES: A Simple Example



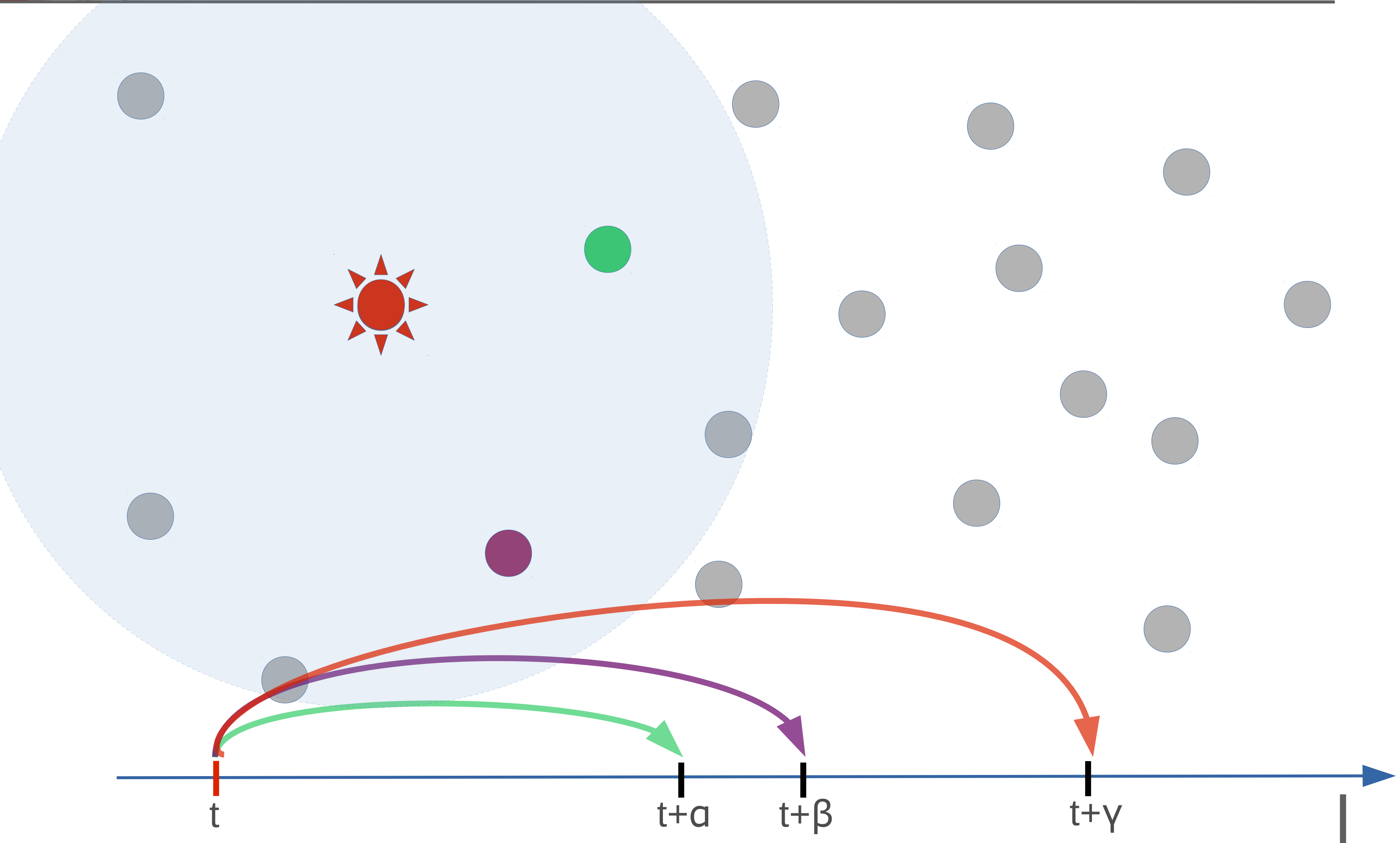
3) At time t+α the green node starts receiving

DES: A Simple Example



 4) At time t+β the purple node starts receiving

DES: A Simple Example



5) At time t+γ the red node stops transmitting

Implementation of DES

- **Data structures:**
  - a set of **state variables** (*to describe the modeled system*)
  - an **event list** (*pending events that will be processed in future*)
  - a **global clock** (*the current simulation time*)
- **Simulator:**
  - the simulator is mostly made by a set of "**handlers**", each one managing a different event type
- **Notes:**
  - events are not produced in (simulated) time order but **have to be executed in the correct time order**
  - in fact, the pending event list is a priority queue

DES + Single CPU = **Sequential** Simulation

- All such 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)

- Multiple intercon ...), that is CPUs or ho ...
- Each EU manages ...
- Aggregating resou ... large and complex mo ...
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There is a **synchronization** problem!

Parallel Discrete Event Simulation (PDES)

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- Each EU manages **a part of the simulation model**
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- Eac…
- Loc… …ve to be **de**…

“Concurrent” events
can be executed
in parallel → **speedup!**

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 f[…] multiple EUs → **very large and complex m[…]**
- Each EU manages […]
- Locally generate[…] **delivered to remo[…]**

The model has to be **partitioned**.
This is not easy…

Parallel And Distributed Simulation (PADS)

«Any simulation in which more than one processor is employed»

(K.S. Perumalla)

- This is a very simple and general definition, there are many different "flavors" of PADS
- A lot of good reasons for going PADS:
  - **scalability**
  - **performance** (obtaining the results faster)
  - to model **larger** and **more complex** scenarios
  - **Interoperability** and **composability**
  - to **integrate** simulators that are **geographically distributed**
  - **Intellectual Property** (IP) protection

Parallel And Distributed Simulation (PADS)

- **Main issue**: there is **no global state**
- **PADS** = interconnected model components... usually called Logical Processes (**LP**s)
- Each LP manages the evolution of a part of the simulation
- The LPs interact for **synchronization** and **data distribution**
- Each LP is usually executed by a processor (or a core)
- The **communication** among LPs is **costly**

Parallel, Distributed or… Mixed?

- **Parallel**: the processors have access to some **shared memory** or a tightly coupled interconnection network
- **Distributed**: **loosely coupled** architectures (e.g. distributed memory)
- **Real world**: **heterogeneous** execution architectures (e.g. HPC + Public Cloud)

On the (Lack of) Global State...

- In a **sequential** simulation there is a **global state** that represents the simulated system at a given time
- In a **PADS**, such a global state is **missing**
- This means that:
  - the model has to be **partitioned** in LPs
  - **synchronization** mechanisms have to be implemented
  - data is produced locally (within the LP) but can be of interest to other parts of the simulator (other LPs): **data distribution mechanisms**

The Partitioning of PADS

- Splitting the simulated model in parts is complex
- 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

Synchronization: Correct Order of Events

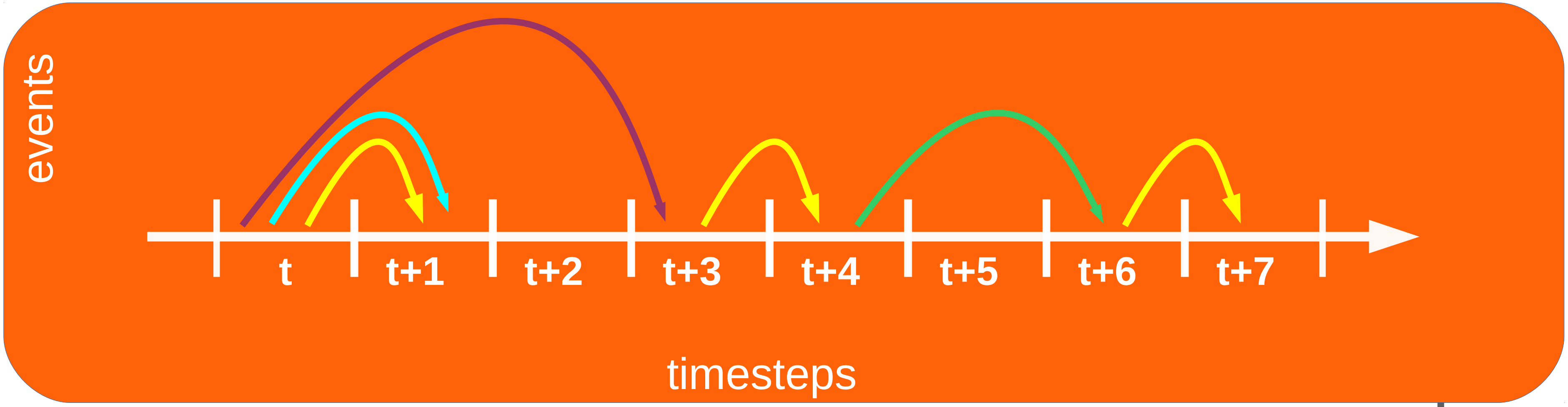
- A **network** interconnects the LPs
- Each LP is executed by a different CPU (or core) → **likely at a different speed**
- The network can introduce **delays** and **faults**
- The PADS is **correct** only if it obtains exactly the same results of the sequential simulation
- Synchronization mechanisms are used to coordinate the LPs → **many approaches can be used**

In-depth: Synchronization, **Approaches**

- Among the many variants...
- Three **main methods**:
  - **time-stepped**: *the simulated time is divided in fixed-size timesteps*
  - **conservative**: *synchronization errors are avoided (i.e. high communication cost for coordination)*
  - **optimistic**: *there are errors that must be fixed with roll-backs (i.e. memory consumption)*

In-depth: Synchronization, Time-stepped

- The **simulated-time** is divided in **fixed-size timesteps**
- All events in the same step are **concurrent**
- Quite **efficient** and **simple**
- The **timestep size is an issue**



Data Distribution: Dissemination of Information

- Simulation components produce **state updates** (that can be relevant for other components)
- For overhead reasons **broadcasts** must be **avoided**
- Goal: **matching data production and consuming**
- **Only the necessary data has to be delivered to the interested components**
- There are both **communication** and **computation** aspects to consider

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Scalability

Cloud – *hundreds*

Fog – *thousands*

Things – *millions (billions)*

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

Big Data

- Big Data is produced logging IoT devices
  - Produced data can provide new insights into customers and internal operations

- Data must be integrated and analyzed in a coherent and coordinated fashion

10 Of The Biggest IoT Data Generators

- **Air travel**
  - Prevent failures, reduce fuel consumption, adjust speeds, reduce travel times
- **Mining**
  - Safety: automating machines, humans are not required to stay close to the vehicles and risk their lives
- **Cars**
  - Data sent to manufacturers, road operators, drivers, authorities, etc.

Source: http://www.cbronline.com/news/internet-of-things/10-of-the-biggest-iot-data-generators-4586937

10 Of The Biggest IoT Data Generators

- **Utilities**
  - Worldwide revenue estimations by the IoT for the utilities industry by 2018 is $201 billion
  - Smart meters are just an example
- **Cities**
  - Street lamps talking to the grid, urban parks connecting to services and rivers sending out alerts on pollution levels
  - All this data is generated on a daily basis, and it's stored in the cloud
  - Millions of sensors, deployed in every city will constantly produce huge amounts of information
- **Wearables**
  - Wearable devices collecting data on health, fitness and wellness

Source: http://www.cbronline.com/news/internet-of-things/10-of-the-biggest-iot-data-generators-4586937

10 Of The Biggest IoT Data Generators

- **Sports**
  - Wearables and intelligent clothing to improve performances
- **Logistics**
  - Transportation of goods
  - Most of this data will be RFID
- **Healthcare**
  - Smart healthcare, with sensors being deployed across all areas in a medical unit
- **Smart homes**

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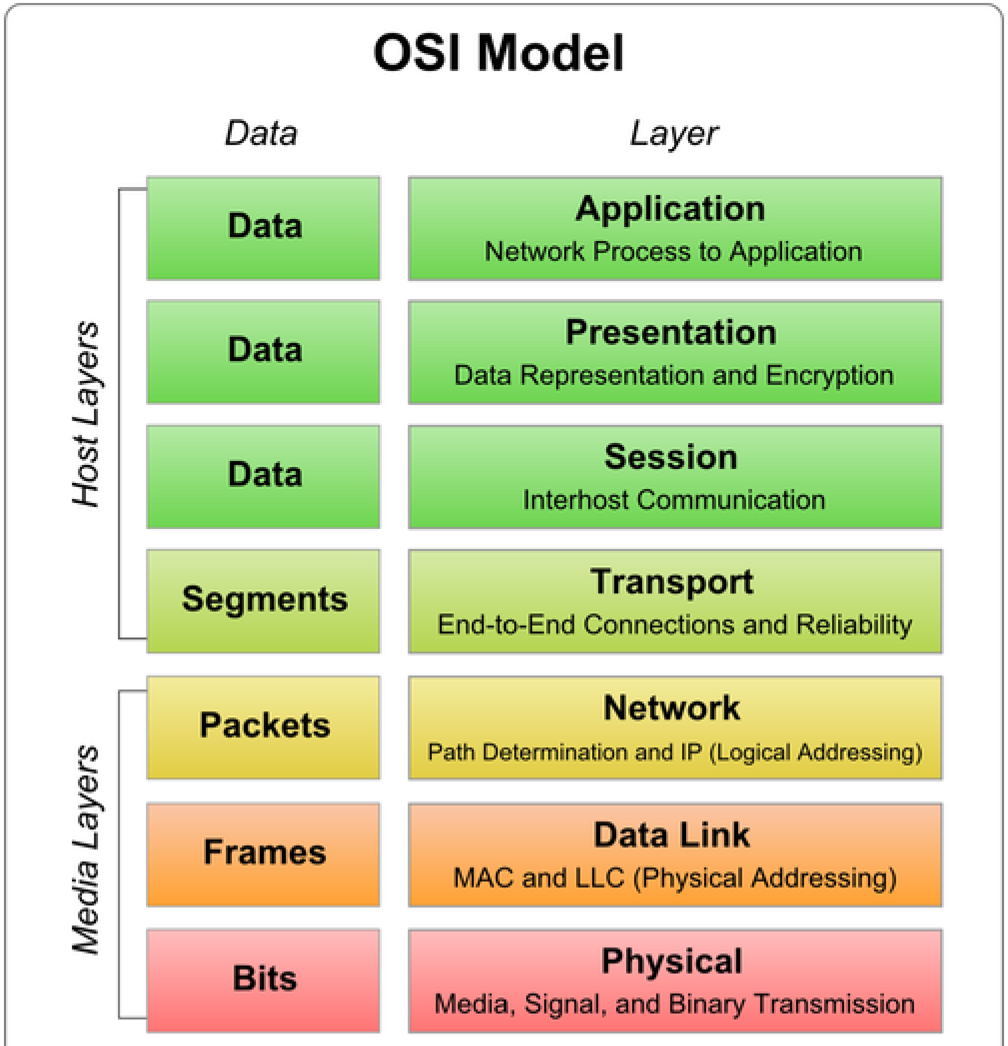
Simulation of IoT Models

- What is the “appropriate” **level of detail** for IoT simulations?
  - very detailed → **huge overhead**
  - few details → **oversimplified → wrong results**



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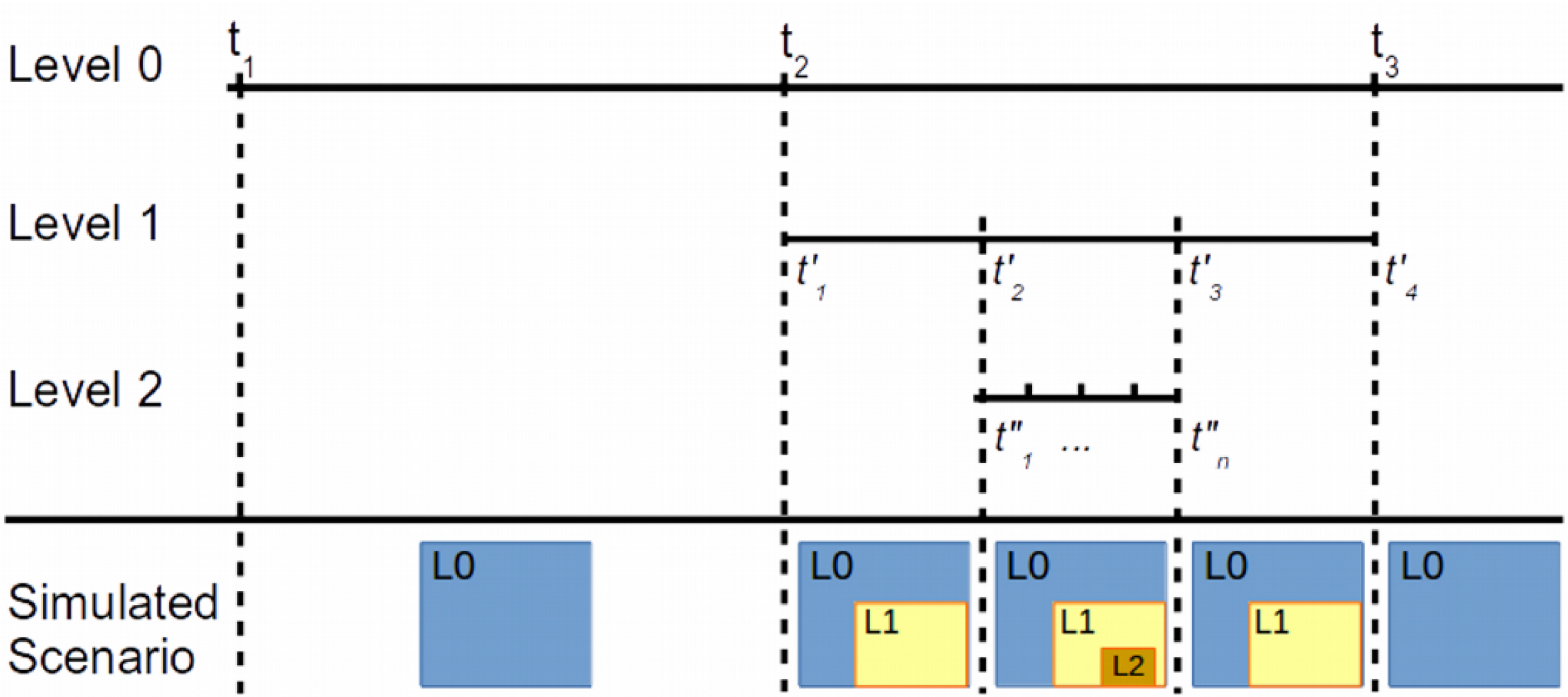
Simulation of IoT Models

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

Multi-level Simulation Models



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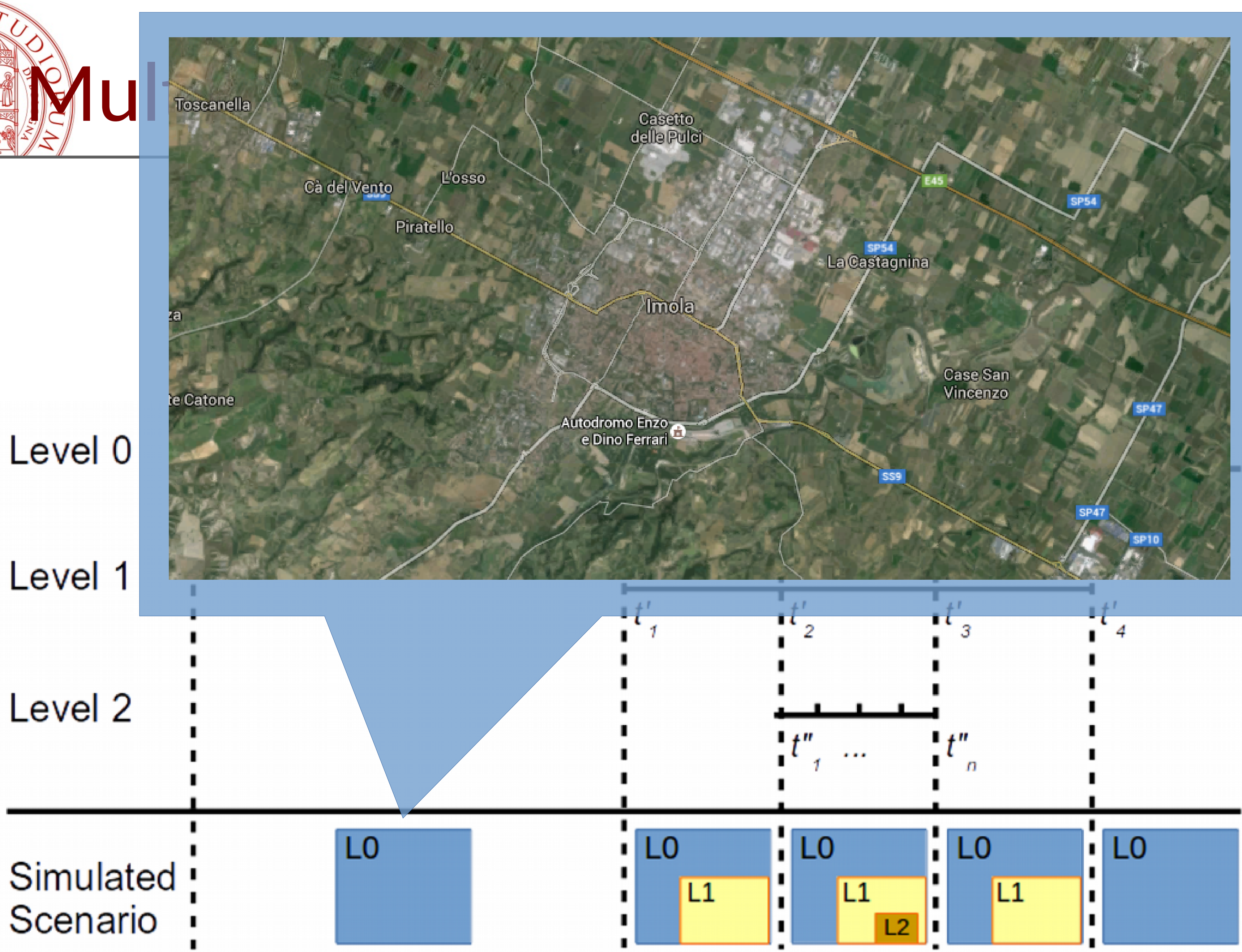

Toscanella
Casetto delle Pulci
Cà del Vento
L'osso
Piratello
E45
SP54
La Castagnina
Imola
Case San Vincenzo
Autodromo Enzo e Dino Ferrari
SS9
SP47
SP10
Level 0
Level 1
Level 2
Simulated Scenario
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t'_3
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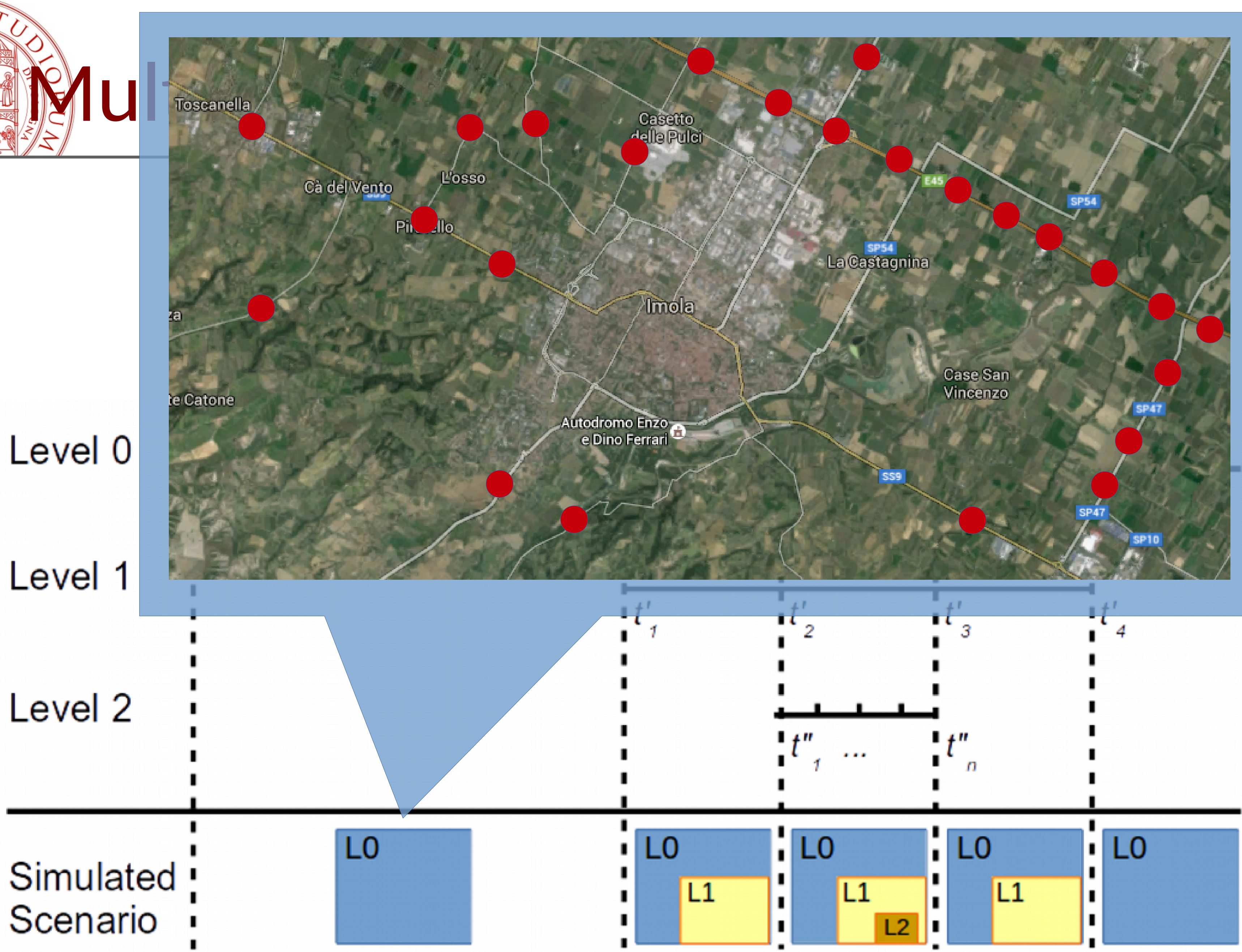

Toscanella
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L'osso
Cà del Vento
La Castagnina
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Case San Vincenzo
Autodromo Enzo e Dino Ferrari
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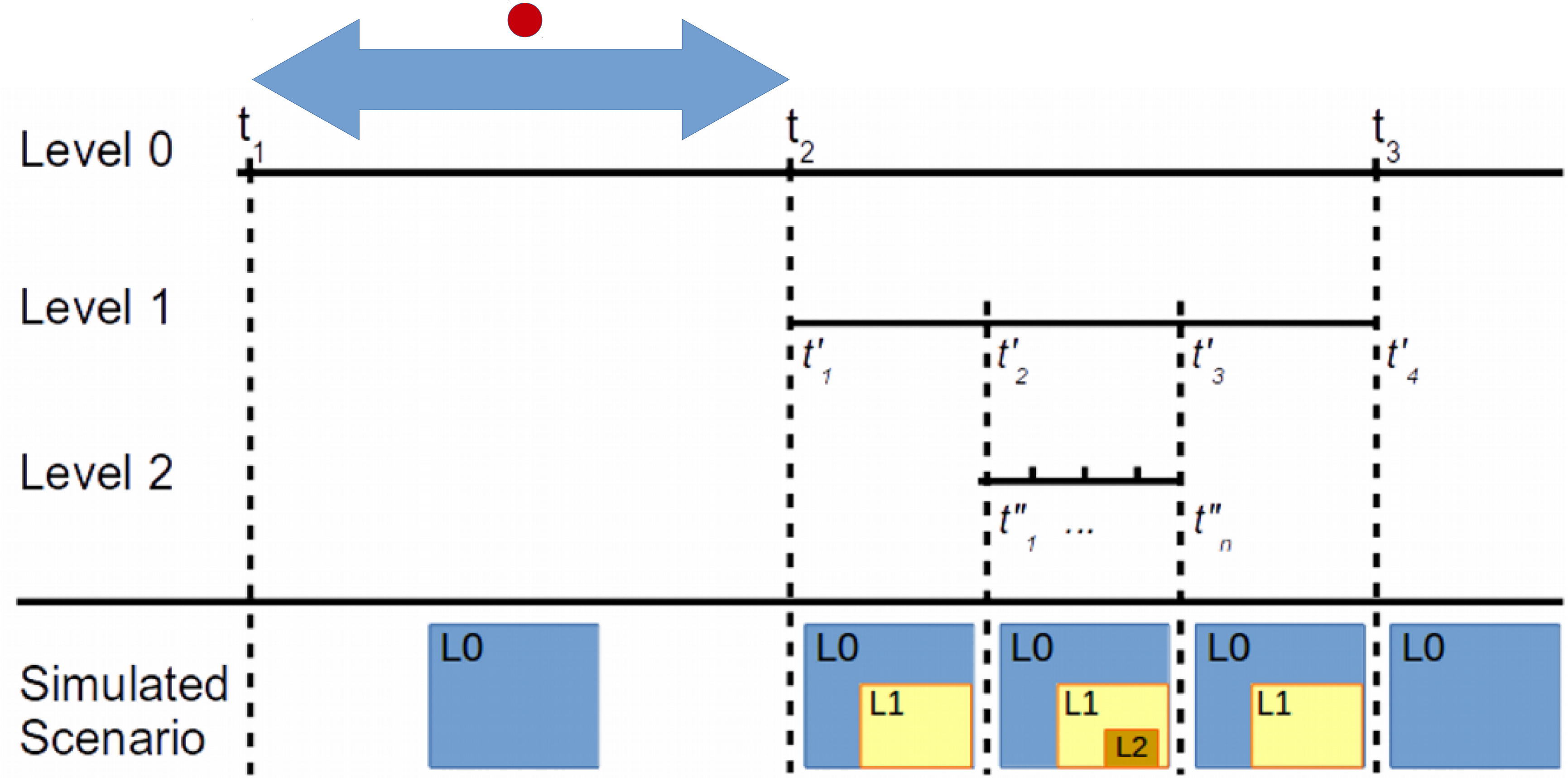
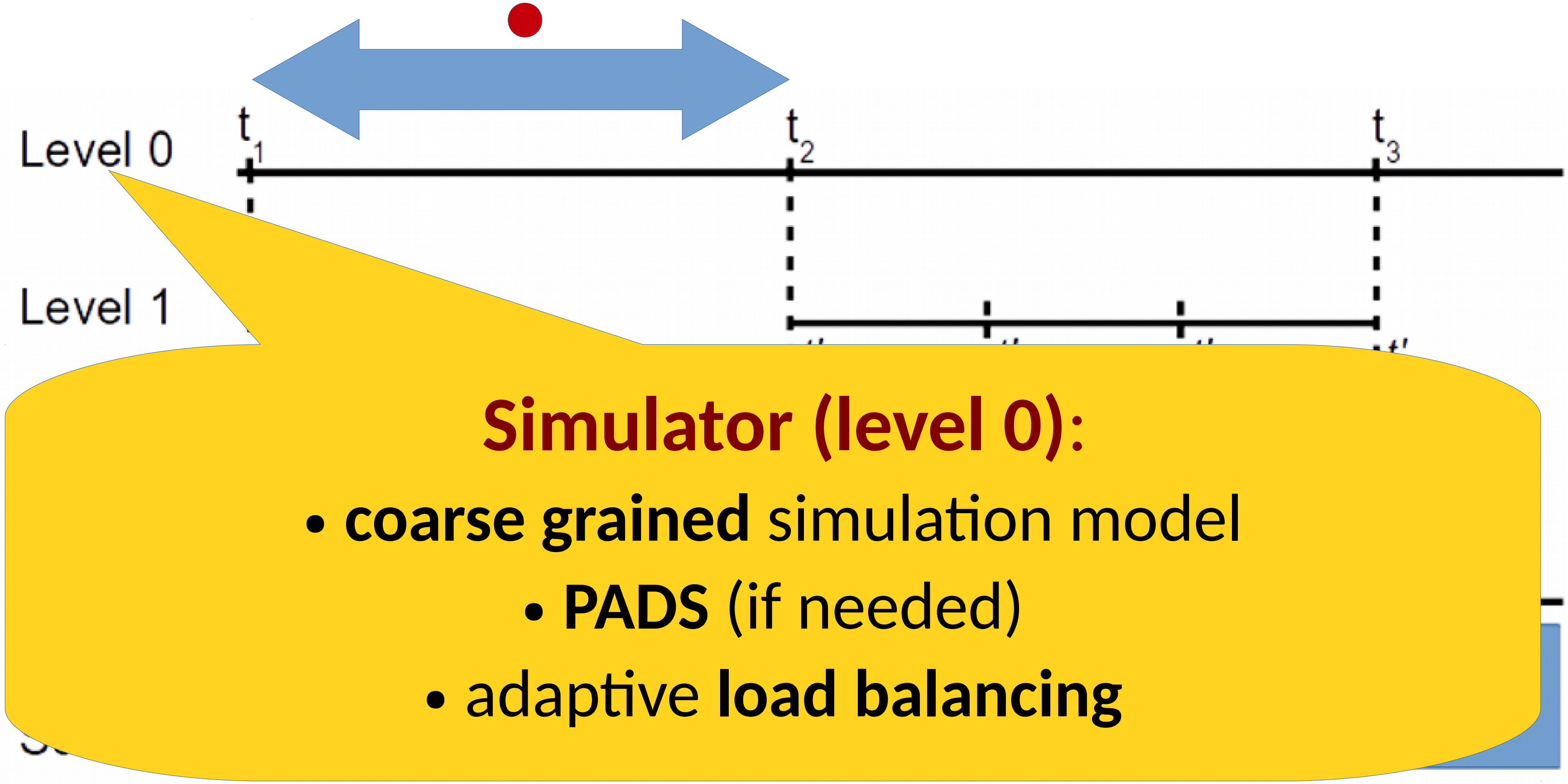
Multi-level Simulation Models



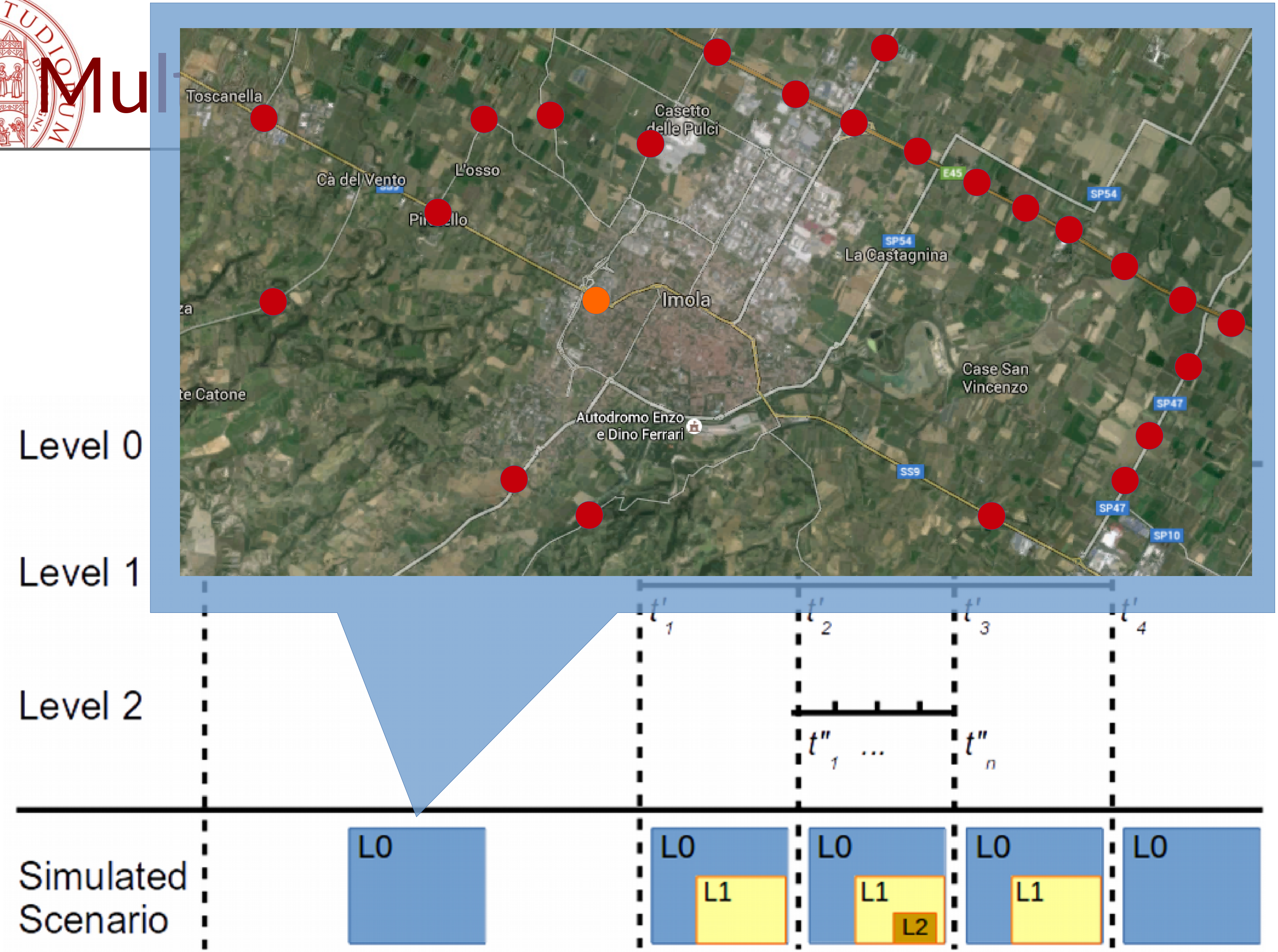
Multi-level Simulation Models



Simulator (level 0):

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

Mul



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L1
L2

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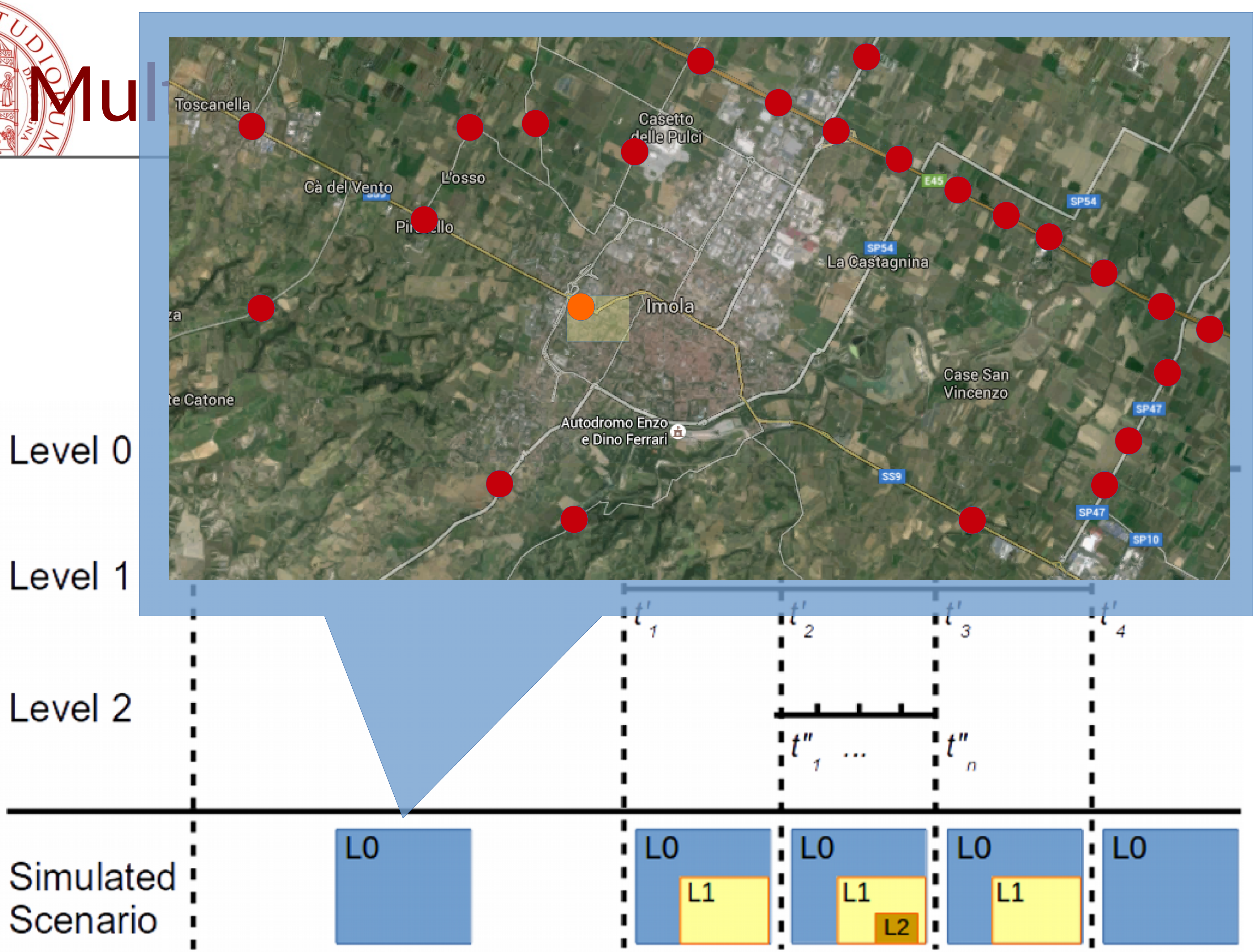

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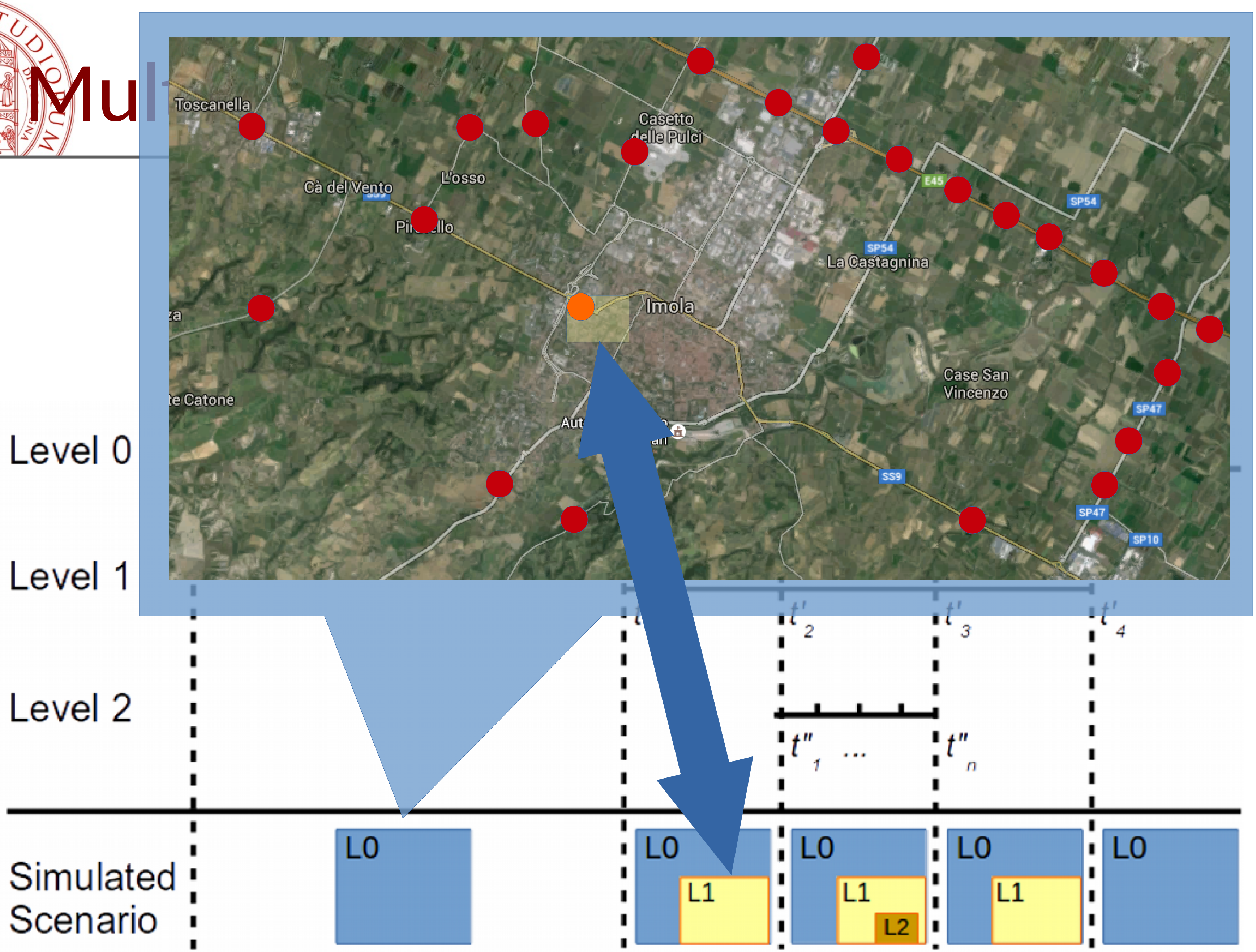
Toscanella
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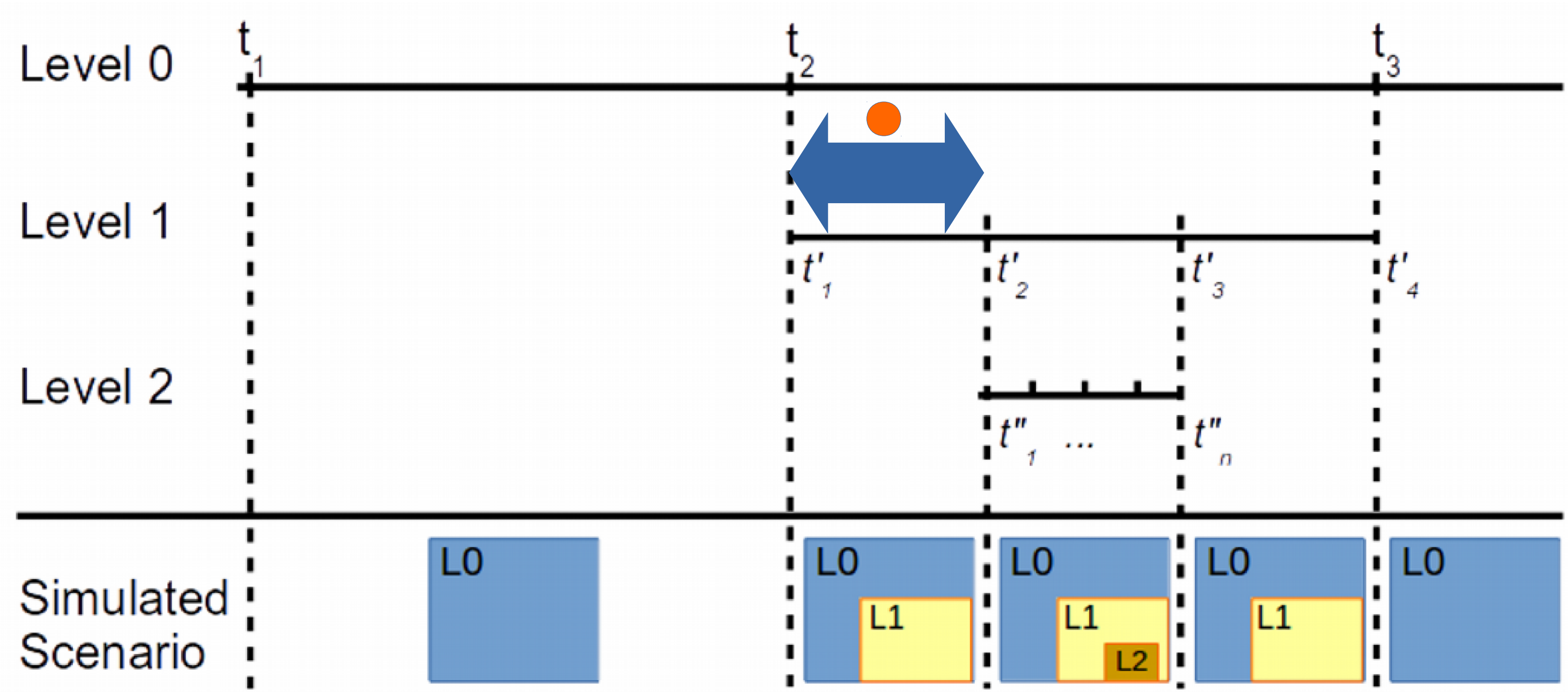
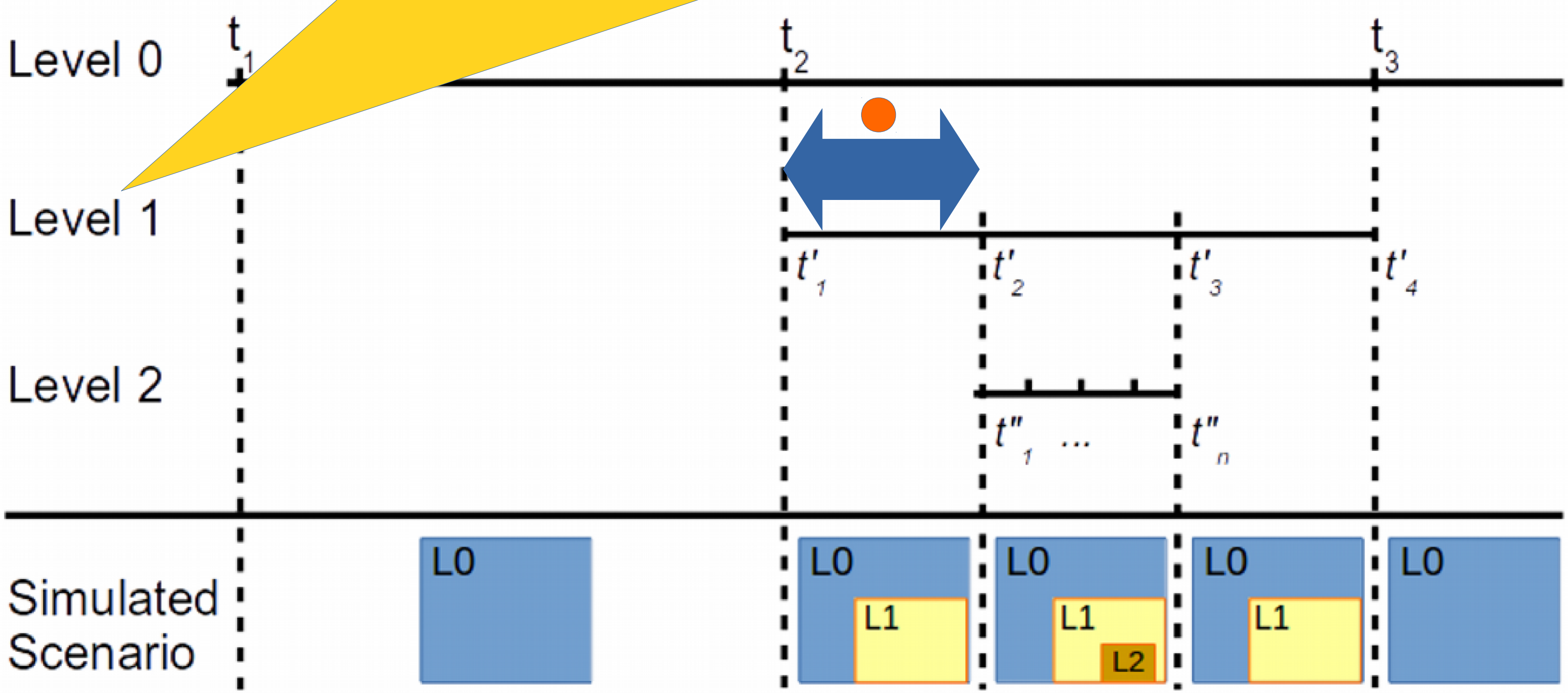
Multi-level Simulation Models



M

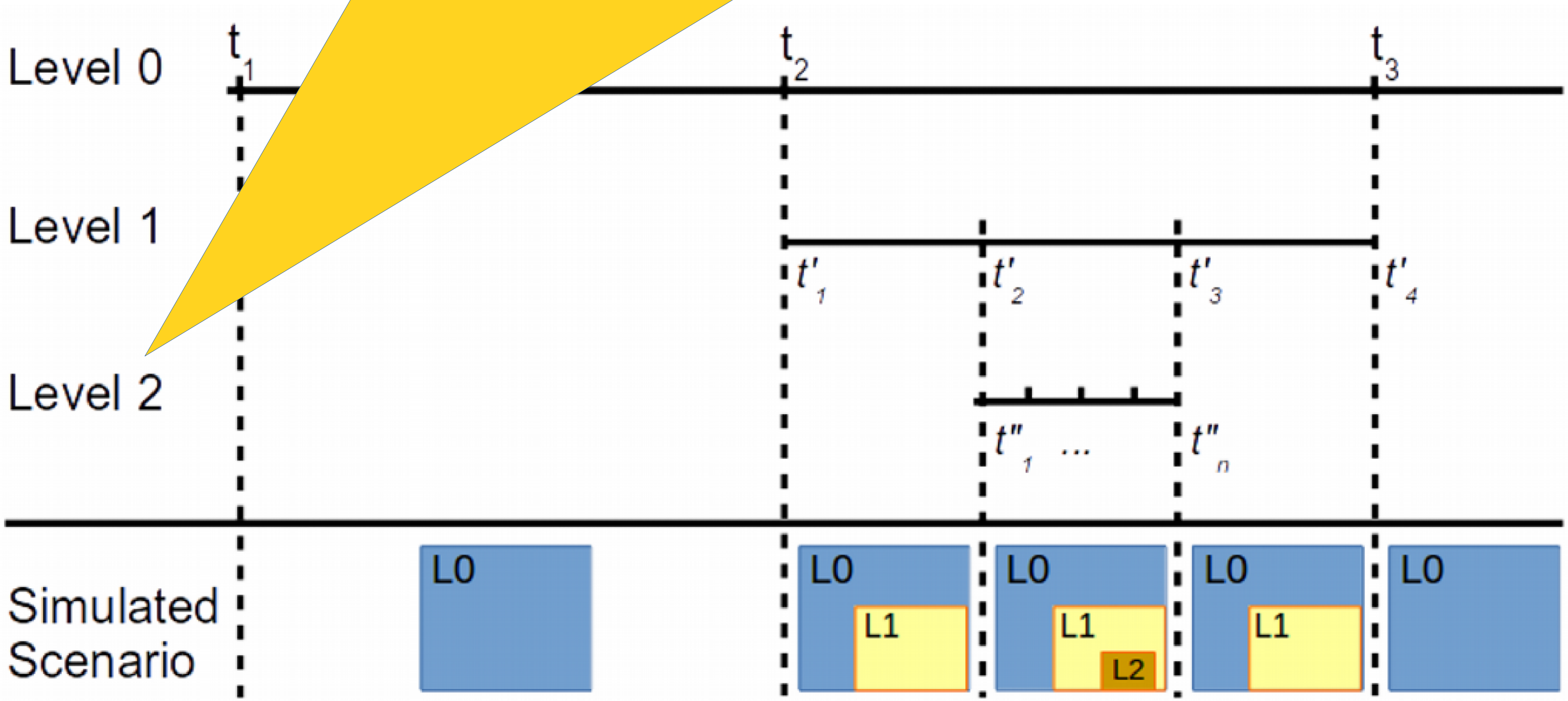
Simulator (level 1):

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



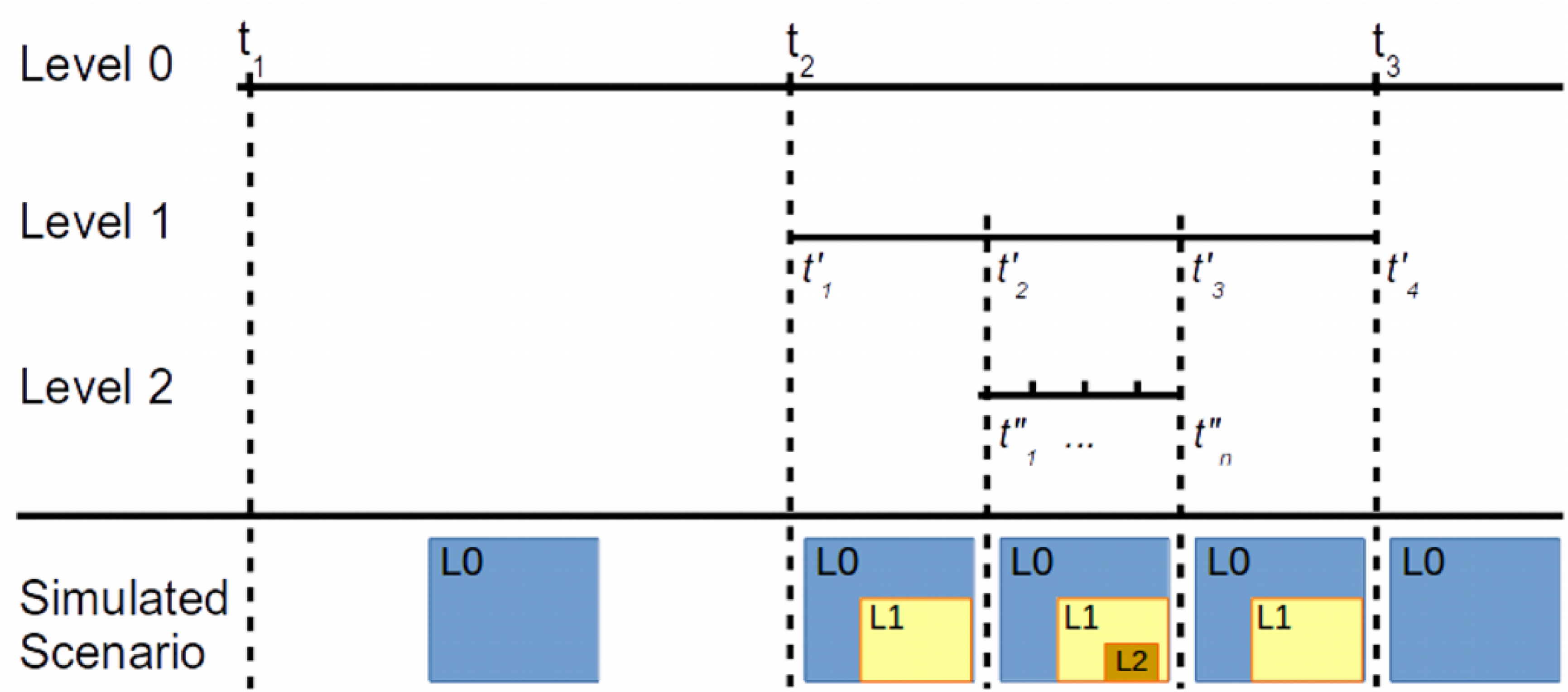
Simulator (level 2):

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



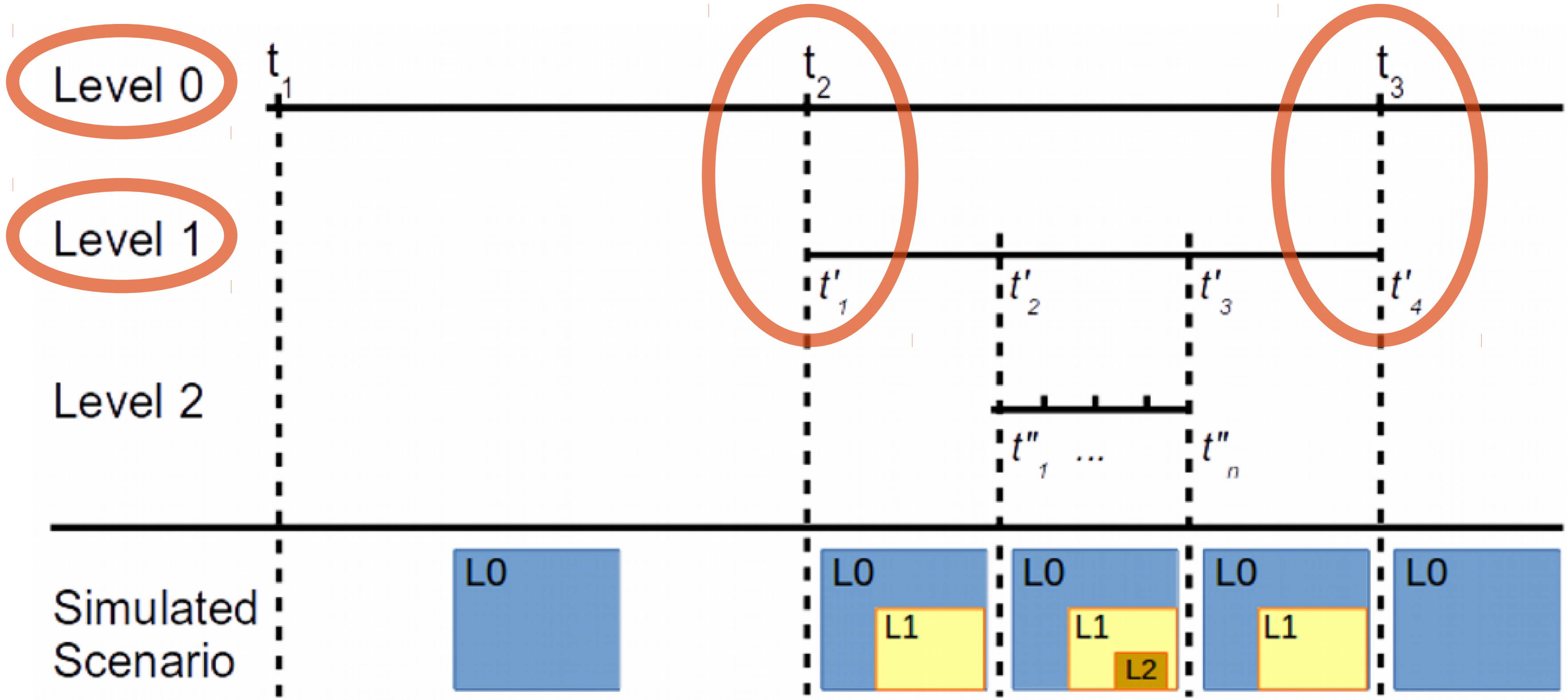
Multi-level Simulation Models

Synchronization and **Interoperability**



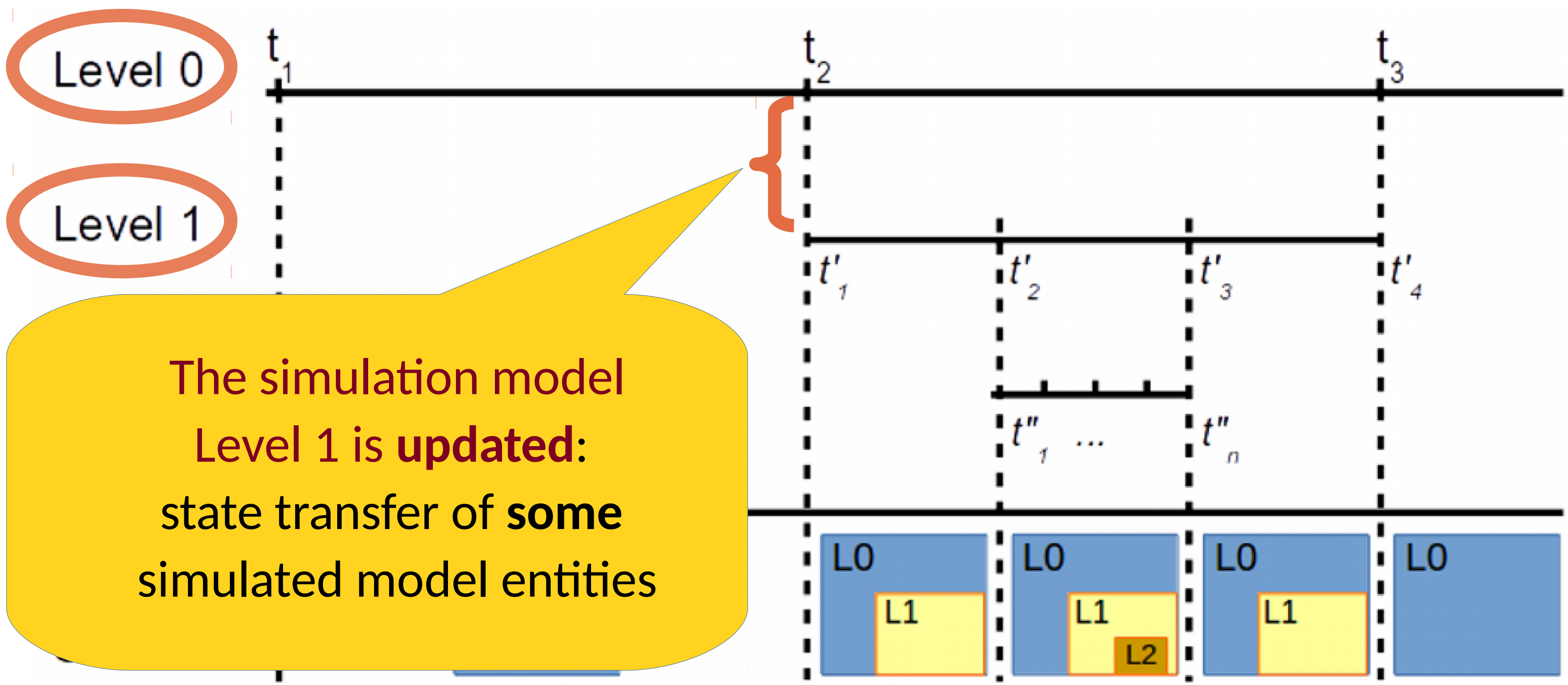
Multi-level Simulation Models

Synchronization: at level 0 timesteps



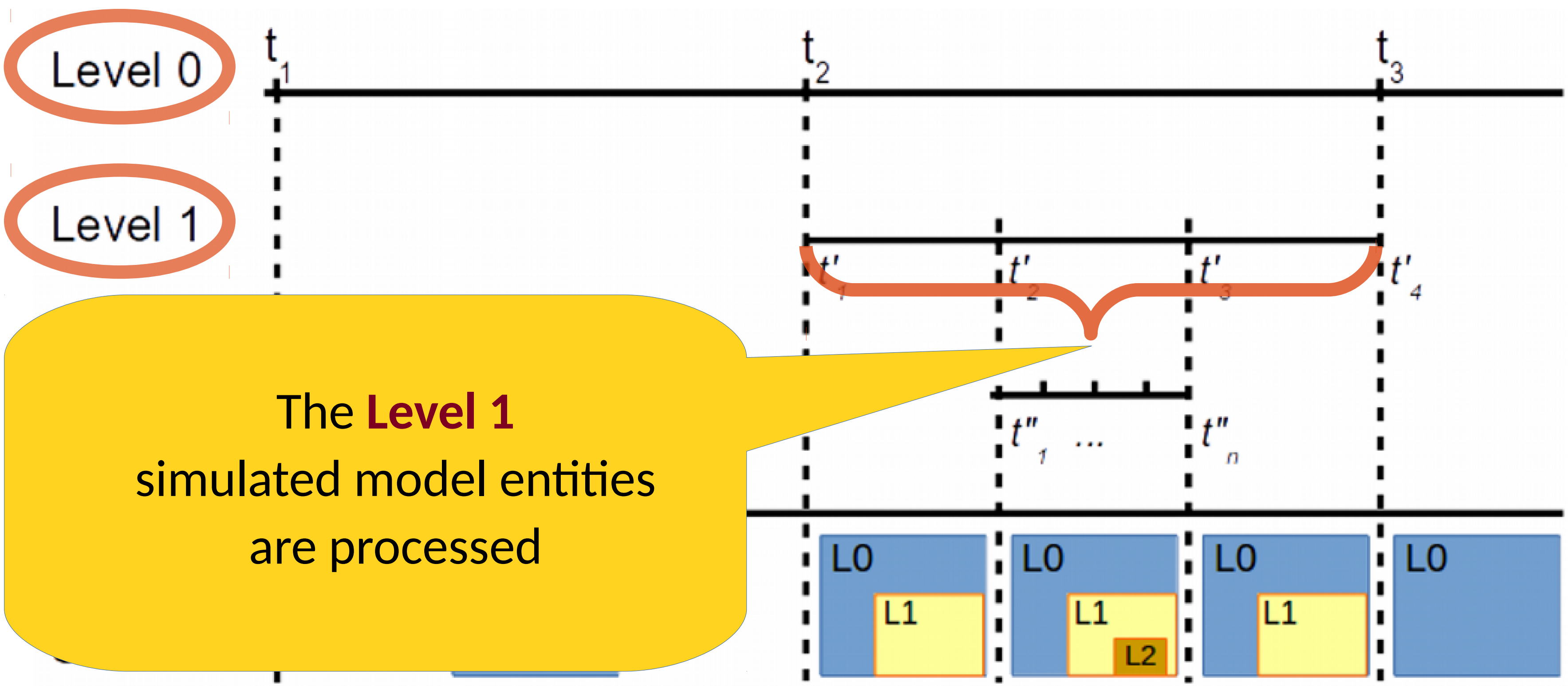
Multi-level Simulation Models

Interoperability



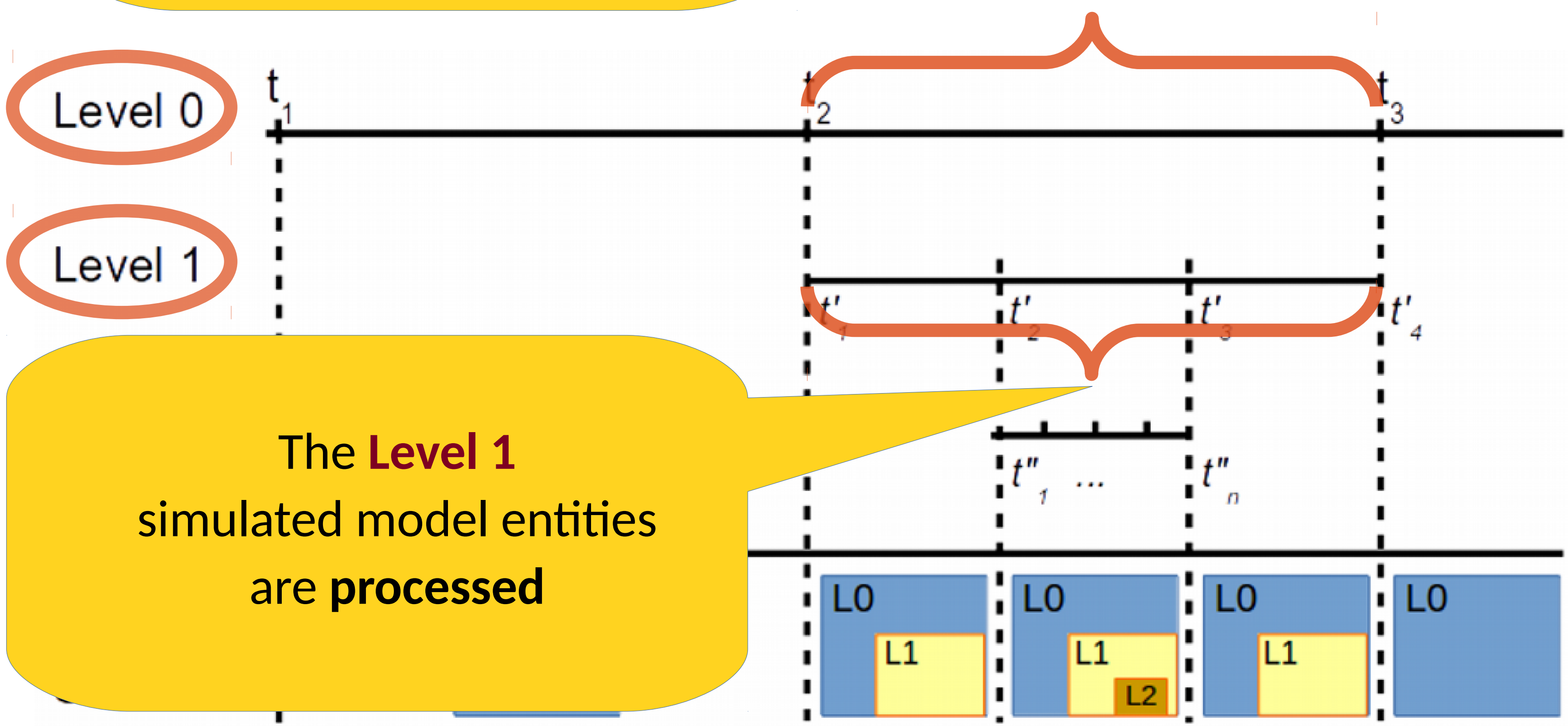
The simulation model
Level 1 is **updated**:
state transfer of **some**
simulated model entities

Multi-level Simulation Models



...lation Models

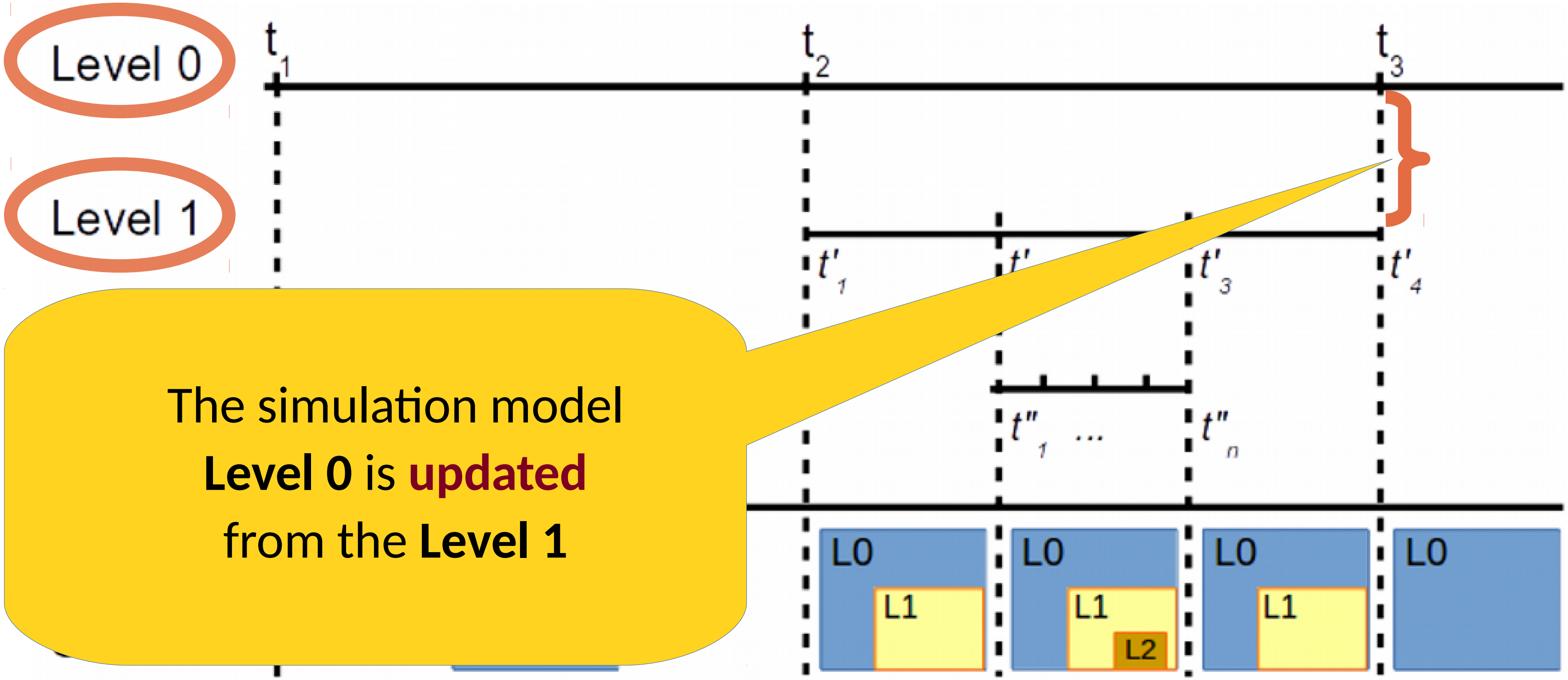
All the remaining
Level 0
simulated model entities
are **processed**



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

Multi-level Simulation Models

Interoperability



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

Outline

- Introduction on IoT
- A brief simulation introduction
- Specific challenges in the simulation of IoT
- Multilevel simulation models / Heterogeneous simulation models
- Visionary: simulation of the IoT using the IoT
- Case study: smart shires
- Simulation tools: a very small review
- Demo: using a parallel/distributed simulation tool for modelling a massively populated IoT

Simulation of IoT using IoT

- A **huge number** of interconnected devices
- Each one with (very) **limited computation** and **communication** capabilities
- In some extent this is the implementation of the **ubiquitous** / **pervasive computing** paradigm
- Is it possible to **use the IoT** to run (very) **large scale simulations**?

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Where I'd Like Some More Technology…

Smart Cities

- Currer
  cities"
- Servic
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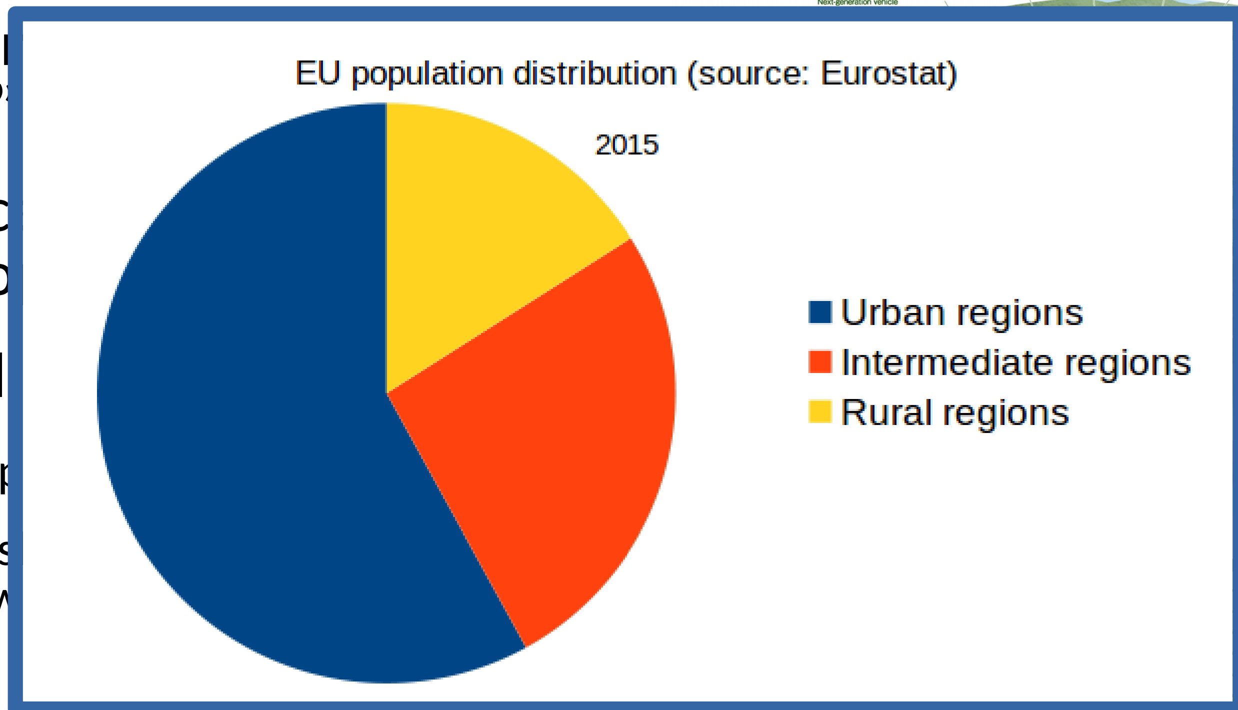
  - Imp
  - Pus
    tow



What about decentralized areas?

Shires aren't Cities

- **Goals**:
  - Promote the underestimated potential (Tourism, healthy lifestyle, products, …)
  - Reduce technological gaps with cities
- **Not** possible implementing (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

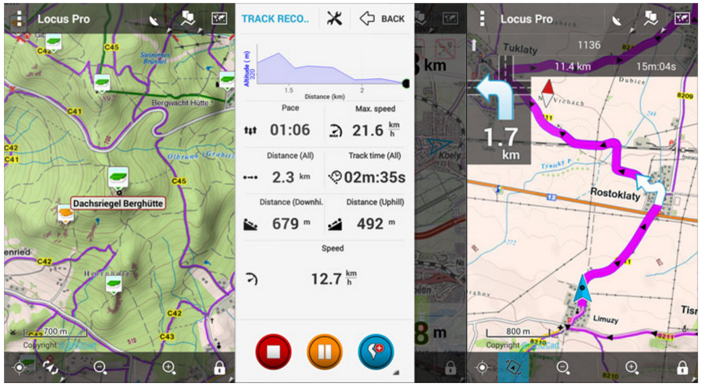
Killer Applications

- Wealth, health
  - Even more urgent in poorly served regions
- As in smart cities, services for citizens and municipalities

- But they need to be **cheap**

Killer Applications

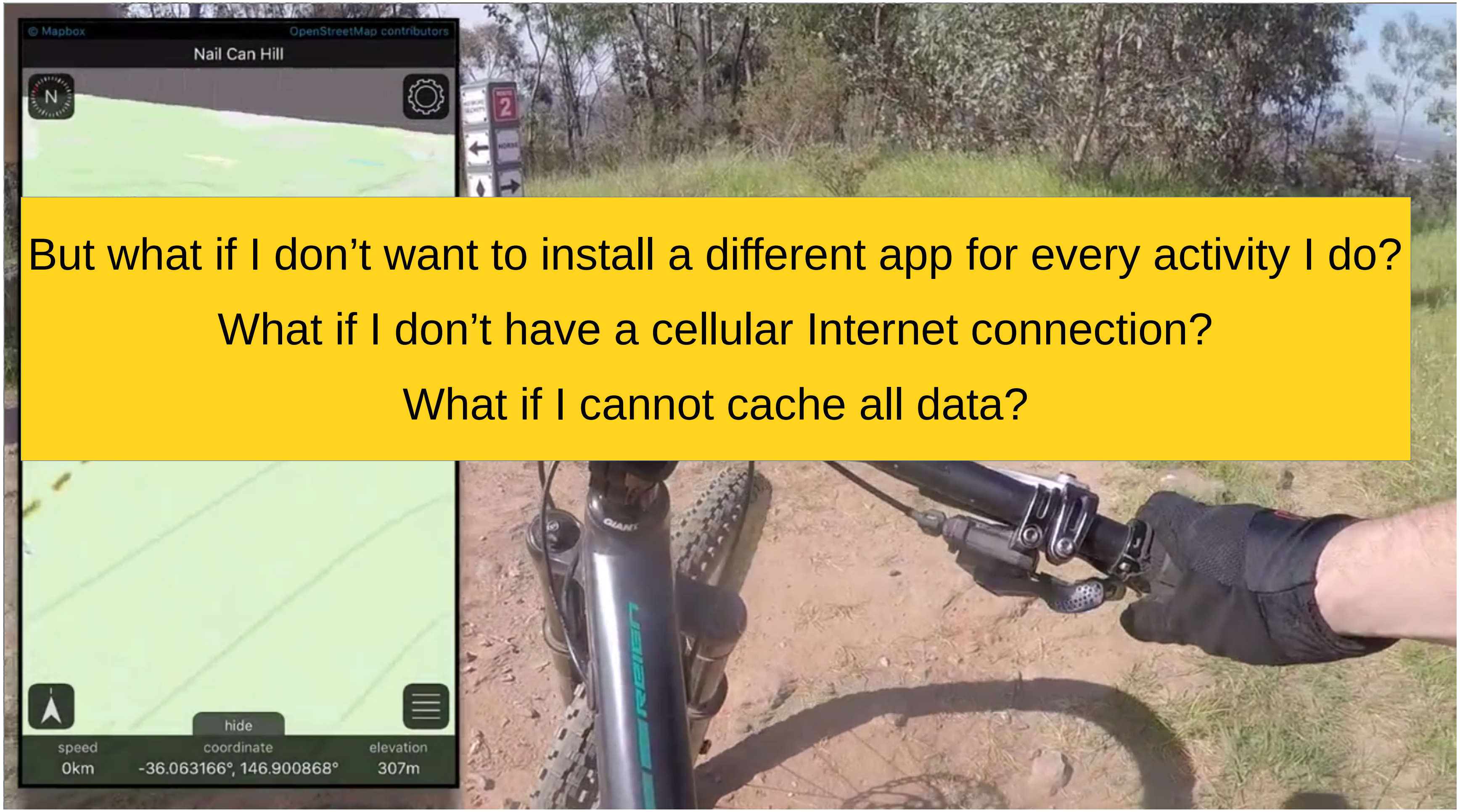
- Tourism
- Proximity based applications, local exchange information, parks, sportsmen care
- Need for communication even in areas where there is no cell coverage



Roam MTB App

https://www.youtube.com/watch?v=qc9TMqCrGVU

Roam MTB App



But what if I don't want to install a different app for every activity I do?

What if I don't have a cellular Internet connection?

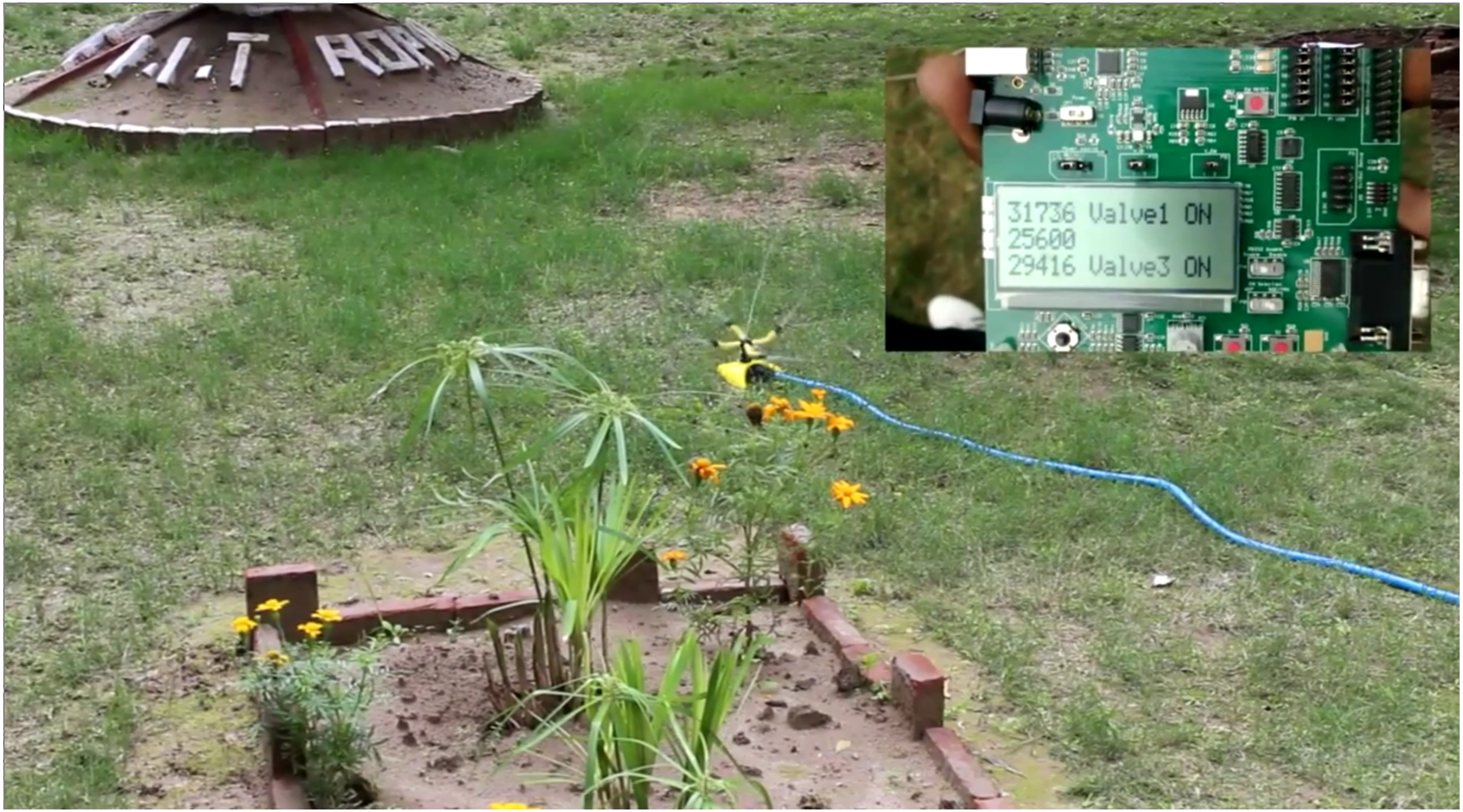
What if I cannot cache all data?

https://www.youtube.com/watch?v=qc9TMqCrGVU

Killer Applications

- Production chain in rural environments
- Smart water, metering, agriculture, animal farming
- Sensors are cheap, they can be massively exploited

Smart Irrigation using Wireless Sensor Networks



Snippet from
https://www.youtube.com/watch?v=kRUe91d0T3g

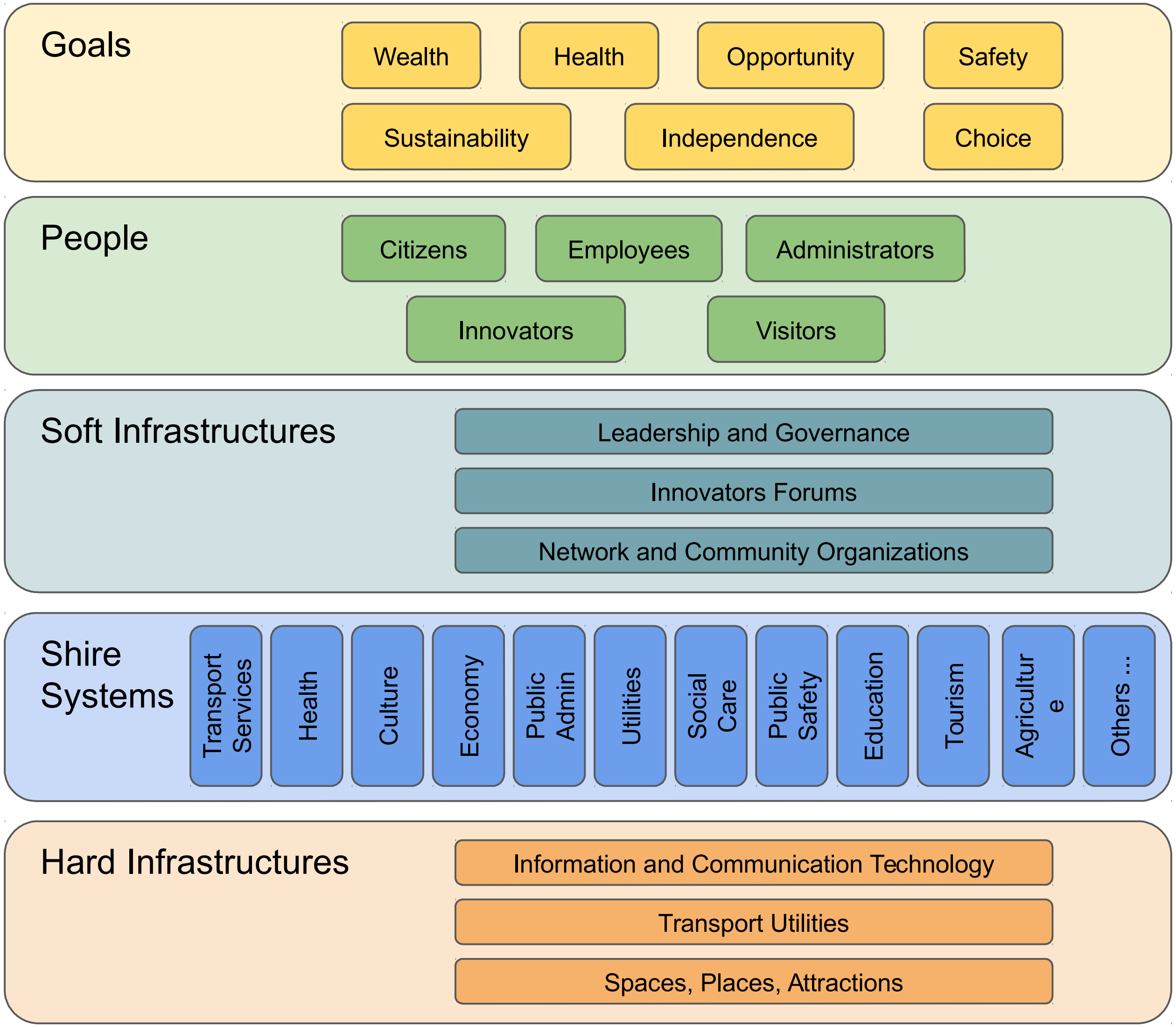
Arduino Garden Controller
Automatic Watering and Data Logging

Snippet from
https://www.youtube.com/watch?v=O_Q1WKCtWiA

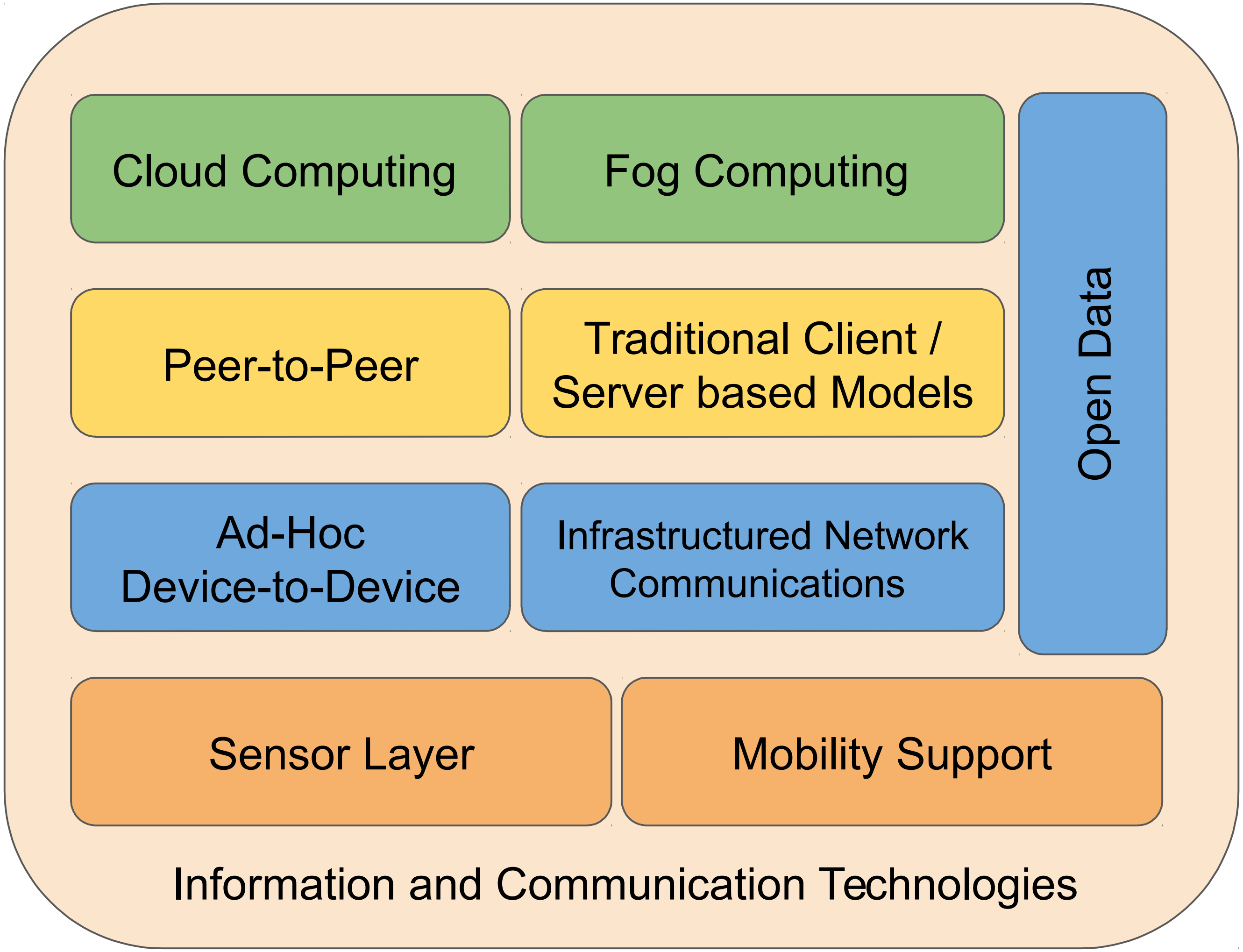
Killer Applications

- Network-based video surveillance, smart traffic management systems, traffic light control
  - Harder and in proportion more costly than in cities
- Monitoring resources and facilities
- Security and emergencies

Components of the Architecture



Information and Communication Technologies



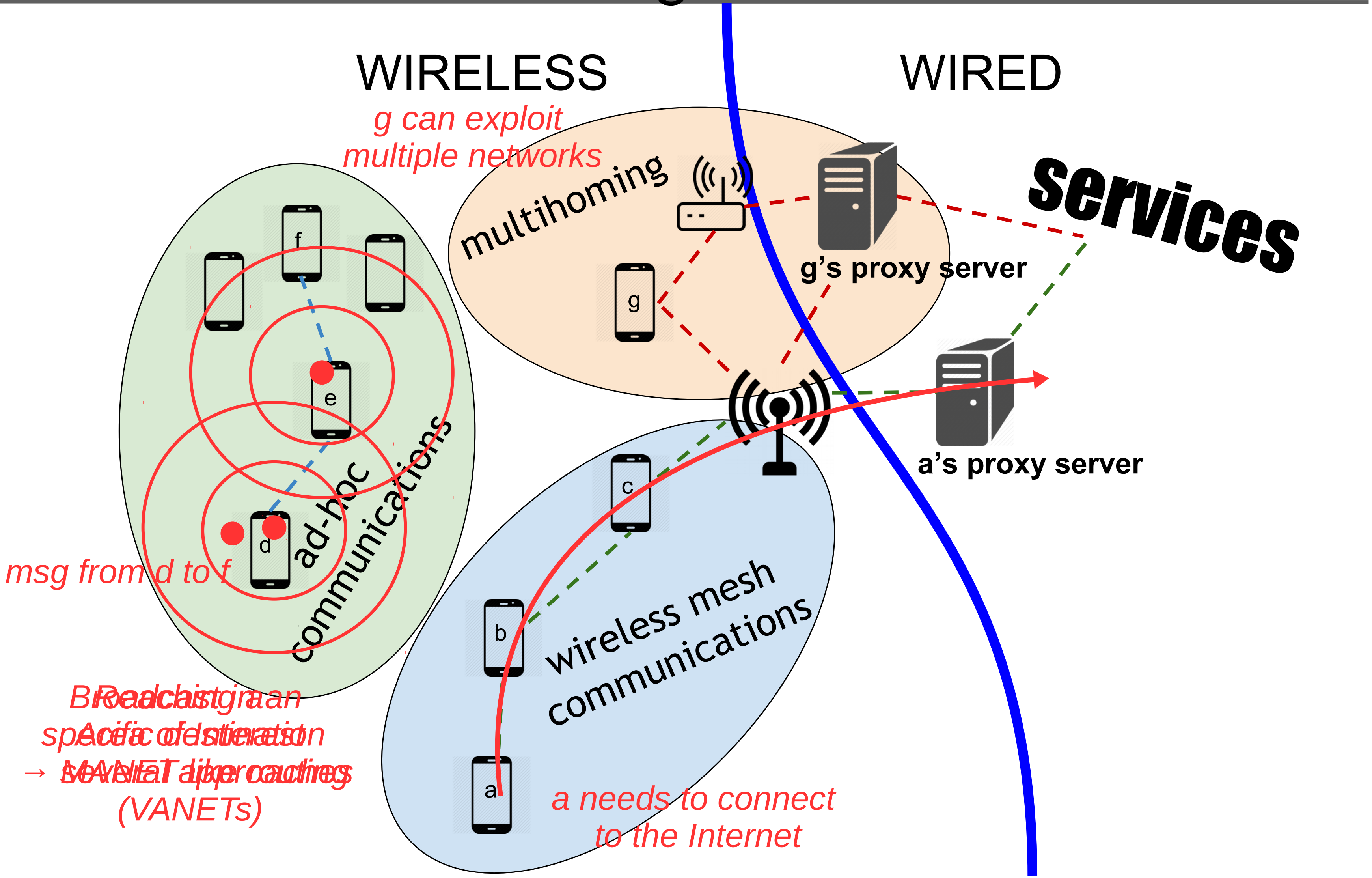
Sensing as a Service

- Use of IoT to share and reuse sensor data to create complex services
- Use of **D2D**, **multihop** and **multipath** communications to interconnect devices and sensors
- Sensed data collected by an information processing system, managed as open data within the middleware, to be used by applications

Cloud / Fog Computing

- Data produced by the IoT must be managed by powerful and reliable distributed computation systems
- Fog computing as an alternative to cloud
  - Moves computation from datacenters to the edges of the network
  - Resorts to a collaborative multitude of end-users to carry out distributed services

Device-to-Device, Ad-Hoc Communication, Dissemination Strategies



Smart Market

COLDIRETTI
FORZA AMICA DEL PAESE

Sei in : HOME > Notizie

Consumi: Coldiretti, in 15 MLN fanno spesa contadino, in 5 anni

Tweet G+1 0 Mi piace 0

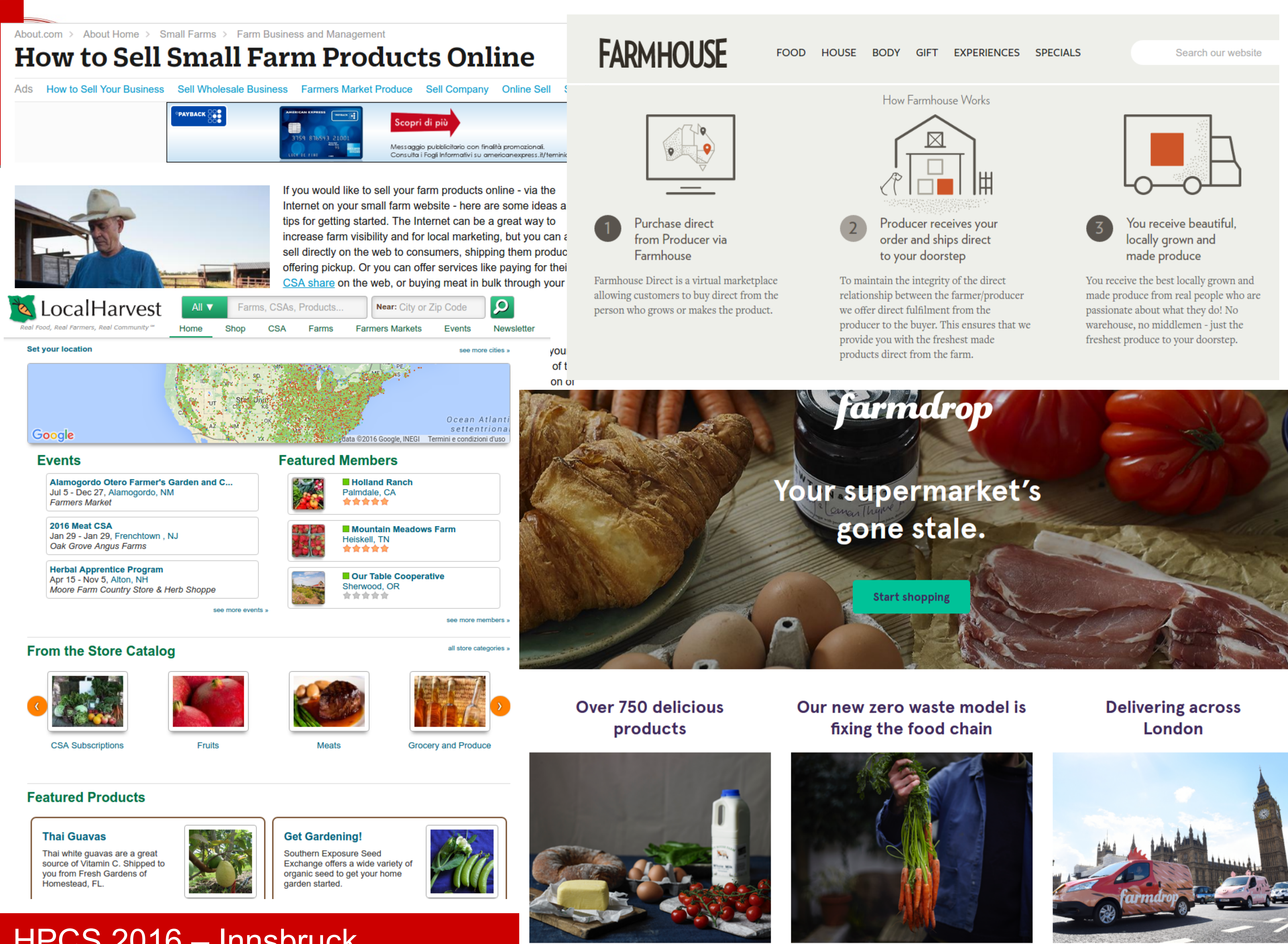
Il contadino batte la globalizzazione: un italiano su quattro fa la spesa da lui

Secondo Coldiretti negli ultimi cinque anni infatti i consumatori che fanno la spesa nelle fattorie o nei mercati degli agricoltori dove è stato raggiunto il record di 15 milioni di presenze nel 2015

Lo leggo dopo | 14 maggio 2016

Tweet 31 G+1 LinkedIn Pinterest

MILANO - Nel mercato globalizzato dell'Unione europea, del Ttip e dove anche Amazon si è messo a fare concorrenza agli alimentari tradiziona vince - a sopresa - il vecchio contadino tornanto prepotentemente di moda. Negli ultimi cinque anni, infatti, triplicati gli italiani che fanno la spesa nelle fattorie o nei mercati degli agricoltori dove è stato raggiunto il record di 15 milioni di presenze nel 2015 (un italiano su quattro).


About.com › About Home › Small Farms › Farm Business and Management
How to Sell Small Farm Products Online
Ads How to Sell Your Business Sell Wholesale Business Farmers Market Produce Sell Company Online Sell
Scopri di più
If you would like to sell your farm products online - via the Internet on your small farm website - here are some ideas a tips for getting started. The Internet can be a great way to increase farm visibility and for local marketing, but you can a sell directly on the web to consumers, shipping them produc offering pickup. Or you can offer services like paying for thei CSA share on the web, or buying meat in bulk through your
LocalHarvest
Real Food, Real Farmers, Real Community
Home Shop CSA Farms Farmers Markets Events Newsletter
Set your location
see more cities »
Events
Alamogordo Otero Farmer's Garden and C...
Jul 5 - Dec 27, Alamogordo, NM
Farmers Market
2016 Meat CSA
Jan 29 - Jan 29, Frenchtown , NJ
Oak Grove Angus Farms
Herbal Apprentice Program
Apr 15 - Nov 5, Alton, NH
Moore Farm Country Store & Herb Shoppe
see more events »
Featured Members
Holland Ranch
Palmdale, CA
Mountain Meadows Farm
Heiskell, TN
Our Table Cooperative
Sherwood, OR
see more members »
From the Store Catalog
all store categories »
CSA Subscriptions
Fruits
Meats
Grocery and Produce
Featured Products
Thai Guavas
Thai white guavas are a great source of Vitamin C. Shipped to you from Fresh Gardens of Homestead, FL.
Get Gardening!
Southern Exposure Seed Exchange offers a wide variety of organic seed to get your home garden started.
FARMHOUSE
FOOD HOUSE BODY GIFT EXPERIENCES SPECIALS
Search our website
How Farmhouse Works
1 Purchase direct from Producer via Farmhouse
Farmhouse Direct is a virtual marketplace allowing customers to buy direct from the person who grows or makes the product.
2 Producer receives your order and ships direct to your doorstep
To maintain the integrity of the direct relationship between the farmer/producer we offer direct fulfilment from the producer to the buyer. This ensures that we provide you with the freshest made products direct from the farm.
3 You receive beautiful, locally grown and made produce
You receive the best locally grown and made produce from real people who are passionate about what they do! No warehouse, no middlemen - just the freshest produce to your doorstep.
farmdrop
Your supermarket's gone stale.
Start shopping
Over 750 delicious products
Our new zero waste model is fixing the food chain
Delivering across London

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 Configuration

- Adapt communications based on the locally available net technologies

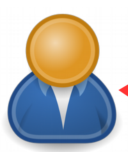
Smart Market Configuration

- Adapt communications based on the locally available net technologies

Smart Market Configuration

- Adapt communications based on the locally available net technologies

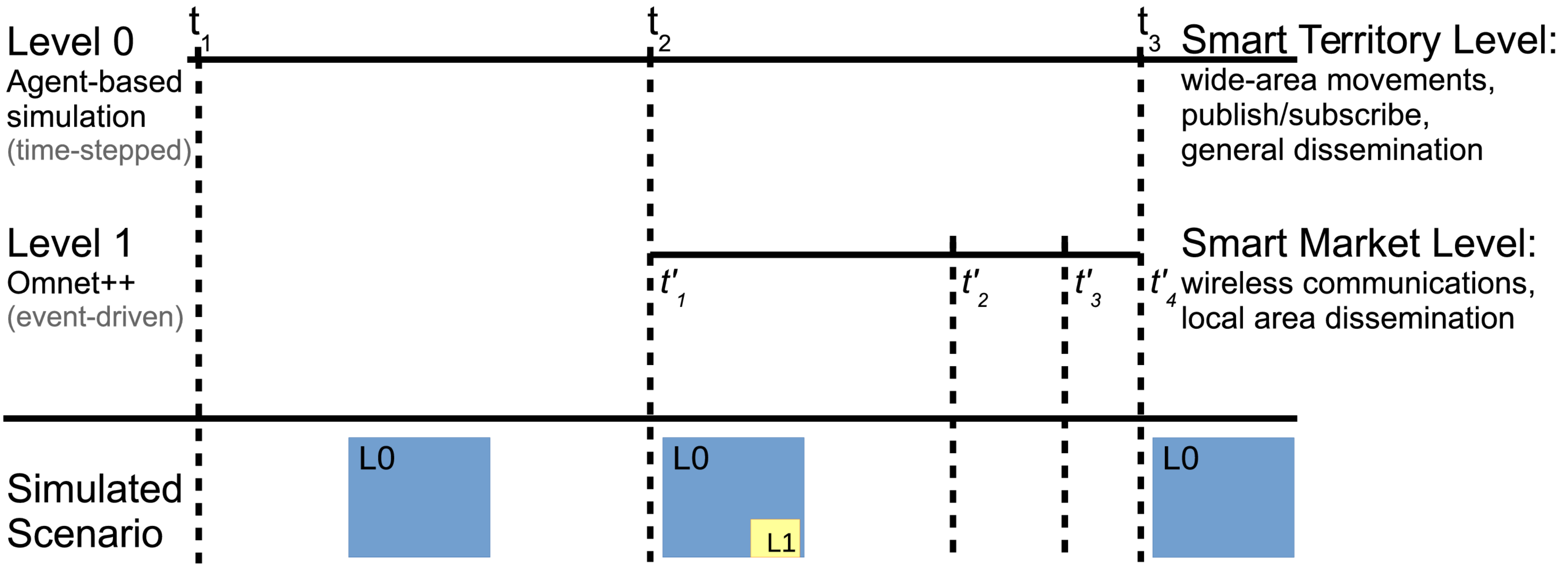
MANET



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
  - 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

Interaction Between 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

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Simulation Tools for IoT

- Domain specific simulators
  - OMNeT++
  - ns-2 / ns-3
  - Simulation of Urban MObility (SUMO)
  - PeerSim
  - …

Simulation Tools for IoT

- IoT simulators (1/5)
  - **GAIA/ARTÌS** [url]
    - ***Notes:*** *adaptive PADS (load balancing based on migrations), multi-level models (interoperability with domain specific simulators). Testbed based on Smart Cities / Smart Shires*
  - **SimIoT Toolkit** [url]
    - ***Notes****: back-end on Cloud, the testbed is a health monitoring system for emergency situations. Preliminary performance evaluation based on 160 identical jobs submitted by 16 IoT devices*

Simulation Tools for IoT

- IoT simulators (2/5)
  - **MAMMOTH** [url]
    - ***Notes:*** *software architecture based on emulation. Development has stopped in 2013 (?)*
  - **DEUS + Cooja + ns3** [url]
    - ***Notes****: integrates the DEUS general-purpose discrete event simulation with the domain specific simulators (Cooja and ns-3). Results show good scalability. Is DEUS monolithic or PADS?*

Simulation Tools for IoT

- IoT simulators (3/5)
  - **DPWSim** [url]
    - ***Notes:*** *designed to provide a cross-platform and easy-to-use assessment of "Devices Profile for Web Services" (OASIS standard). Large scale environments are not a main goal*
  - **SDL → ns3** [url]
    - ***Notes****: use a model-driven simulation (based on the standard language SDL) to describe the IoT scenario. An automatic code generation transforms the description into a ns-3 model*

Simulation Tools for IoT

- IoT simulators (4/5)
  - **IOTSim** [url]
    - ***Notes:*** *extends the Cloudsim functionalities. Designed for the modelling and simulation of IoT applications in shared Cloud data centers. Supports batch data processing using the MapReduce model. Open Source (?)*

Simulation Tools for IoT

- IoT simulators (5/5)
  - **Hybrid Cooja + OMNeT** [url]
    - ***Notes:*** *hybrid simulation environment in which the Cooja-based simulations (i.e. system level) are integrated with a domain specific network simulator (i.e. OMNeT++). Availability and Scalability?*

Simulation Tools for IoT

- IoT simulators (5/5)
  - **Hybrid Cooja + OMNeT** [url]
    - ***Notes:*** *hybrid simulation environment in which the Cooja-based simulations (i.e. system level) are integrated with a domain specific network simulator (i.e. OMNeT++). Availability and Scalability?*

Others?

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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 the tutorial 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/

Stefano Ferretti

- E-mail: <s.ferretti@unibo.it>
- http://www.cs.unibo.it/sferrett/

Related Work

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

pdf

Simulation of the Internet of Things

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University of Bologna

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