Key Research Priorities
The AMADEOS Contribution

Francesco Brancati
Resiltech s.r.l.

Workshop on Medium-Term Research Priorities for Cyber-physical Systems of Systems

The AMADEOS key-research priorities, and presentation outline

- 3Years European FP7 project, started in Oct 2013.
- Main AMADEOS goals:
  - To bring time awareness and evolution into the design of (Cyber-Physical) System-of-Systems (SoS),
  - to establish a sound conceptual model,
  - a generic architectural framework and
  - a design methodology, supported by some prototype tools, for the modeling, development and evolution of time-sensitive SoSes with possible emergent behaviors.
- AMADEOS key research priorities (and presentation outline):
  - Reduction of the SoS cognitive complexity
  - Modelling Cyber Space and Stigmergic channels
  - Assuring a global time base in order to support the causal analysis of behavior.

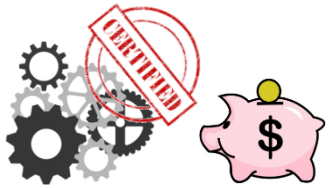
The Costs are accrued in the non-physical domain

The major cost elements during the specification, design, operation, evolution and maintenance of a large CPSoS are accrued in the *non-physical domain*.

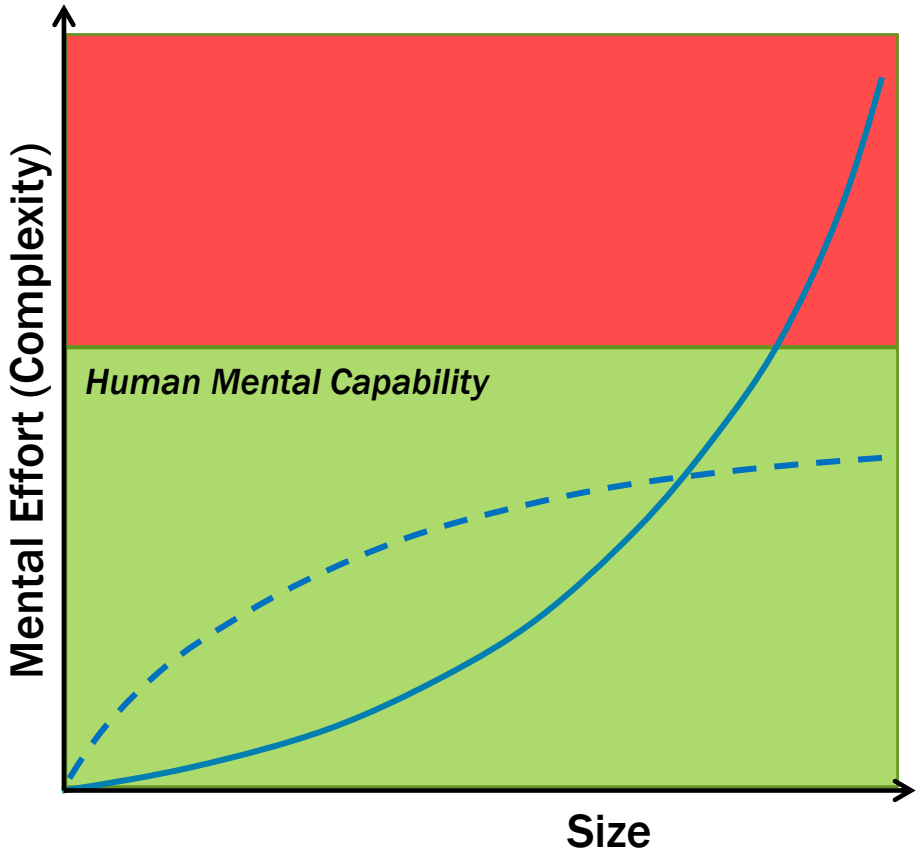
Compared to the cost of the ***engineering effort,*** the hardware costs of a CPSoS are modest—and getting even smaller as the hardware technology moves forward.

The *engineering effort* depends to a considerable degree on **the *cognitive complexity*, i.e.,** the time needed to *understand the behavior of a system*.

Any reduction of the cognitive complexity of a large system is thus of utmost economic significance and reduces the probability of the occurrence of design errors.

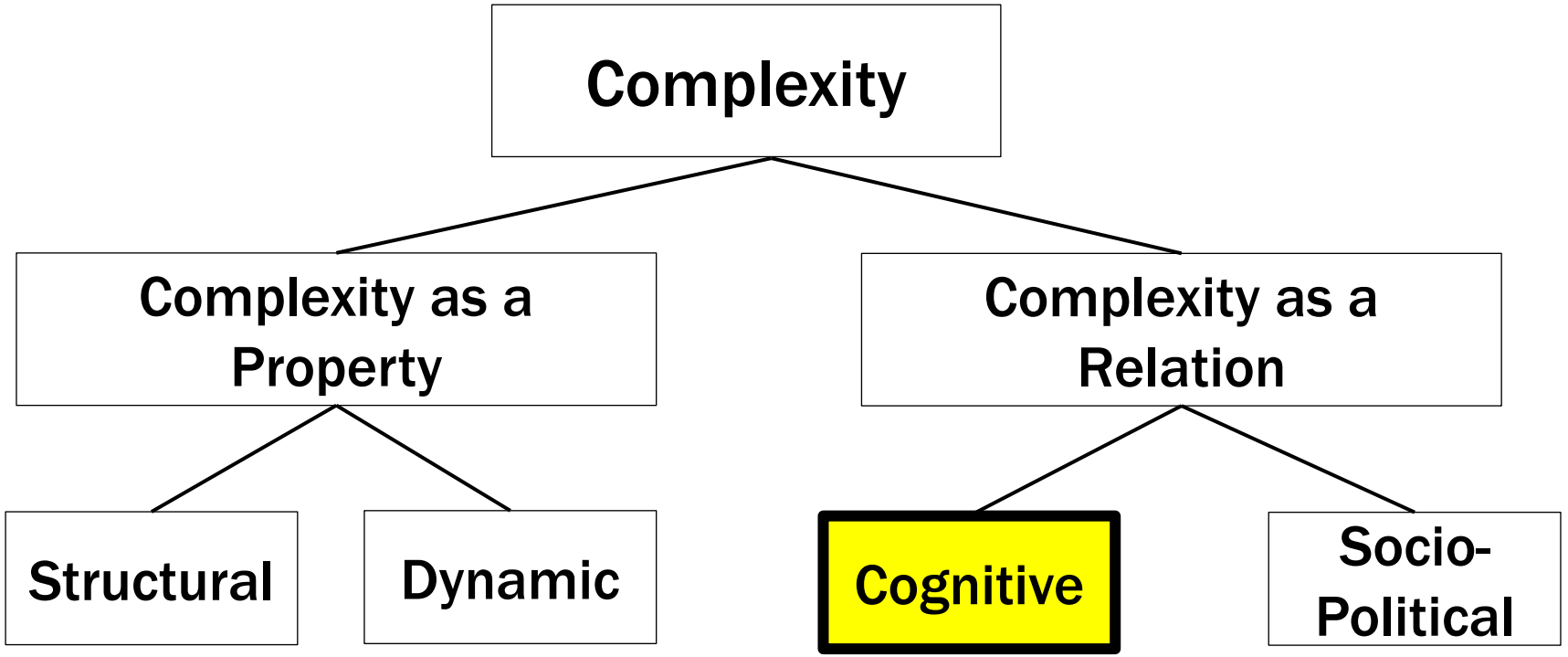


Size versus Mental Effort to Understand



If the mental effort required to understand a particular system function grows with the system size, there is a limitation to the size of the system we can build

Complexity



- Topological
- Components
- Links

- Behavior
- Causality
- Feedback

Relation between a Scenario and an Observer

Relation between a Scenario and Society

A Mental Model to understand the behaviour of a system

Understanding the behavior

means that a *mental model* that establishes *causal links* between

- the ***observable inputs***,
- the ***state***
- and the ***observable outputs***

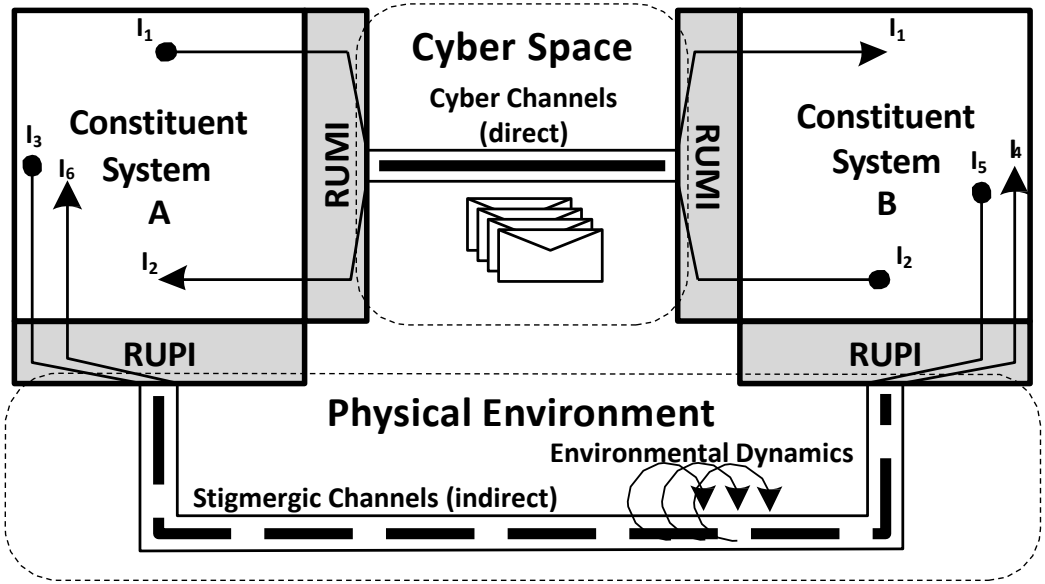
of the system has been formed.

Consequences

1. The input and output Itoms (information Items) of the constituent systems must be *observable at their interfaces*.
   - In case the behavior depends on the internal state of a system, this internal state *must also be observable*.

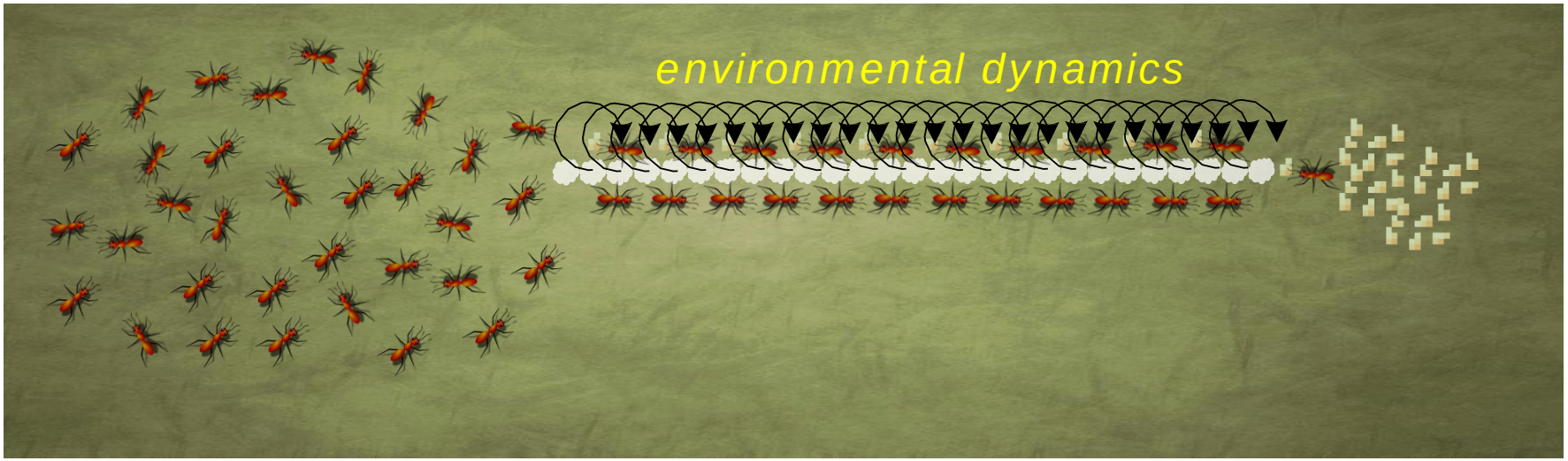
2. Causal Order presupposes Temporal Order.
   - The *Temporal Order* of all input and output messages can be established if the messages are time-stamped with a ***global time*.**

Cyber Space and Physical Environment



- Interaction is transfer of information at *Relied Upon Interfaces (RUIs)* of Cses
  - Relied Upon Message Interface: Message-based comm.
  - Relied Upon Physical Interface: Sensors, Actuators
- **A *stigmergic information channel* is present if one CPS acts on the environment common to many CPSs, changes the state of this physical environment and another CPS observes the changed state at some later point in time.**

Stigmergic Channels



- Ants find food and build/enforce trail by leaving traces (*pheromone*) in environment on way back.
- In case food source depleted,
  - ants stop leaving traces,
  - The environment evaporates traces autonomously
    ⇒*environmental dynamics*.
  - the trail disappears.

Modelling Stigmergy to Understand Emergence

A phenomenon of a whole at the macro-level is emergent if and only if it is new with respect to the non-relational phenomena of any of its proper parts at the micro level.

Many **emergent phenomena** come about by feedback loops among CSes closed via stigmergic channels

Need to model all interactions explicitly including Stigmergic ones

Consequences

1. The input and output Itoms (information Items) of the constituent systems must be *observable* at *the relied upon interfaces*.
   - In case the behavior depends on the internal state of a system, this internal state *must also be observable*.

2. Causal Order presupposes Temporal Order.
   - The *Temporal Order* of all input and output messages can be established if the messages are time-stamped with a ***global time*.**

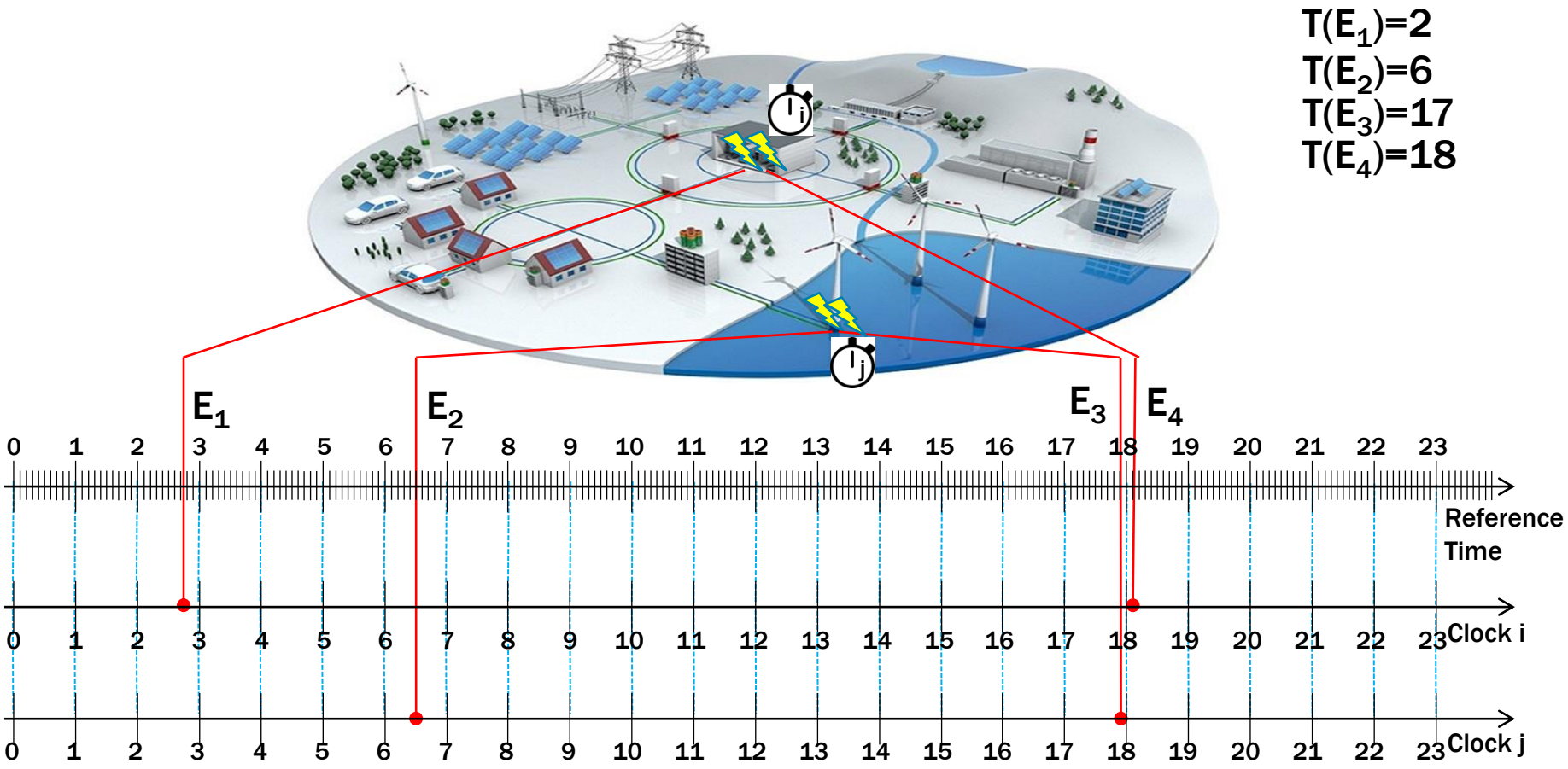
The Need for *Global Time*

A dependable *global (physical) time* provides the backbone of the temporal infrastructure of an SOS.

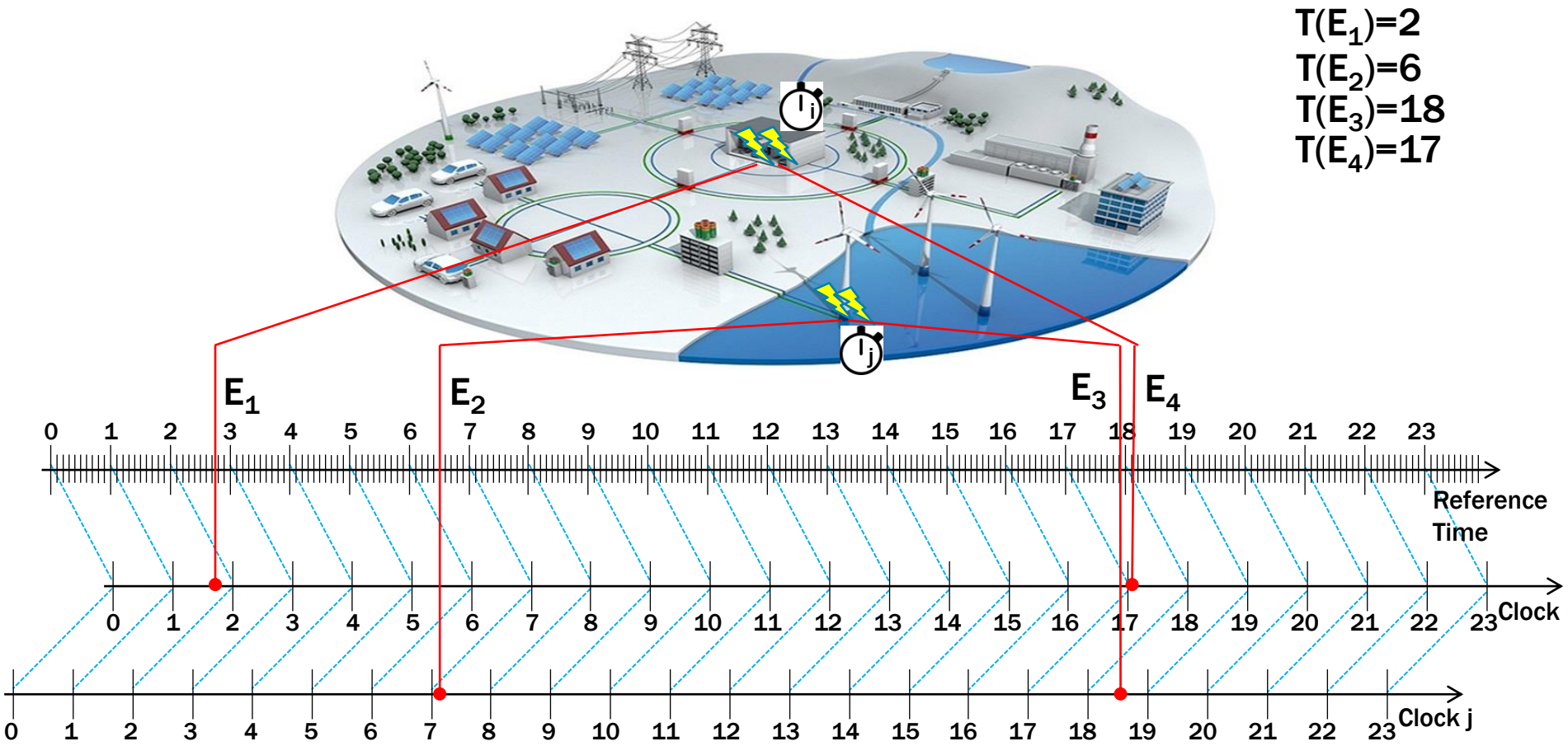
A global time is needed to:

- Interpret the time-stamps across the diverse systems
- Control and synchronize the *durations of the physical time frames*
- Specify the *temporal properties* of interfaces
- Synchronize inputs and output actions
- Synchronize *stigmergic* and *message-based* information
- Allocate resources *conflict-free* (e.g, in time-triggered communication, scheduling)
- *Detect errors* promptly
- Strengthen *security protocols*

Ordering Distributed Events



Ordering Distributed Events



Measure and Uncertainty of the Measure

- Two Research Directions:
  - To design precise and dependable synch mechanism (even in absence of GPS)
  - To Provide mechanism to let the SoSs live with the time uncertainty
- The local Clock is a measurement tool
  - It should provide
    - The measured time
    - The uncertainty of the measurement tool
- In AMADEOS we tackle this need…
  - a light, highly-portable, low intrusive oracle of the quality of clock synchronization.
  - to allow to keep the nodes of a network aware about the quality of synchronization to a time reference.

Conclulsion

- Any reduction of the cognitive complexity of a large system is of utmost economic significance and reduces the probability of the occurrence of design errors.
- Understanding the behavior means that a mental model that establishes causal links between the observable inputs, the state and the observable outputs of the system is available.
- Constituent systems interact using stigmergic-channels (RUPI) and cyber-channels (RUMI)
- Since temporal order is a precondition of causal order, the availability of CPSoS wide global timestamps supports the causal analysis of behavior.

References

- Related Publications (http://amadeos-project.eu/documents/publications/)
  - H. Kopetz, O. Höftberger, B. Frömel, F. Brancati, A. Bondavalli, “Towards an Understanding of Emergence in Systems-of-Systems” In Proceedings of the 10th Annual System of Systems Engineering Conference (SoSE), May 2015.
  - H. Kopetz, B. Frömel, and O. Höftberger. “Direct versus Stigmergic Information Flow in Systems-of-Systems” In Proceedings of the 10th Annual System of Systems Engineering Conference (SoSE), May 2015.
  - A.Ceccarelli, M.Mori, P.Lollini, A.Bondavalli, “Introducing Meta-Requirements for Describing System of Systems” In Proceedings of the 16th International Symposium on High Assurance System Engineering (HASE), Daytona Beach, CA, USA, 8-10 January 2015.
  - H. Kopetz. “A Conceptual Model for the Information Transfer in System of Systems.” 17th IEEE Symposium on Object/Component/Service-oriented Real-time Distributed Computing (ISORC). 2014.
  - A. Bondavalli, F. Brancati, A. Ceccarelli, L. Falai and M. Vadursi. "Resilient Estimation of Synchronisation Uncertainty through Software Clocks", IJCCBS, Vol. 4, October, 2013, pp. 301 - 322.

Thank You

for Your attention