Distribution Middleware Technologies for Cyber Physical Systems

Encuentro UPV/EHU – CIC Energigune

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Isidro Calvo

Ismael Etxeberria

Adrián Noguero

Isidro.calvo@ehu.es

Dept. de Ingeniería de Sistemas y Automática

E.U. de Ingeniería de Vitoria-Gasteiz

UPV/EHU

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Distribution Middleware Technologies for Cyber Physical Systems

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Cyber Physical Systems (CPS)

CPS integrate computation and physical processes

The term CPS was coined around 2006 by researchers of different disciplines:

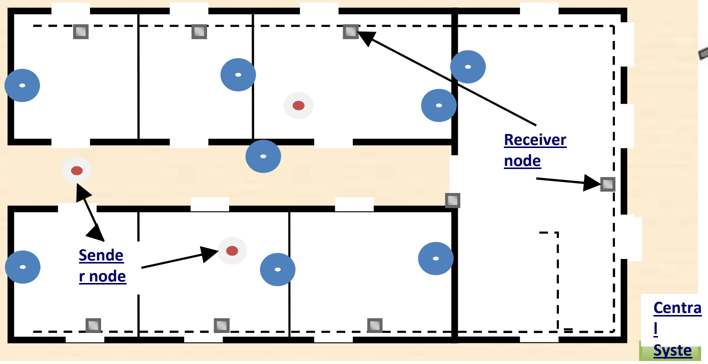
- Real-time systems
- Hybrid systems
- Control systems

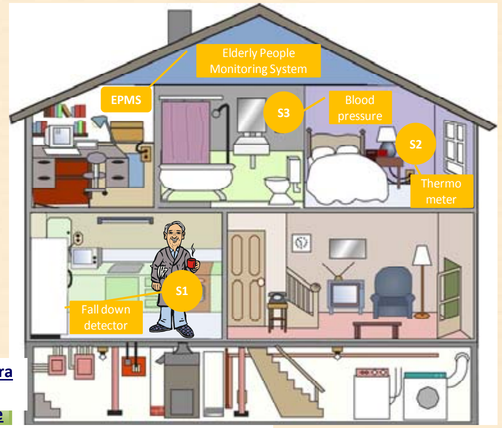
Internet of things vs. CPS => Two different communities

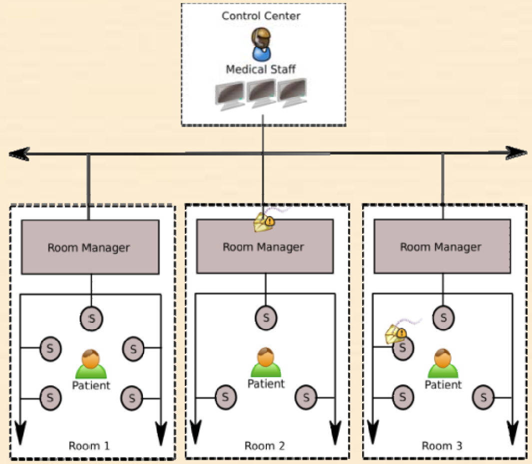
CPS are increasingly used in several domains:

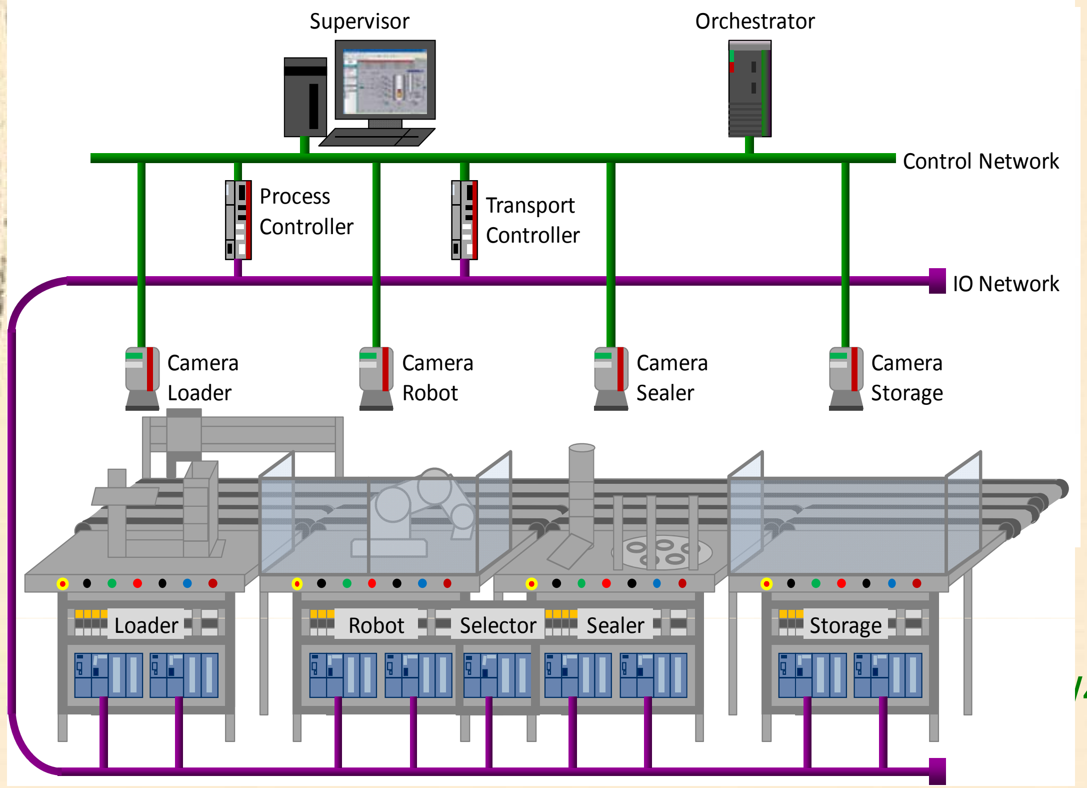
- Healthcare
- Transportation
- Process control
- Manufacturing
- Electric power grids

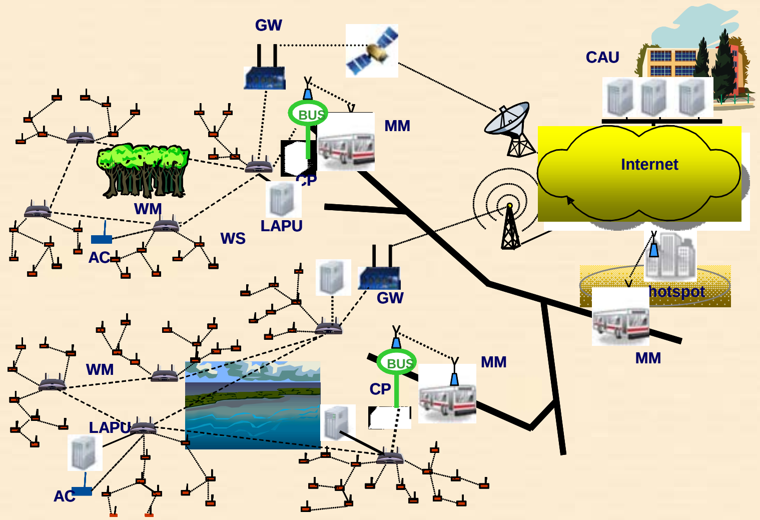
Application domains











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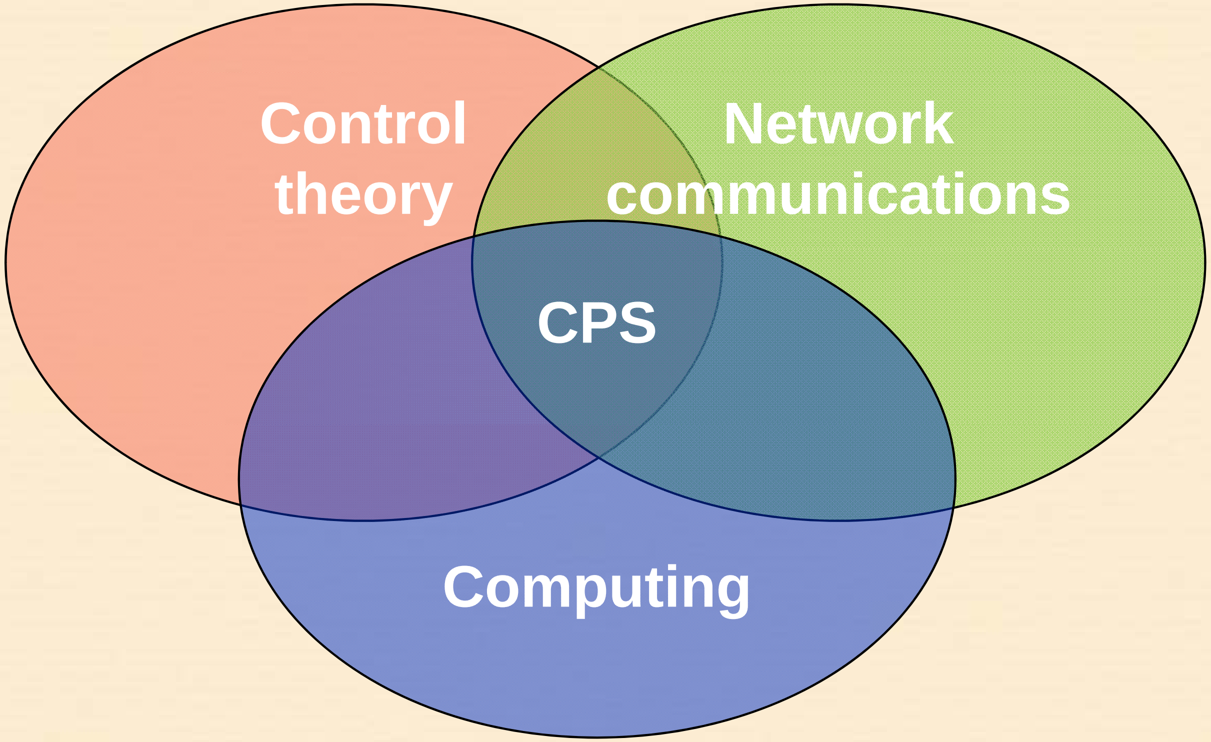
Cyber Physical Systems (CPS)



Technology implications

CPS benefit from **advances in several research domains**:

- Networked control systems
- Hybrid systems
- Real-time computing and networking
- Wireless technologies
- Smart sensors and actuators
- Security
- Model driven development
- Evolution in computing platforms:
  Low cost / Small size / High performance
- High bandwidth networks
- Improvements in energy capacity and management

Difficulties of building CPS

Building CPS is not a trivial task:

- **Integration** of different technologies
- **Different points of view** must be considered:
  Computing (concurrency and real-time issues), Control theory, Network communications
- **Heterogeneous** embedded hardware and software platforms
- **Fault-tolerance**: Dependable and safe systems
- Flexibility and adaptability to changes
- Scalability to build large systems
- Maintenance: CPS are created to work for long periods of time (e.g. several years)

- **Of course: Building new systems on schedule and keeping low costs!**

Communication issues

- Radical approaches:

  Design of new specific technologies and protocols from scratch for CPS

- **Pragmatic approach:**

  Use in short to medium term of worldwide accepted standards even though they provide lower performance:

  - Internet Protocols (IP)
  - IEEE802.11 (Wifi)

  Use of patches to improve their performance

Use of middleware technologies

- Ease the construction of new applications
- Hide low level implementation details
- Generic middleware technologies (J2EE, .NET, CORBA, DDS, or Web Services) drawbacks:
  - Tend to be excessive and introduce performance overhead
  - Do not match some specific requirements of CPS

- **Need of specific middleware architectures for CPS which introduce specific services and abstractions**
  - **Avoiding reinventing the wheel**
  - **Keep an adequate performance**

Main requirements of CPS

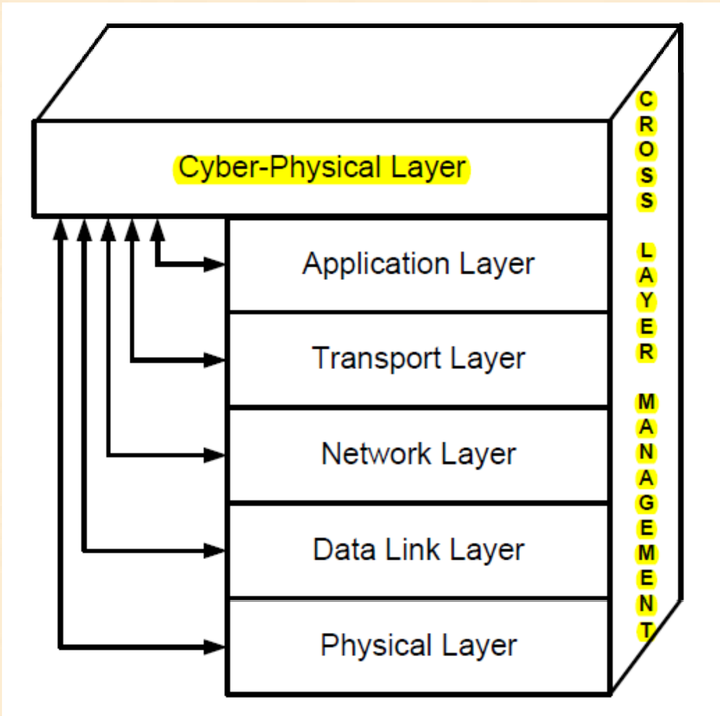
The nature of CPS imposes specific requirements different from general purpose computing:

- **Dealing with time:** Physical world is concurrent and reacting in time is critical
- **Close integration:** Highly coupled systems
- **Solving heterogeneity:** Mixture of platforms and technologies (computing platforms, OS, programming languages, network technologies)
- **Low resource devices:** CPU, memory, network bandwidth and energy consumption
- **Dynamic reconfiguration and reorganization:** Capable of adapting to changes in the physical world or changing requirements
- **Dependability and robustness:** Safety must be ensured even in adverse situations. Sometimes, CPS require certification.

New theories and tools are required

Lack of theory and **tools that help designers to build CPS** in an efficient way

- Extending **abstractions** that integrate in the existing nextwork infrastructures and reference models
- Koubaa, A and Anderson, B. (2009) proposed a **protocol stack** for CPS on top of the TCP/IP stack



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Need of distribution middleware in CPS

- Preeminence of TCP/IP stack
- Best effort techniques => Difficult to achieve timing predictability
- CPS require combining different types of traffic with different Quality of Service (QoS) requirements
- Convergence of Internet technologies with embedded systems
- Programming directly over TCP/IP sockets is complex, especially as the number of devices increases
- According to T. Pearson (2005), **the use of middleware produce up to 50% decrease in software development and costs**
- Middleware technologies:

  Provide an additional layer on top of the TCP transport layer

  Follow modular approaches

  Solve scalability and heterogeneity needs

General purpose middleware specs

- Success of some middleware specifications

  CORBA, ICE, DDS, Web Services, OPC (in industrial environments)
- Used for distributing information (Distribution middleware specifications)
- Do not solve specific challenges involved at the construction of CPS:

  Real-time, management of the resources, management and schedulability of distributed systems, etc.
- Lack of specific features for CPS domain applications

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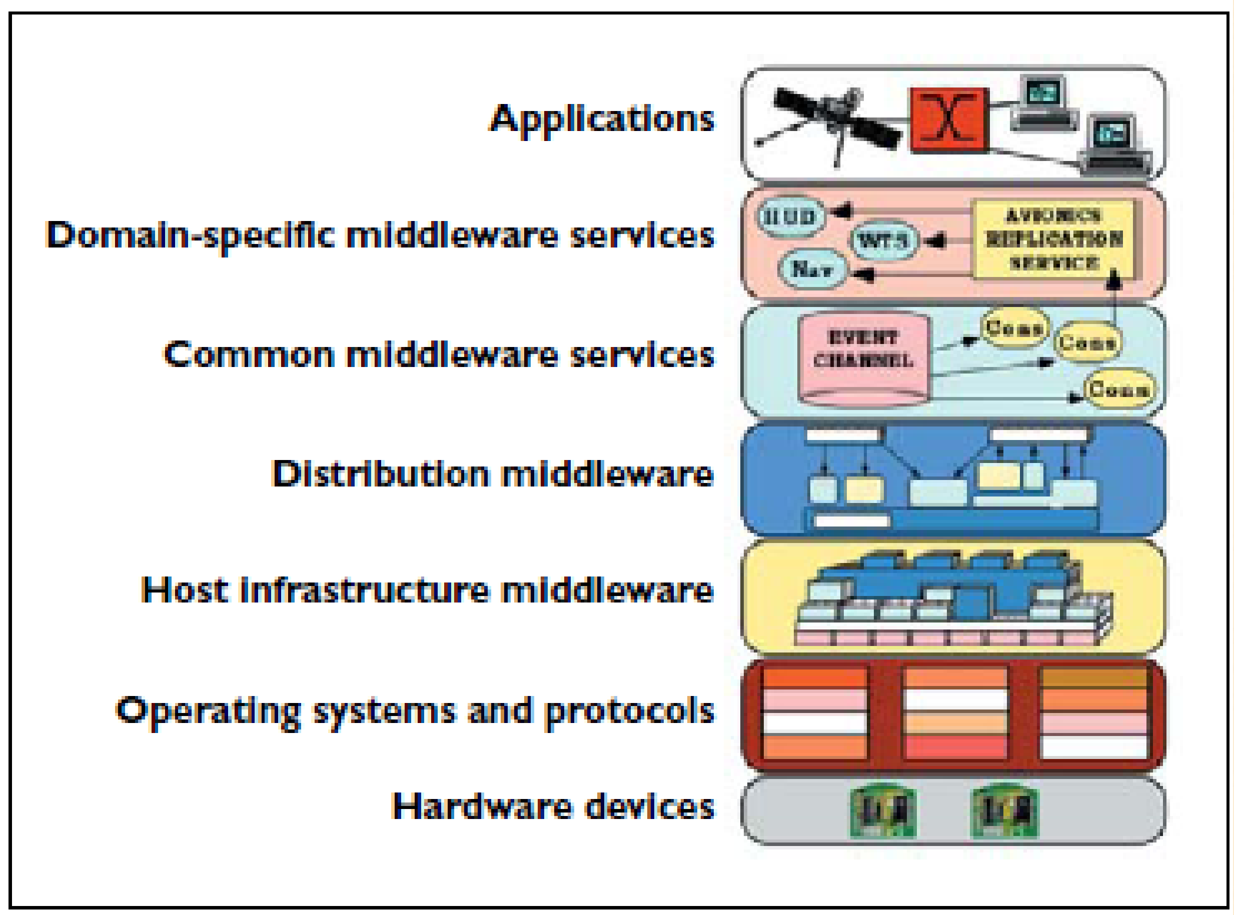
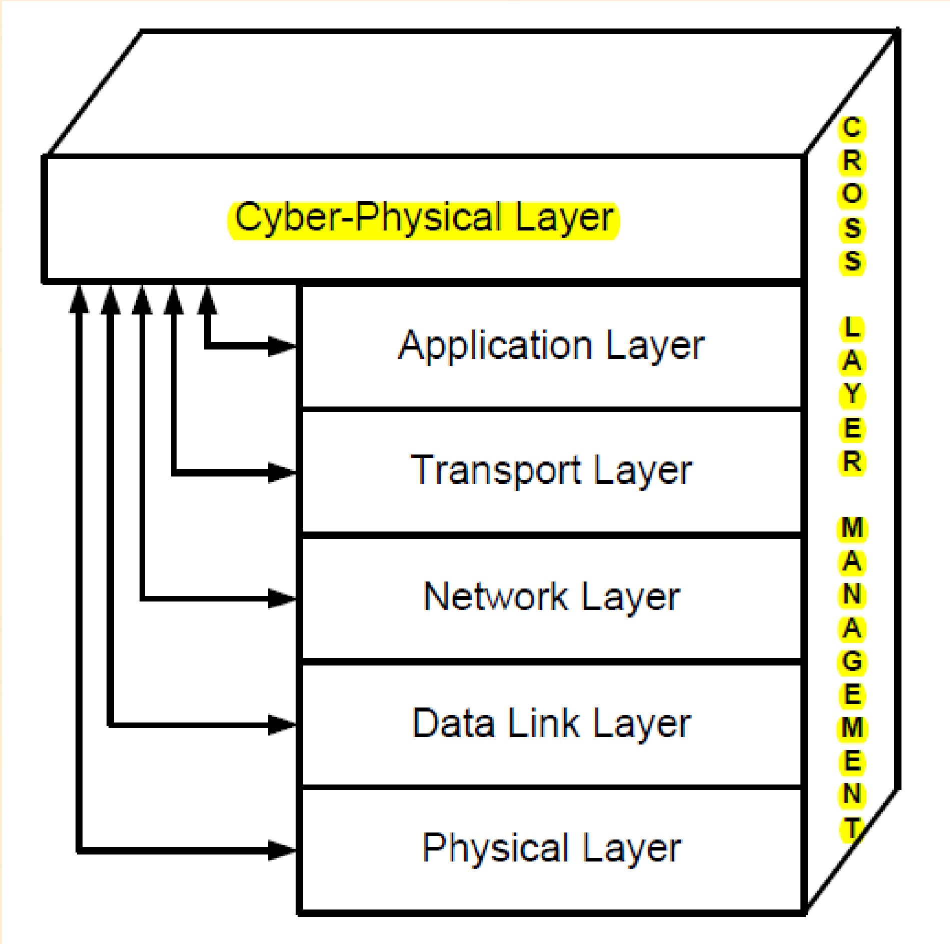
Layered middleware architectures

- Middleware is organized in a hierarchy of several layers (D.C Schmidt, 2002)



Middleware architectures for CPS

- Provide specific services for CPS and software abstractions
- The Cyber-Physical Layer



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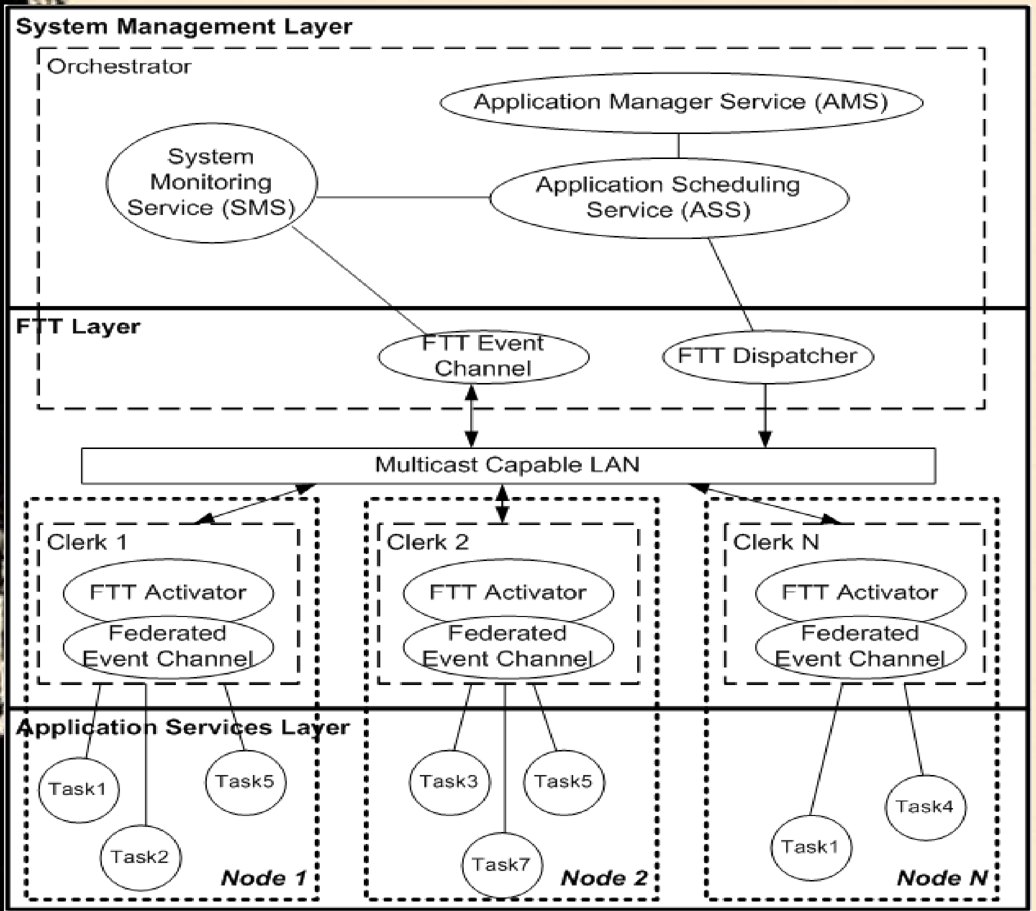
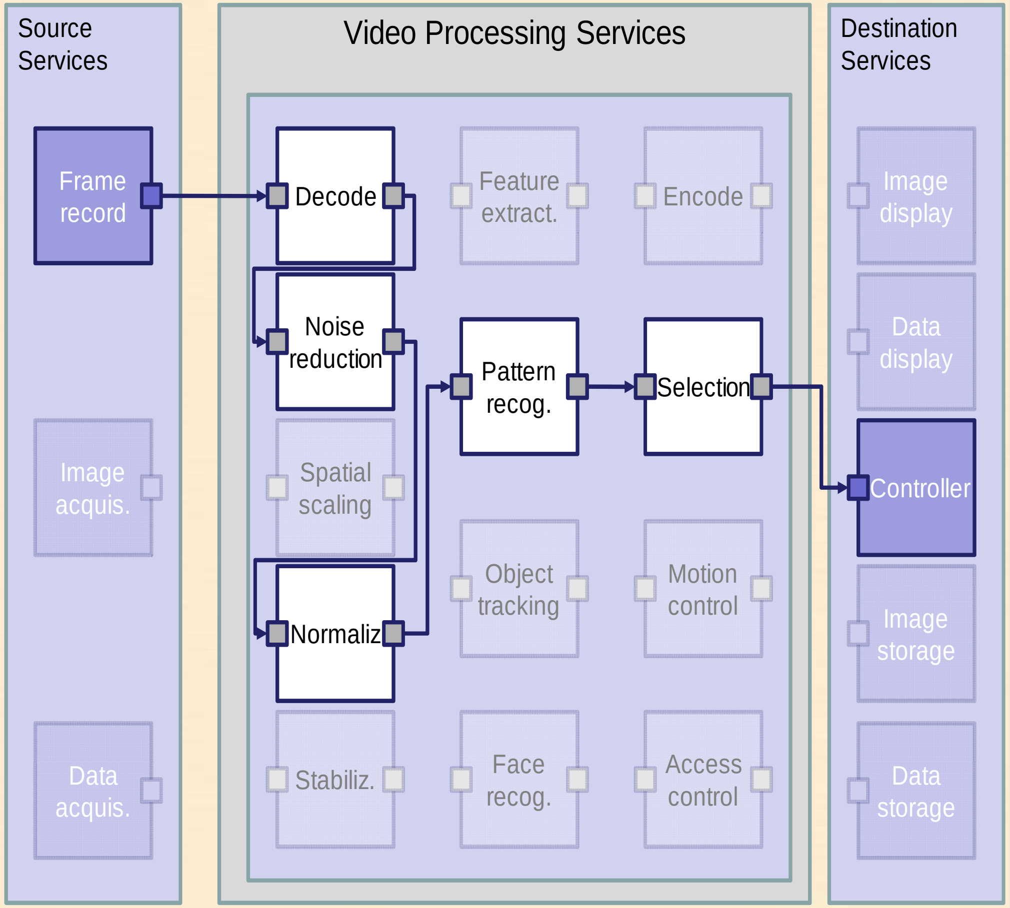
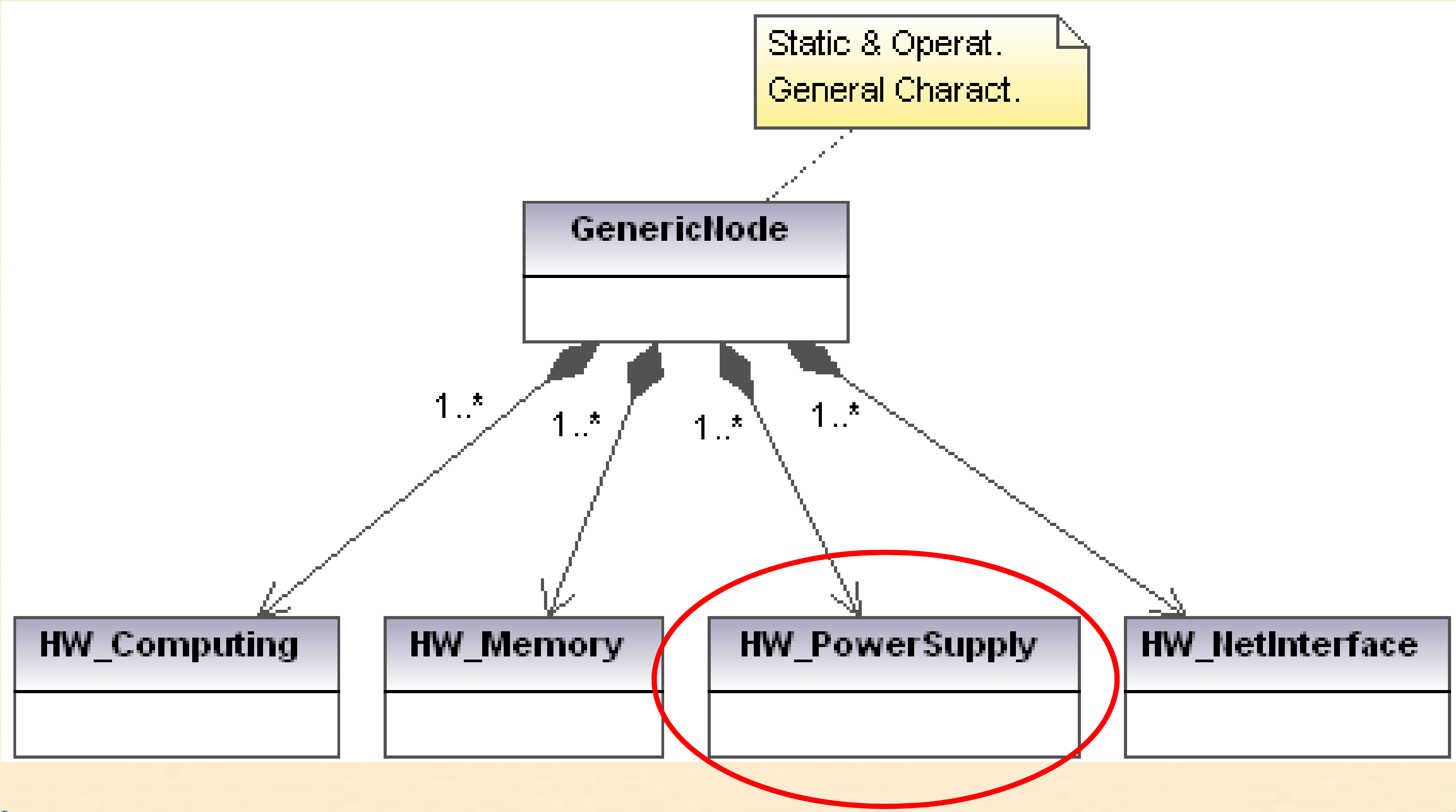
- Synchronizing the tasks activations of a distributed system according to a plan that may be changed at run-time (*PhD Adrian Noguero*)





Infrastructure modelling

- CPS require a close interaction with the underlying infrastructure.
- It is necessary to model both static and dynamic attributes



Conclusions

The design of CPS:

- ❑ Involve the use of different computing, communication and control technologies
- ❑ Require satisfying simultaneously several restrictive constrains
- ❑ Frequently, IP technologies are accepted
- ❑ New abstractions that represent CPS entities are needed
- ❑ Specific middleware architectures may provide services and abstractions for CPS
- ❑ Infrastructure modelling must be considered

Algunos proyectos recientes:

- Proyectos Europeos:
  - iLAND, m**I**dd**L**ew**A**re for deterministic dynamically reconfigurable **N**etworke**D** embedded systems (2009-2012 ARTEMIS)
- Proyectos Nacionales:
  - QoS DREAMS, QoS **D**riven **RE**configur**A**tion of Distributed Syste**MS** (2013-15 MINECO)
- Proyectos autonómicos / EHU
  - Diseño de sistemas distribuidos ciber-físicos con el estándar IEC61499 (EHU13/42, 2013-2015)
  - FACTWARE, Arquitectura Middleware para la composición y reconfiguración dinámica y determinista en aplicaciones de automatización industrial (SAI11/31, 2011-12)
  - Diseño de un entorno para la construcción de laboratorios remotos (EHU09/29, 2007-2009)

Docencia en Masters

- Máster en Ingeniería de Control, Automatización y Robótica
  - Dept. Ing. Sistemas y Automática

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Thank you

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