London Workshop on the Control of Cyber-Physical Systems

… On the (new) discipline:

Systems and Control Science

From the HYCON2 position paper (copies in this room)

Control is ubiquitous

- No sophisticated device (mobile phone, camera, washing machine, car, train, …) without lots of control loops
- High-precision and energy efficient manufacturing require precise control of a large number of variables
- Control technology constitutes a large part of the turnover of the European electrical/ electronics industry

High-performance control is a key technology for European competitiveness

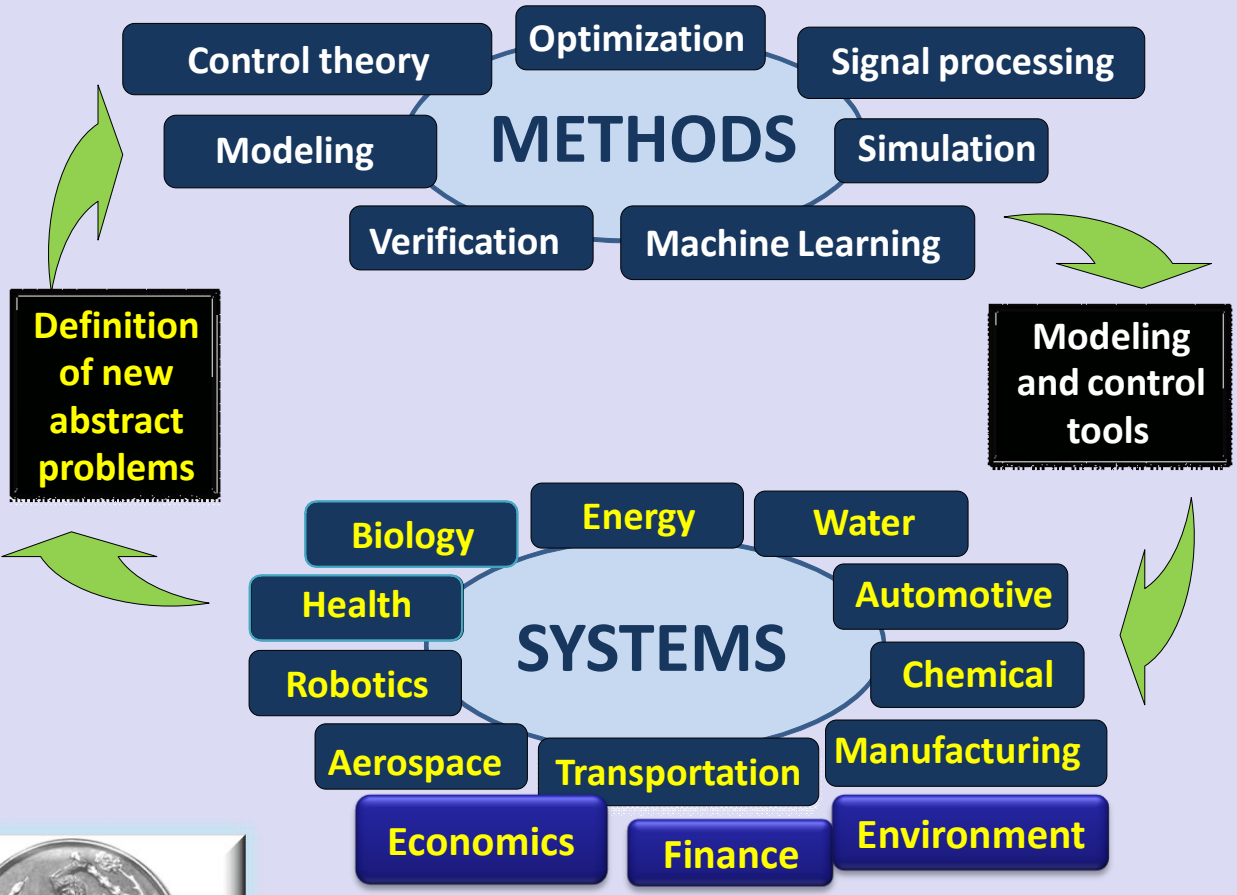
Systems and control science – what is it about?

Systems and Control Science provides the foundation for the realization of control and real-time decision support systems:

- **Mathematical modelling of physical and social phenomena** to understand and to predict their dynamic behaviours and the interactions with other systems
- **Design of control strategies and algorithms** to optimize the behaviour of systems so that they accomplish the intended functions and satisfy constraints, and such that negative effects are minimized
- **Implementation of control strategies** by sensing devices, actuators, computing elements, communication systems,... and integrating them into a performing system under cost constraints
- **Validation and verification** that the implemented control strategies together with the physical or social systems, satisfy constraints and performance requirements.

Control: Generic contributions and applications

Close BI-DIRECTIONAL interaction between methodological developments & advances in applications



- *abstract mathematical representations*
- *general solutions to theoretical problems*
- ***general tools for analysis and design***

- *specific performance requirements*
- *specific modeling needs*
- *specific HW/SW implementation constraints*
- ***tailored solutions to complex problems***

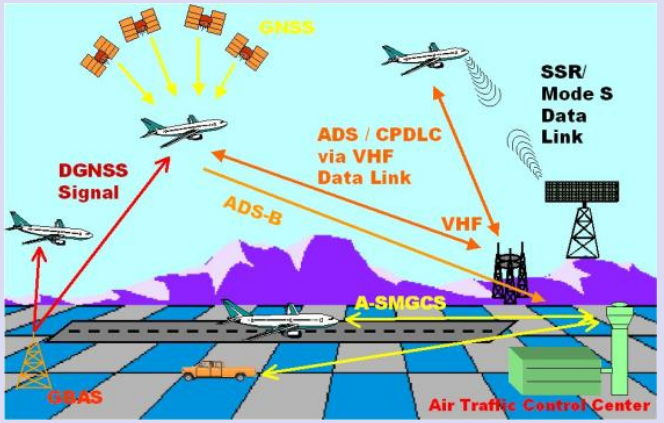
SYSTEMS (Complex, SoS, CPS, etc…) - Different layers: each layer has its own *life* (size and time scale of models) but it is strongly connected to the other layers: small variations at a particular point in the lowest layer can generate chaos or blackout at the highest level

New **fondamental approaches and tools** are needed

Systems and Control Science provided ,and is providing very efficient methods and technologies

- **higher level**: networks of interactions
- **intermediate level**: interactions between systems
- **lower level**: devices to control

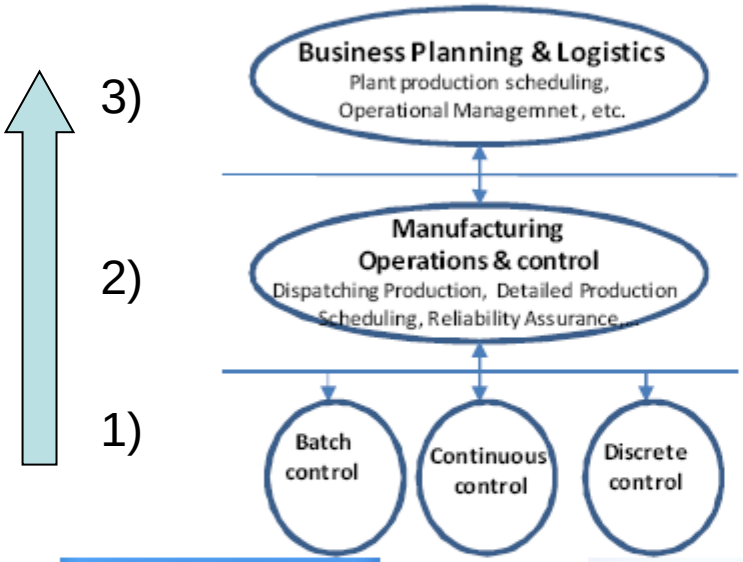
Ground traffic and air traffic management



Ground traffic and air traffic management are large-scale control problems with distributed decision makers.

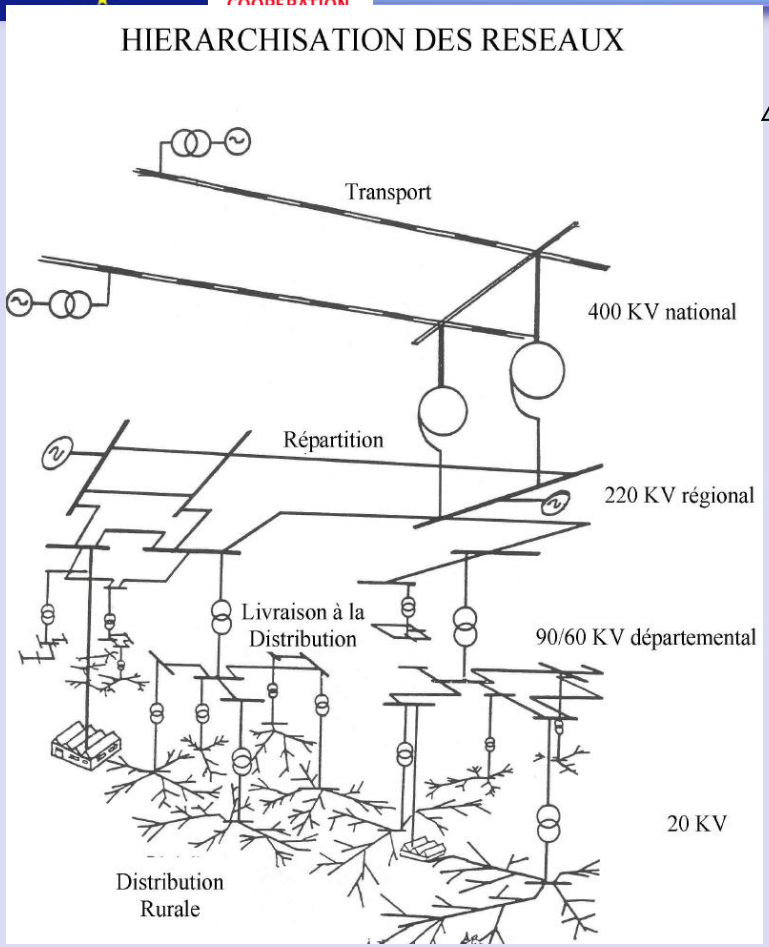
3) traffic flow
2) interactions between electronic devices
1) electronic devices for making vehicles cleaner or safer

The generic automation hierarchy
Applicable to various manufacturing processes and utilities



- Today automation has a wider definition, which significantly exceeds the control of the actual machine.
- Automation includes areas such as logistics, production planning and scheduling.
- What distinguishes the different levels in this hierarchy is most of all the different time scales.
- The principle automation functions are applicable to various manufacturing processes and utilities.
- Systems and control technology is a enabler for generic automation functions.

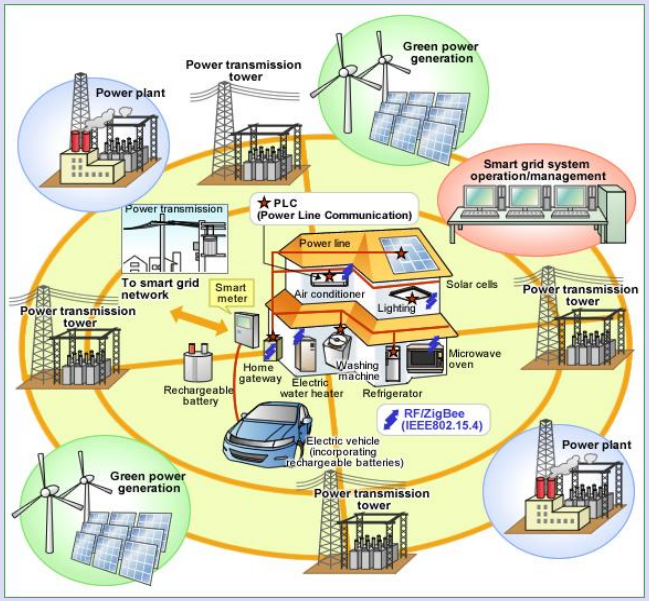
Contribution of control to societal needs



3)

2)

1)

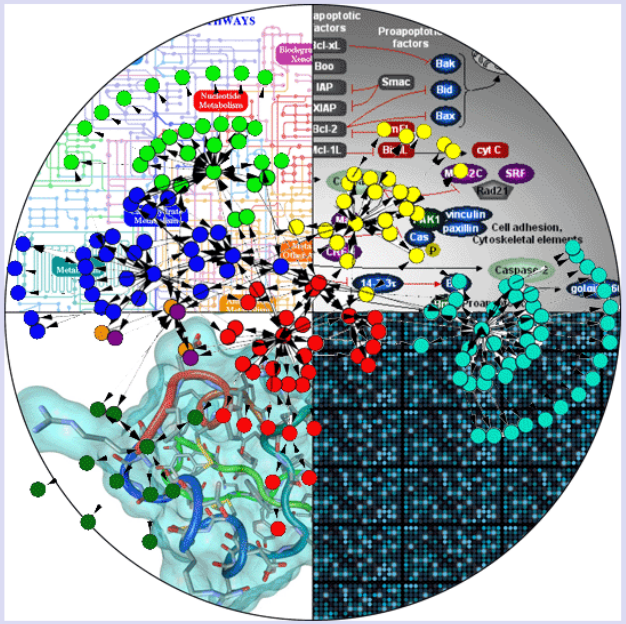


3) overall network security, mitigation of large disturbances

2) balancing produced and consumed power

1) electro-technical devices for ensuring local distribution

Cellular and biomolecular research



3) networks of interactions (transcription networks)

2) interactions between molecular species

1) microfluidic devices to control the cellular environment

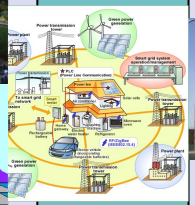
Key Challenges

… On these three levels we need:

- Make full use of the embedded computing power in all technical systems to achieve optimal performance
- Extract useful information from the enormous amount of data acquired, communicated, and stored in technical systems
- Construct dependable, performing, evolvable and evolving systems with reduced engineering effort.
- Guarantee safety and user-friendliness of automated systems
- …. CONTROL …

Five key challenges for future R&D and Innovation

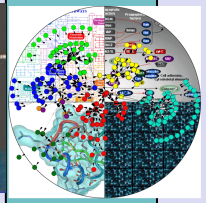
Automotive
Water
Biology
Energy
Health
Transportation
Aerospace
Robotics
Manufacturing
Process









Economics
Finance
Environment

CPS & Systems and Control Science

1. System-wide coordination and control of large-scale systems
2. Distributed networked dynamic systems
3. Autonomy, cognition and control
4. Model-based systems engineering
5. Human-machine interaction in automated systems

HORIZON 2020

Summary

- Advanced control technology is a key for
  - the competitiveness of the European manufacturing industry
  - high performance consumer products with embedded computing with which Europe has success on the world market
  - the satisfaction of urgent societal (health, economics, finance, environment) needs

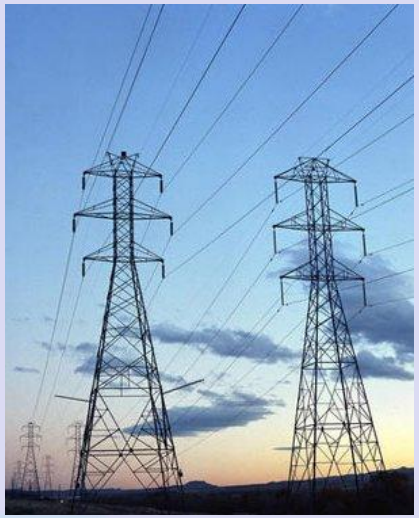
- The strength of **Systems and Control Science** is its applicability across all industrial and societal sectors and that it transfers developments from one sector to the others, thus leading to innovations on a broad scale.

Systems and Control Science

(good key word)

= NEW DISCIPLINE merging
Control, Communication and Computer Science
at the heart of the future technologies
for "PHYSICAL" and "SOCIAL" systems

System-wide coordination and control

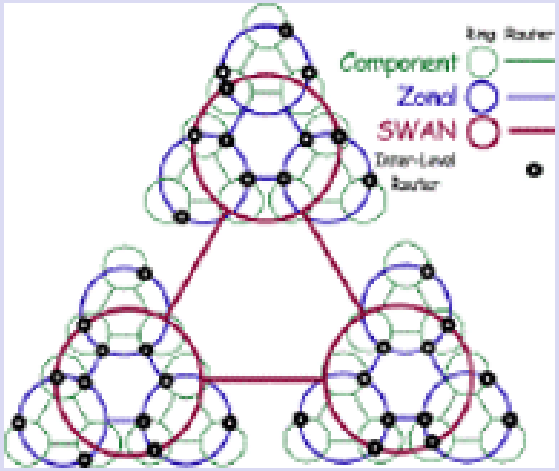


- Enormous needs, chances and challenges for economic and ecological optimization in the management of complex systems
- Deep vertical integration and standardized communication needed!

Distributed and networked dynamic systems

Wireless communications are revolutionizing the way factories, buildings, transportation systems (cars, airplanes, trains and ships), and homes are automated.

New standards for wireless communication are needed for feedback control purposes



- Control methods for networked systems must take into consideration that communication links may be interrupted or be established only for limited periods of time.
- Ensuring stability and performance for systems in which communication between subsystems is constrained is a new challenge that has to be tackled by the control and the communication community together.

Autonomy, cognition, and control

Systems with (partial) autonomy

- Exhibit goal-oriented behaviour and flexibly change their goals and behaviour depending on context and experience
- Can act in unstructured environments without human intervention and robustly respond to dynamic changes of the environment
- Can Interact with humans and with other cognitive systems to jointly solve a task.
- Will be increasingly important for assistance to the elderly in an ageing society!

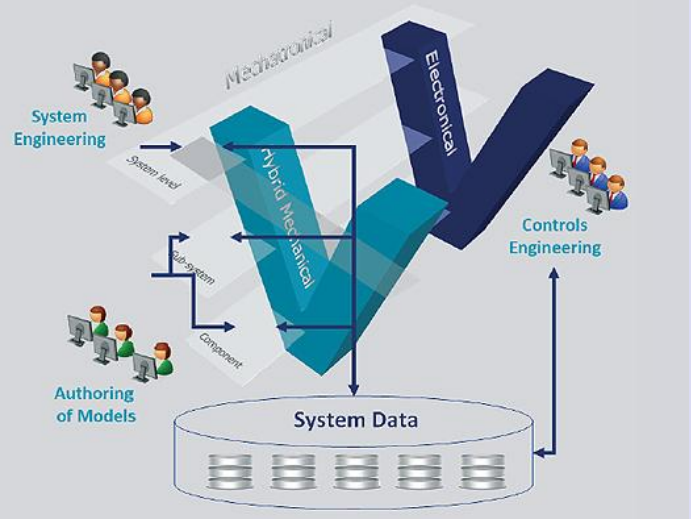
How to ensure safe and certified operation for highly autonomous systems under all conceivable conditions?

How to combine data-based techniques (machine learning) with rigorously founded algorithms to achieve unprecedented performance?

How to extract valuable information from large data sets?

Model-based systems engineering

- Efficient and reliable systems design requires the use of models.
- Different aspects of technical systems are often modeled by different formalisms that are the basis of the use of specific tools.
- This calls for the integration of different formalisms into one environment with efficient re-use of models and integration of results obtained by different tools.



- Integration of mathematically sound control design and analysis methods into industrial environments where heterogeneous data, documentation, models, formalisms and software are used on all design levels with presently weak coupling and no guarantee for consistency.
- Advanced methods for automated design flow support, such as consistency checking and dependency tracking

Model-based design is the key to the development of dependable complex systems and of systems of systems.

Human-machine interaction in automated systems

- The interplay of humans with highly automated systems with complex dynamics and complex controllers is crucial for the functioning and performance of large technical systems.
- This area needs a much deeper investigation, bringing together researchers from cognition, human-machine interaction and systems and control.

Challenge:

Development of a synergistic approach where the capabilities of complex and theoretically well-founded control systems and of humans are combined in the most effective manner to achieve the best possible system performance while guaranteeing safety and integrity.

Requires collaborations of control scientists with behavioural science.

Feedback control is the key for the future

“Real-time measurement, modelling and control platforms will drive a smarter planet through the broad implementation of feedback control.”

Dario Gill, Program Director, Energy Technology and Strategy,
IBM T.J. Watson Research Center

Control algorithms are the core of most systems!