Challenges & Opportunities in Cyber-physical Systems

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ICT Policy, Research and Innovation for a Smart Society

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Convergence of IoT and CPS

- **Focus of current research and development in IoT**
  - Low-cost sensors / computing
  - Provision of connectivity, middleware

  → Enormous amounts of data can be collected in real time

- **How to make use of the data is sometimes not clear**
  - What benefits can be gained from the data?

  → **From sensing to actuation, closing the loop**

→ **IoT is an enabling technology for CPS, especially for large-scale CPS (Energy systems, road traffic, production systems, …)**

→ **Cyber-physical Systems of Systems**

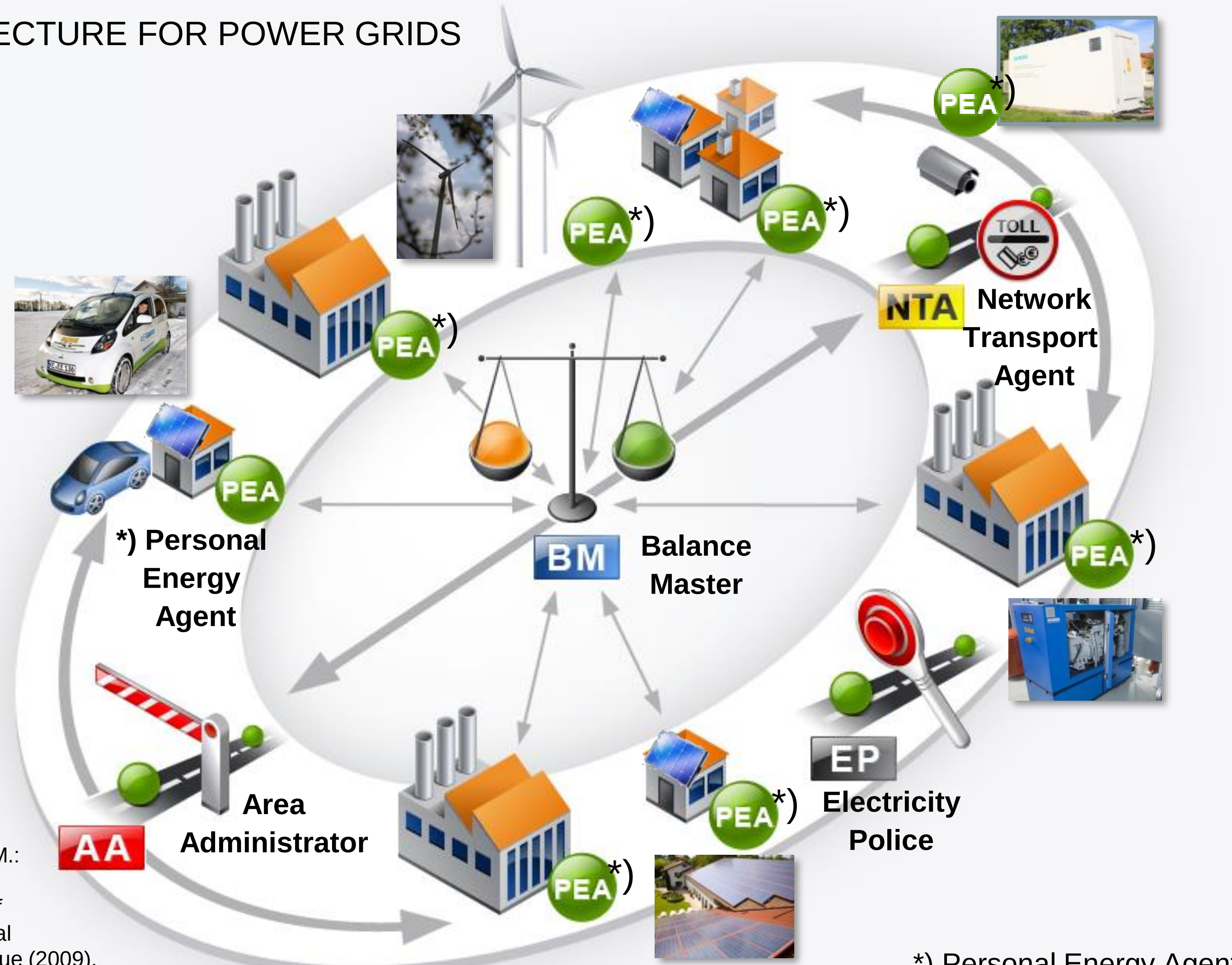
Self-Organizing Energy Automation Systems Coordinating Smart Components Within the Grid

SIEMENS

MULTI-AGENT ARCHITECTURE FOR POWER GRIDS (SCHEMATIC)

Design Principles:

- Smart components.
- Use plug and play for engineering.
- Coordination of local algorithms whenever necessary



Böse, C.; Hoffmann, C; Kern, C.; Metzger M.: *New Principles of Operating Electrical Distribution Networks with a high Degree of Decentralized Generation,* 20th International Conference on Electricity Distribution, Prague (2009).

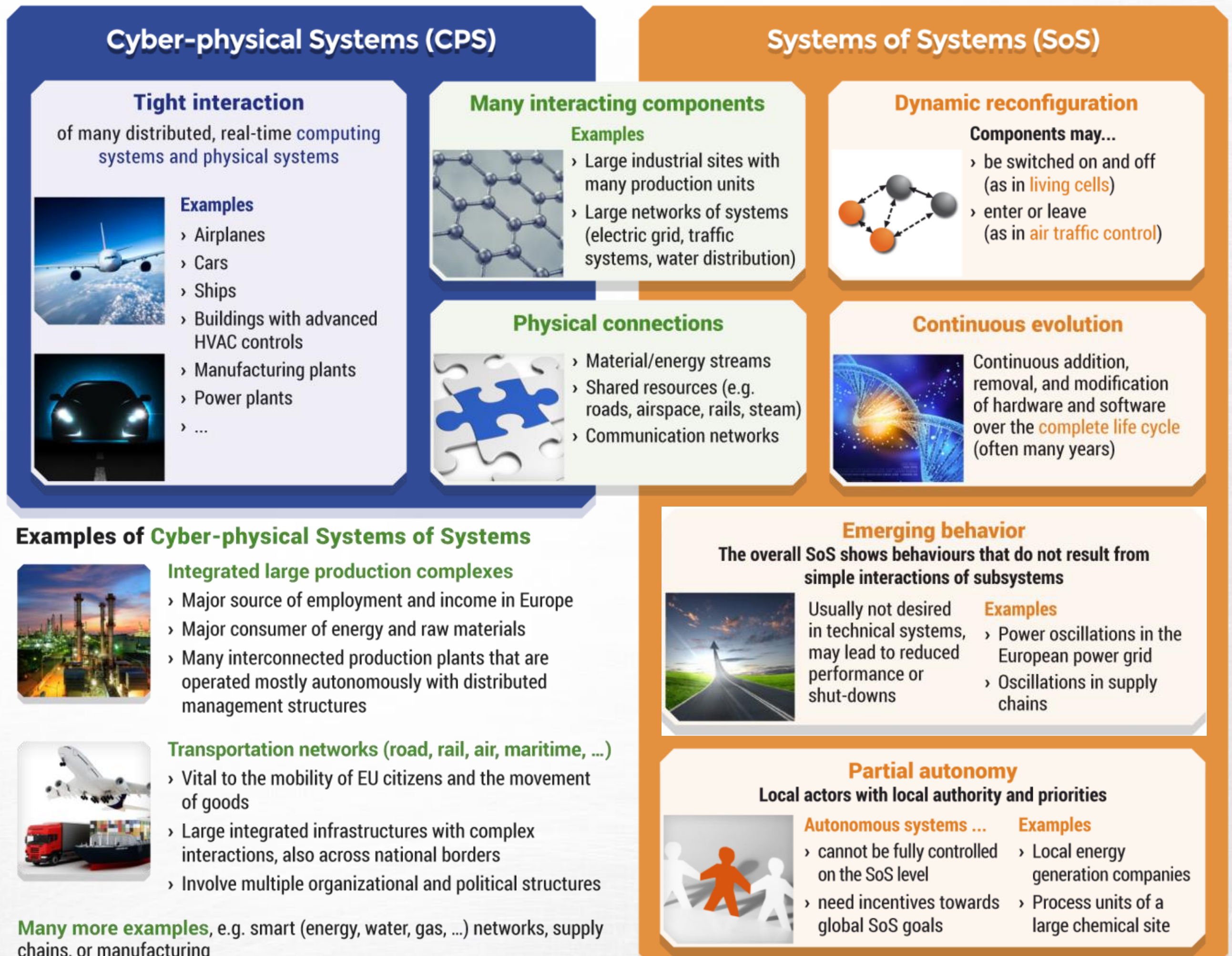
*) Personal Energy Agent

Cyber-physical Systems of Systems

www.cpsos.eu

Large, complex, often spatially distributed Cyber-physical Systems (CPS) that exhibit the features of Systems of Systems (SoS)

www.cpsos.eu



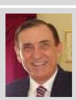
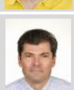
Control and Management of CPSoS

- Not performed in a completely centralized or top-down manner with one “authority” providing all the necessary control signals but with distributed decision power
- Structures vary from a (multi-layered) hierarchy to a fully decentralized structure where only technical constraints, economic incentives and human interactions connect the subsystems.
- **Partial autonomy** of the control and management systems of the components
  - Disturbances can be handled (to some extent) locally
  - Subsystems can exhibit “selfish” behaviour with local goals, and preferences.
  - Autonomy can result from human users or supervisors taking or influencing the local decisions.
- The “managerial element” of the components goes beyond classical local control loops (PID, MPC).

Dynamic Reconfiguration and Evolution

- Addition, modification, replacement or removal of components on different time scales
- Changes of the connectivity and the mode of operation
  - Components may come and go (e.g. in air traffic control)
  - Reaction to faults
  - Changes of system structures and management strategies following changes of demands, supplies or regulations.
- Systems operate and are continuously improved and modified over long periods of time.
  - The infrastructure "lives" for 30 or more years, and new functionalities or improved performance have to be realized with only limited changes.
  - Management and control software has long periods of service, while the computing hardware base and the communication infrastructure change much more rapidly.
- **Engineering is re-engineering and takes place at run time.**

PICASSO IoT/CPS Expert Group Members

Name	Organization Position	Background
Sebastian Engell (Chair) 	**TU Dortmund, Germany** Professor	Automation and Control / Systems Management / CPS
Tariq Samad (Co-chair) 	**TLI, University of Minnesota, US** Professor	Industrial Automation
Massoud Amin 	**TLI, University of Minnesota, US** Director / Professor	Infrastructures / Smart Grid
Chris Greer 	**NIST, US** Program Office Director and National Coordinator	CPS / Smart Grid
Amit B. Kulkarni 	**Honeywell, US** Global R&D Leader for Wireless and IoT	Wireless, Internet of Things
Paul Nielsen 	**Software Engineering Institute, CMU, US** Director / CEO	Software development / CPS / Cyber-security
Martin Serrano 	**Insight Centre for Data Analytics, Ireland** Principal Investigator and Data Scientist	Internet of Things
Haydn Thompson 	**THHINK, UK** Director	Wireless sensors / Transpor-tation / Manufacturing / Smart Cities
O. Sinan Tumer 	**SAP Co-Innovation Lab, US** Senior Director	Co-Innovation / Research Commercialization
Hubertus Tummescheit 	**Modelon Inc., US / Modelon AB, Sweden** CEO / Co-founder	Modeling / Simulation
Ovidiu Vermesan 	**SINTEF ICT, Norway** Chief Scientist, Chair WG01 AIOTI	Internet of Things

Opportunities for EU-US Collaboration on the Internet of Things (IoT) & Cyber-physical Systems (CPS)

PICASSO Opportunity Report

www.picasso-project.eu/outreach/project-reports/

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PICASSO IoT/CPS Opportunity Report: Sources

Discussions within the Expert Group

1st Joint PICASSO Expert Group Meeting, May 2016, Washington D.C.

Strategic documents and roadmaps

CPS (EU)

CPS (US)

IoT (EU)

IoT (US)

PICASSO data collection and analysis efforts

- In particular the report Analysis of Industrial Drivers and Societal Needs - Towards New Avenues in EU-US ICT collaboration
  - Based on interviews with > 100 experts

Funded IoT and CPS projects

- EU funding programmes *FP7, H2020, EUREKA/ITEA, ECSEL, ARTEMIS*
  - 46 CPS projects
  - 32 IoT projects
- US funding agencies *NSF*, *NIST*, *DoE*
  - 23 CPS projects
  - 23 IoT projects

Feedback collection from leading experts

- In-depth 30-minute personal interviews with agencies and major IoT/CPS initiatives
- Interactive webinar on IoT/CPS
- Wide dissemination and public consultation

All public PICASSO reports are available at: http://www.picasso-project.eu/outreach/

Comparison of EU and US Priorities for CPS

EU

High priority

- 13 (Systems) engineering support
- 7 Trust, (cyber-)security, robustness, resilience, and dependability
- 4 Seamless integration, interoperability, flexibility, reconfiguration
- 1 Autonomy and humans in the loop
- 3 Situational awareness

Lower priority

- 1 Validation, verification, and computation of key properties
- 7 Distributed, reliable, and efficient management, control, and automation
- 0 Open R&I environments, test beds
- 1 Reference designs and architecture principles

CPS

US

High priority

- Model-based systems science and engineering 1
- Privacy, cyber-security, trustworthiness 2
- System integration and interoperability 1
- Autonomy and human-computer interaction 1
- Situational awareness, diagnostics, prognostics 5
- Validation, verification, and certification 2
- Prototypes and test beds 2

Lower priority

- Distributed control 4
- Open reference architectures 1
- Education and training 0

The number of funded projects is shown in green

PICASSO EU-US ICT collaboration

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Comparison of EU and US Priorities for the IoT

EU	IoT	US
High priority		**High priority**
4 Semantic interoperability and integration	→	Open architectures, platforms, interoperability 7
2 Open architectures, platforms, and innovation ecosystems	→	Open architectures, platforms, interoperability 7
1 Closing the loop - creating a reliable monitoring/actuating IoT substrate	→	Closing the loop: IoT as an enabler for future CPS 0
1 Security, trust, dependability, and privacy	→	(Cyber-)security, privacy, resilience to faults/attacks, trust 5
Lower priority		**Lower priority**
5 Test beds and pilots		Human-centered IoT systems 0
0 Autonomous IoT devices		Skill-building initiatives 0
1 Smart M2M networks		

The number of funded projects is shown in green

Key Technology Themes (1)

Closing the Loop in IoT-enabled Cyber-physical Systems

- System-wide, cloud-supported control via IoT-connected devices
- Data-based operation
- Control architectures for IoT-enabled CPS
- Performance and stability in the face of unpredictability (outages etc.)

Integration, Interoperability, Flexibility, and Reconfiguration

- Semantic interoperability and semantic models
- Openness and open standards, harmonization of standards
- Automatic (re-)configuration and plug-and-play of IoT and CPS components
- Shared infrastructure access and large-scale pilots for CPS and IoT systems
- IoT and CPS architectures and cross-domain infrastructures

Key Technology Themes (2)

Model-based Systems Engineering

- Integrated, virtual, full-life-cycle engineering & system-wide design
- High-confidence CPS, validation, verification, risk analysis and risk management
- Models of heterogeneous large-scale systems
  - Stochastic models, open simulation/integration, model maintenance, grey-box models

Trust, (Cyber-)security, Robustness, Resilience, and Dependability

- Exception handling, fault detection and mitigation
- Trustworthiness of technical systems
- Behavior-based methodologies to establish trust (intrusion detection and prevention, resilience to cyber attacks)
- New engineering perspectives for safety, security, resilience, reliability, privacy
- Secure real-time and mixed-criticality systems

Key Technology Themes (3)

Autonomy and Humans in the Loop

- Autonomy in large-scale, complex, open systems that are not domain/knowledge-“contained”
- Models of autonomous CPS systems and humans
- Humans in the loop and collaborative decision making
- Analysis of user behavior and detection of needs and anomalies
- Analysis, visualization, and decision support

Situational Awareness, Diagnostics, and Prognostics

- Large-scale real-time data analytics and data management
- Machine learning, learning methodologies, adaptive behavior
- Predictive condition monitoring and maintenance
- Self-diagnosis tools

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Enhancing Collaboration

- **Roadmapping and benefit assessment**, via **joint thematic EU-US workshops**
  - Bring together a **diverse group of experts from academia, industry, and government,** foster discussions about challenges and collaboration opportunities
  - Identify and discuss **specific R&I topics** and **concrete technology and application scenarios**
- **Facilitation of collaboration initiatives**
  - Establishment of **mechanisms/organizations** that serve as **central contact points, coordinators,** and **facilitators for EU-US collaboration actions** and that provide support to potential partners (e.g. universities, companies, industry associations)
- **Lightweight joint research and innovation**
  - Use of fellowship and exchange funding programs
  - Launch of **synchronized initiatives** to support **joint experimentation, new testbeds and demonstrators,** and **industrial standardization activities**
  - Participation in projects with or without trans-Atlantic funding

Thank you very much for your attention!

The PICASSO Opportunity Reports can be found under

www.picasso-project.eu/outreach/project-reports/