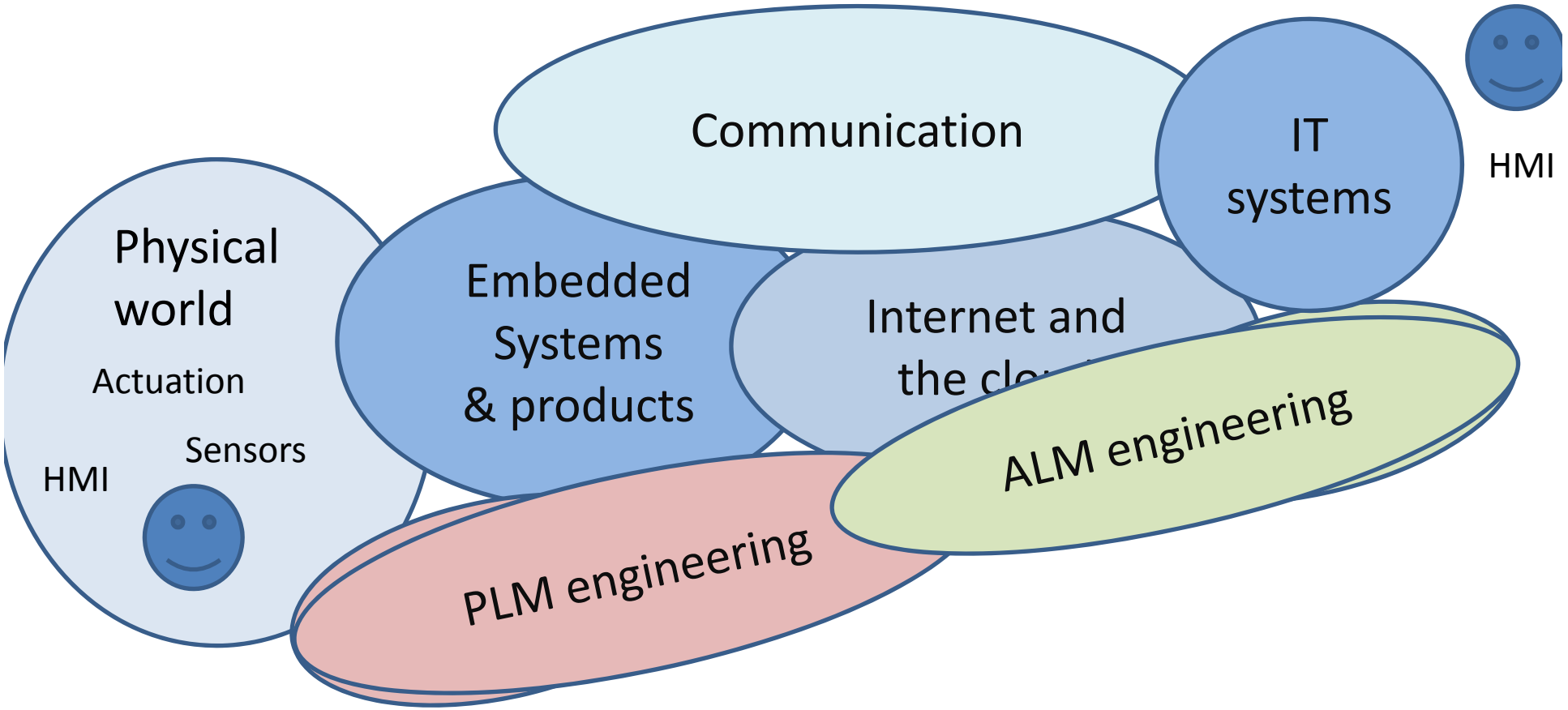
Roadmapping efforts for research, education and innovation in Cyber-Physical Systems

Martin Törngren
Professor in Embedded Control Systems, ICES director
Division of **Mechatronics**, **KTH** – Royal Institute of Technology

Joint work with Victoria Cengarle (Fortiss), John McDermid (Univ. Of York), Roberto Passerone (Trento), Alberto Sangiovanni Vincentelli (Trento/UCB), Saddek Bensalem (Univ. Joseph Fourier), Martin Grimheden (KTH) + contributions from many other experts!

Merging technological areas



CyPhERS
Cyber-Physical European Roadmap & Strategy

Key questions

CPS have large implications for engineering, society and markets

What are suitable strategies for Europe?

What skills and capabilities are required by the CPS engineers of tomorrow?

Preliminary findings to be presented!

Outline

- Background and motivation
- Approach
- CPS characterization
- Strategies: Preliminary recommendations
- CPS curriculum findings
- Conclusions

Underlying efforts

www.cyphers.eu

A strategic research and innovation agenda for CPS

Support Action
Project reference: 611430
FP7-ICT, area ICT-2013.3.4
Start date: 01-JULY-2013
Duration: 18 months

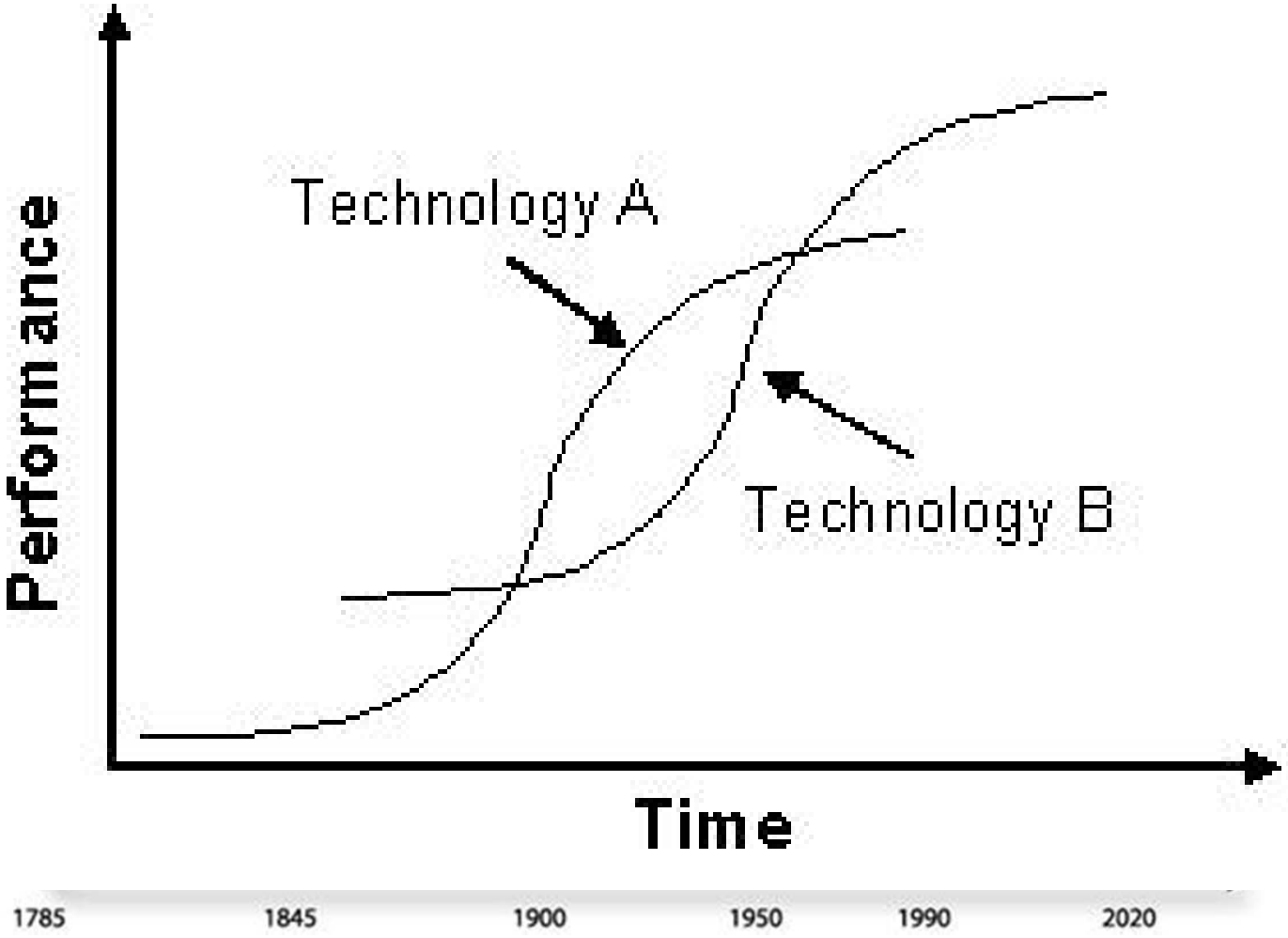
fortiss (Munich)
KTH (Stockholm)
U. Joseph Fourier (Grenoble)
U. Trento
U. York
Siemens (Munich), affiliated partner

EIT ICT Labs, CPS action line:
CPS curriculum and summerschool

KTH, U. Trento, Luleå Univ.

CyPhERS
Cyber-Physical European Roadmap & Strategy

Why (1): CPS – representing a technological paradigm shift



CyPhERS
Cyber-Physical European Roadmap & Strategy

Why (2): Multiple implications of CPS

Technological **Organizational/Business** **Societal**

Push

Software
Networking
Sensors and actuators
Smart components
Packaging/integration
New computing technology
Control methods
Software platforms
Tools
Wireless communication
…

Performance!
Scalability/Sustainability
Risks & costs!
Sustainability!

Theory and Engineering methodology

Design
Integration
Behavior
Architecture
Information
Life-cycle

Societal impact
Legislation
Standards
Education

Management
Competence
Value chain positioning
Business models

Pull

Energy
Transportation
Healthcare
Competitive production
Comfort
Entertainment

CyPhERS
Cyber-Physical European Roadmap & Strategy

Why (3): Impact on engineering education

List of topics:

- Math, statistics
- Electronics, computer architecture
- Compilers, operating systems
- Embedded software
- Optimization
- Models of computation, Formal methods
- Internet and web software, Wireless
- Security and Safety
- Control systems, Systems engineering
- Human machine interaction
- Team work, Project management
- Configuration management
- Process approaches, Life-cycle concerns
- Standards,
- Sustainability, recycling,
- **…**

Expanding set of (interconnected) application domains and societal concerns

Future engineers:

- "4 times during their professional life they will have to re-learn!" (Quote from Petru Eles at ESWeek)

Making the case for young people to go for engineering

CyPhERS
Cyber-Physical European Roadmap & Strategy

Why (4)
- CPS at KTH and in Europe

- New initiatives at KTH
  - Integrated Transport Research Lab
  - Strategic industrial collaborations
  - CPS Engineering lab
- ACCESS, CAS, iPACK and ICES centers
- Evolving engineering programs

KIC's

ECSEL

H2020

CyPhERS Cyber-Physical European Roadmap & Strategy

Approach of CyPhERS

www.cyphers.eu

State of the art

- NIST CPS reports
- PCAST reports
- SoS, CPSoS
- ICTLabs SIA
- H2020
- ARTEMIS SRA
- Industrie 4.0
- ITEA roadmap
- …

Technology assessment

Domain analysis

CPS in the world

Market analysis model

CPS characterization

SWOT analysis

Preliminary recommendations and strategies

Expert workshops and interactions

- CPSWeek 2014
- Stockholm
- Munich
- National meetings
- Feedback

CyPhERS Cyber-Physical European Roadmap & Strategy

Cyber-physical systems (~2006)

- Integration of computation, networking and physical processes where CPS range from minuscule (pace makers) to large-scale (e.g. national power-grid).
- Not new as such from an engineering point of view!
- But
  - Increasing scale, extending to SoS!
  - Products to services
  - New domains and cross domains!
  - From closed to ubiquitous mass-products
  - Never so easy to design, produce and market
  - New threats and risks

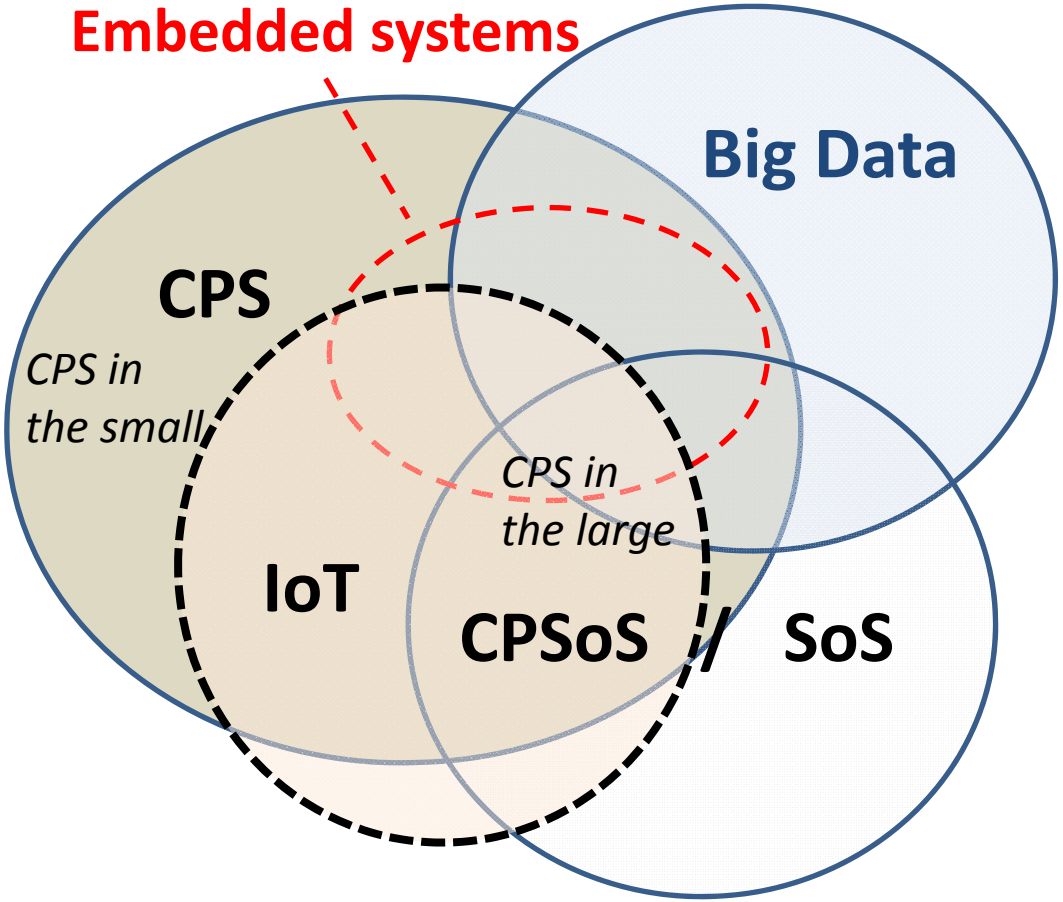
CPS characterization

www.cyphers.eu
Deliverable D2.2

- Deeply Embedded vs. IT Dominated
- Single Domain vs. Cross Domain
- Closed vs. Open
- Degree of Autonomy
- Centralized vs. decentralized organization
- Adaptability
- Human In-/Outside the Loop
- Level of integration

Other non CPS specific characteristics

CPS relation to other concepts



Different perspectives!!

Set sizes are not representative

Building systems out of the underlying technologies!

Trend of increasing overlap!

A strategic research and innovation agenda for CPS – considerations and focus

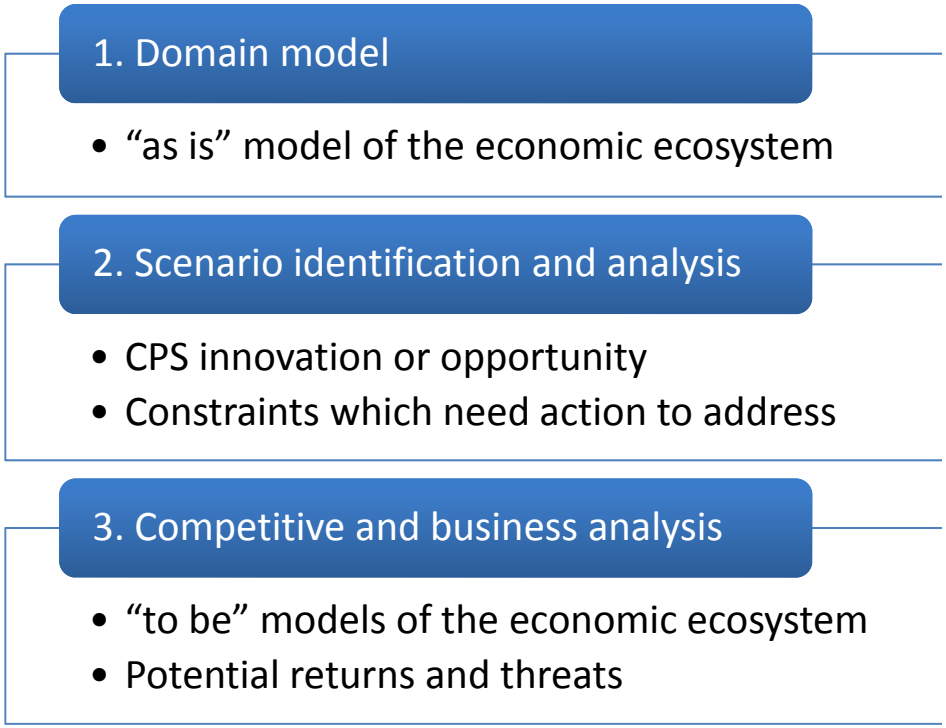
- Directed to funding agencies and policy makers
- Europe's position and SWOT analysis
  - Health, manufacturing, smart grid, smart cities, and transportation
  - Commonalities cross-domains; Domain specific
- Strategies: topics shared across domains
  - Technology
  - Market
  - Societal
  - Programs

Topics shared across domains - Technology

- Security, privacy and safety in conjunction with other CPS properties
- End to end life cycle engineering
  - Requirements management, Model-based engineering, V&V
  - Reference architectures, Platforms
  - Information management,
  - Information interoperability across life-cycle
- Human machine interaction
- Collaborative adaptive systems, machine learning
- Infrastructure as enabler (e.g. broadband)

Topics shared across domains - Market

- Economic impact of the CPS innovation on the ecosystem, and assessment of disruptiveness
- Value chains – and missing pieces
- Market disintermediation
- Products and services positioning
- Business models



CyPhERS Cyber-Physical European Roadmap & Strategy

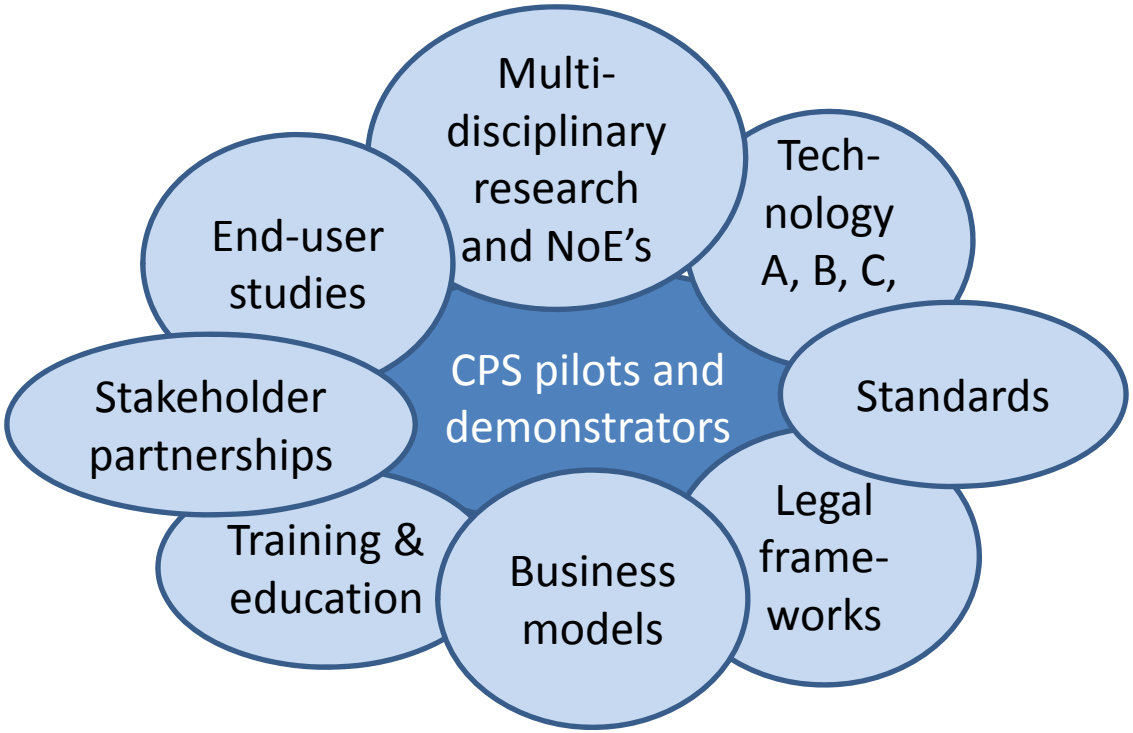
Topics shared across domains – Societal aspects

- Strengthen teaching and training (engineering & beyond)
- Regulatory frameworks - legislation and standards
  - Blocking standards and legislation; Harmonization
- Open distribution of high quality standardized data
- Stakeholder partnerships and concerns
  - Application domain requirements and metrics
  - Include experts on social, urbanisation and business aspects
  - Safety, security and privacy
- Fragility of infrastructure, hazards and lack of understanding

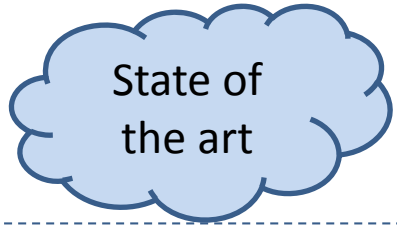
Topics shared across domains - Research and innovation programs

- Programs stimulating cross domain R&I
  - Cross-domain/discipline collaboration schemes
  - NOE's
  - Example gap: embedded systems vs. manufacturing
- Technology / services integration – driven by application domains
- Support and stimulate research & innovation efforts balanced throughout TRL levels
- Harmonization of SRA's and actions by agencies

"Industry as lab" - Getting stakeholders together



Approach of CPS curriculum task



Trends and best practices
Engineering education
CPS education
CPS agendas (CyPhERS)

Didactic analysis

State of the art analysis

Synthesis of curriculum guidelines

Recommendations for further work

- WESE at CPSWeek 2014
- Industrial meetings
- National workshops
- Meetings with leading universities

CyPhERS
Cyber-Physical European Roadmap & Strategy

Trends and best practices analysis (1): Identified CPS strands

- Foundations approach
  - Reconciling the underlying disciplinary theories and finding common, shared, abstractions; e.g. "MOC"s
- Extension approach
  - A particular discipline and curriculum, e.g. in computer science, is extended with complementary courses
  - Bachelor in some basic disciplined followed by a CPS masters
- Project and problem oriented approach

- The approaches are not mutually exclusive

Trends and best practices analysis (2): engineering education,

- CDIO (an old trend)
- ABET (even older trend)
- INCOSE
- MOOCs
- E-Learning
- Design thinking

- Body of knowledge on learning outcomes and recommendations in engineering and technology
- CDIO = Improve engineering fundamentals and creating engineers ready to engineer
- Capstone courses; Design -> Creativity

CyPhERS Cyber-Physical European Roadmap & Strategy

From disciplinary to "Pi-shaped" People and Design Thinking

Cultures;
Disciplines; Systems

- Find the balance between depth and breadth,
- And between analysis and synthesis
- Combine with complementary skills
- Teach experts, with various expertise, able to synergistically work with other experts.

Take aways - Directed, balanced and "modern" CPS education

- Paradigm shift motivates extra efforts for revising programs
  - Increasing space of knowledge and skills!
  - Internet and embedded; Security and safety
- Ready to engineer; Long lasting knowledge; Learn to Learn
- Balances and the concept of synergy:
  - T-shaped engineers: Depth vs. breadth and project skills
  - Academia and industrial collaboration: Combining best practices and Addressing "non-academic skills"
- Need to strengthen conditions for and status of teaching
- Importance of educational platforms

Final take aways

- CyPhERS and CPS curriculum ongoing work with deliveries in February (CyPhERS)
  - Feedback is welcome – this is the right time!
  - http://cyphers.eu/project/D3.2.feedback (market model)
- Technical paradigm shift
  - Technology-Market-Societal implications
  - Addressing cross-domain/discipline-/technology barriers and their integration