# HCPS 系统工程科学理论与方法 ——计算理论和软件方法的角度

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- 1. Concepts
- 2. Research System Engineering Research Foundation and Methods
- 3. Computational Model and Theory of HCPS
- 4. Theory and Methods of Architecture Modelling for HCPS
- 5. Reserach Problems in HCPOS
- 6. Research Problems with the Use of Learning Based Al
- 7. Summary

HCPS Background: CPS and CPS System Enginering Discipline (2006–2010)

### CPS Emerged as a New Form of Engineering Systems

- Networked of Interacting Computing, Communication and Control systems Enabled with
- Open architecture with increasing scale and dynamic plug-and-play
- Human are users

### 2006-10: Cyber-Physical Systems (CPS)

- USA NSF CPS Workshops
- EU InterLink WG Ensemble Engineering
- Integration of Cyber Systems, Equipment & Physical Systems through Network



Networked Embedded/control Systems

# 1. Physical processes with

- sensors and actuators and
- controlled by microprocessors
- 2. Cyber Systems
  - store, process and analysis data and
  - compute control decisions
  - realise the control and coordination of the physical processes
- 3. Networks:
  - Transfers data from sensors and control decisions to the actuators

- System Engineering Emerged from
  - Intersection of Computing, Communication and Control Engineering Disciplines
  - Suport open architecture with increasing scale and dynamic plug-and-play

HCPS Background: CPS<sup>+</sup> and CPS<sup>+</sup> System Engineering Discipline (2010–2015)

# CPS Architecture Extended CPS Horizontally and Vertically

- + Big Data, Cloud Computing, Learning based AI systems for better performance, and
- + Develop value added services to different types of stakeholder
- Human are users

### 2006-10: CPS

- USA NSF CPS Workshops
- EU InterLink WG
- Cyber, Physical & Equipment



Networked Embedded/control Systems

# 2010-15: CPS<sup>+</sup>

- Networked CPSs with BigData and Cloud
- Al empowered services &
- Autonomous systems



Interaction and Collaboration

### 1. BigData + Al

- Value-added services
- Better and intelligent control
- 2. Cloud
  - Solutions to BigData + Al
  - Enable multiple domain interaction & collaboration

3. Open multi-layered systems of CPSs

# System Engineering Emerged from

- Further intersecting with BigData, AI, Cloud Computing, and Ubiquitous Computing Technologies
- Suport open architecture with increasing scale and dynamic plug-and-play

HCPS Background: HCPS and HCPS System Engineering Discipline (2015-)

### HCPS Extends CPS<sup>+</sup>Architecture with

- + Human interacting and collaborating with CPSs in control tasks
- + Control switchs between human and machines
- + Humen interact and collaborate with machines in intelligent environments

2006-10: CPS

- USA NSF CPS Workshops
- EU InterLink WG
- Cyber, Physical & Equipment



Networked Embedded/control Systems

## 2010-15: CPS<sup>+</sup>

- Networked CPSs with BigData and Cloud
- AI empowered Autonomous systems and services



### 2015-: HCPS

- Human in ambient intelligence interacting with CPSs
- AmI -- Ubiquitous Computing & IoT



### System Engineering Emerged from

- Further intersecting with Ubiquitous Computing, Social Computing
- Combination of human and machine intelligence
- Increasing scale and ever evolving, open, multi-layered, autonomous, intelligent

#### General Architecture of HCPS



- The bottom layer: Unit HCPSs
- Second bottom layer: System of Unit HCPSs
- Upper layers: cross-domian systems of HCPSs -- vertically and horizontally open and evolving architecture

### State of the Art

- CSP and HCPS has been one of the most active reserach areas
- Lot of it on case studies and experinces
- Most consider only point solutions of methodology, tools, and models that ease part of the design and anlaysis
- The design technology challenge is to address the entire process
- Systems engineering for HCPS is
  - an interdisciplinary field of engineering and engineering management
  - focuses on how to design, integrate, and manage complex HCPSs over their life cycles
  - deals with issues such as requirements engineering, reliability, verification and validation, maintainability, and many other disciplines
  - ensures successful system design, development, implementation, and ultimate decommission

- System Engineering in general can be decomposed in to
  - a Systems Engineering Technical Process, and
  - a Systems Engineering Management Process
- Development and use of tools and methods for
  - Requirements Engineering, and System architecture,
  - Abstraction, Modeling, Verification and Validation (including Simulation and Testing),
  - System dynamics, and Systems analysis,
  - Statistical and dynamic analysis,
  - Reliability analysis,
  - Optimization, and
  - Decision making

For better comprehension and management of complexity in system development

Reserach in System Engineering Foundation and Methods for HCPS

- Based on, instead of rejecting, the existing approaches, models, and tools
  - Need to develop new modeling approaches
    - to integrating different computing systems, physical systems, human systems, control logic, and implementation architectures, and
    - for innovative combination of the exsiting appraches, models and tools
  - 1. Need to devlop design platforms has to integration the new techniques and to integrate a set of today's poorly interconnected tools
- There seems to have little significant advances in the first, and no such a platform of the second, even for CPS
- We see the essencial and foundemental challenges are related to the lower layer
  - where interactions among human, cyber and physical behviours are most intesive

### Identify Research Problems in Three areas

- 1. Human-Cyber-Phiscal Computational Model and Theory
  - Hunman behviour, control switch between human and machine in OODA loops
- 2. Theory of HCPS architecture modelling, decomposition and refinment
- 3. Theory of programming for HCPS
- 4. Operation systems Methods Software Defined HCPS

# Evolution from HPS through CPS to HCPS



Human和Cyber与Physical

system交互,并共同控制 **Gyloea招望期Physisiala\$ysytstem**。 Physical system。

# Computational Model of HCPS

# Problem: HCP interaction mechanism & switches of control

### Propose to define a model of HCP Automata

- Model human behavior as an Oracle
- Huaman and CPS interaction, in closed loop
- Human intelligence tasks/processes specific

### Develop a HCPS learning framework

- Abstraction and representation H-C-P interaction information
- Timed and probabilistic behavior

# Computability and complexity study

Relative complexity

### **Initial Research Progress**

1. HCPS自动机的定义; 2. 构建满足规约的HCPS学习框架; 3. 无人驾驶案例实验结果符合预期



### Further work needed

- 1. Define and study relative computablity and complexity
- 2. Multi-human oracles
- 3. Compositional verification
- 4. Extensition to Timed and probablistic automata
- 5. Eqivalence between HCPS automata: can a HCPS automon be reduced to a machine leraning model?
- Challenges:
  - 1. Test on realistitic and different applications hard to find collaboration partners and data
  - 2. Automata with different deep learning models and their compositions



- Multi-dimensional and multilevel abstraction
- interfaces contracts of different granularities for information hiding and blackbox integration
- Multi-view & multi-notation modelling
- Based on UTP, Institutions & Hybrid Hoare Logic for linking theories and methods



#### Challenges:

1. compositional refinement and verification;

2. specification and verification of emergent behaviour

- 1. How to extend the classical of "execution units" to include those for physical and human entities?
  - physical and human execution unitis can be movable, need for real-time-space scheduling in the task management
- 2. How to extend the classical model of "tasks" to define phyiscal and human tasks based on the new models of execution units
  - how control flow may move around between ordinary processors and phyiscal & human units?
- 3. How to extend the classical model of "memory" to represent those inactive phyiscal and human entities
  - in order for the processes to access their states, such as colour, temperature, location, speed, etc
  - The information could be any kind of 'physical signal' that is stored electronically, physically or even chemically
- 4. How to extend the abtraction inter-process communication and synchronisation coordination among phyiscal and human processes in real-time time and space
  - E.G. ensure that two physical tasks do not take place at the same location within a period of time
  - Communication of phsical signals among phsical tasks

Source of Challenges: complex heterogeneity of execution units, tasks and memories

- Challenges Related to the Use of Learning Based AI
  - 1. Trustworthy AI: Interpretable AI, controllable AI, verifiable AI, composable AI
  - 2. Specification and decomposition of behviour of combined classical computing and control system together with learning based AI systems
    - specification of controlled state space into subspaces controlled by classical control system and those by learning based AI controllers?
    - extending the state space defined by a classical control model with state space controlled by intelligent control?
- Challenges in Programming HCPS
  - 1. Semantic theories of mixed classical programs (such as C) and deep learning programs
    - could such a program be reduced to a deep learning program?
  - 2. do we need new programming languages and paradigms?
- Al enabled requirements modelling and architecture based system sythesis
  - 1. Al enabled design patterns
  - 2. Component-based AI enabled system synthesis

- Over 15 years after the notion of CPS was proposed
  - 1. It has become one of the mostly active research topic, and very much hyped term
  - 2. Models, methods and tools are attempted for different concrete issues
  - 3. But little fundamental advances in the development of the scientific foundation for HCPS system engineering
- We have identified fundamental research problems
  - 1. computational model and theory
  - 2. Theory of architecture modelling and refinement
  - 3. Programming HCPS
  - 4. Al enabled requirements modelling and architecture based system sythesis
  - 5. HCPOS/Software Defined HCPS