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# Human-cyber-physical systems:

## concepts, challenges, and research opportunities



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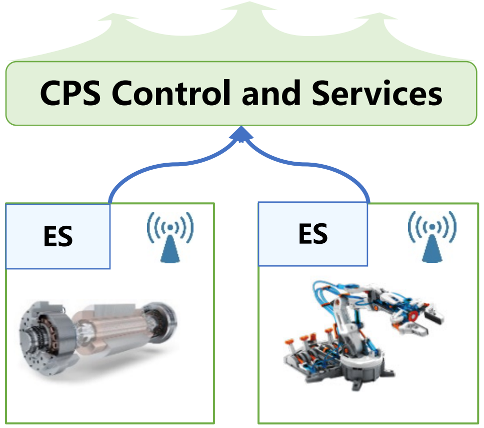
# Concepts: Human-Cyber-Physical Systems (HCPS)

**System Engineering Emerged from**
- **Intersection of Computing, Communication and Control Enabled with**
  - **Big Data, Cloud Computing, IoT and Ubiquitous Computing**
  - **Open architecture with increasing scale and dynamic plug-and-play**

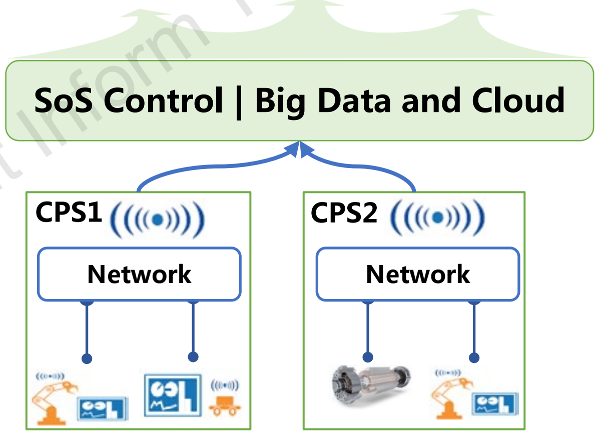
**2006-10: CPS**
- USA NSF CPS Workshops
- EU InterLink WG
- Cyber, Physical & Equipment

**2010-15: CPS+**
- Networked CPSs with Big Data and Cloud
- Autonomous and AI empowered

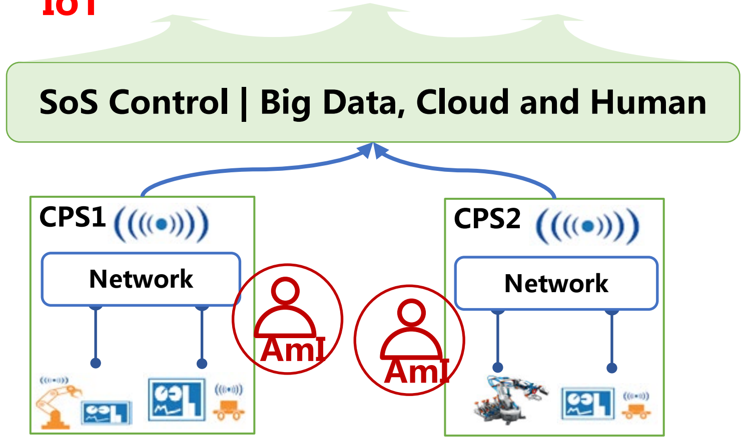
**2015-: HCPS**
- Human in ambient intelligence interacting with CPSs
- AmI - **Ubiquitous [Weiser 1991] & IoT**




Networked Embedded Systems




Cross-Domain CPSs




Ubiquitous HCP Hybrid Intelligent Comp

**Increasing scale and ever evolving, open, multi-layered, autonomous, intelligent**

# Importance and Applications/New Infrastructures

- **HCPS Represents the State of the Art of ICT-Based System Engineering**
- **HCPS is Enabling Technology of New Industry Revolution**

## Industry Internet

- 1st of the 8 priority development areas
- Integrate through network hardware, data, physical equipment to improve the efficiency of the industrial chain

## Industry 4.0

- One of the 10 development programs
- Through CPS for integration of supply, production, sales for their digitisation and intelligent empowerment

## New Infrastructure Development

- Made in China 2025
- New Infrastructures: information, integration, and innovation infrastructure

**Information Infrastructures, Integration Infrastructures & Innovation Infrastructures**

# Clarification Remarks

- There are commonly used concepts
  - IoT, Ubiquitous Computing, Human-Machine Interactions, Ambient Intelligence / Smart Environment, CPS/HCPS
- They are related, but they have different intensions and extensions
  - IoT is mainly for connecting, tracking and identifying "things"
  - Ubiquitous Computing is about collecting and processing sensor data and generating a smart environment – views of "things"
  - CPS, however, is mainly about control and management of the physical worlds – "things"
- HCPS is about the combination of the above
- The above notions are increasingly unified

# Challenges and Research Directions

## Challenges

### 1. Complex heterogeneity
- Heterogeneous resources
- Heterogeneous sub-systems
- Heterogeneous interactions

### 2. Lack of abstractions
- Abstraction of time in cyber systems
- Mismatch of abstractions in computing and physical systems

### 3. Blackbox system integration
- Cyber, human, physical systems
- Different existing hardware and software

### 4. Complex system requirements
- Functionality, performance, safety and security, QoS

## Research Problems

### 1. Theory of HCP Computation
- HCP computational model
- Mechanisms of HCP interactions
- Computability and complexity

### 2. Architecture Modelling and Design
- Unified meta semantic model
- Composition & refinement of contracts model for blackbox integration

### 3. Specification and Verification
- Institutions of specification and verifications
- Tools – model checking, theorem proving

### 4. Software-Defined HCPS
- Hardware & software abstractions
- Programming model
- Specification and programming language
- Model-driven development

# Computational Model of HCP Computation

**Question:** **HCP interaction mechanism & switches of control**

## Propose to define a model of HCP automata

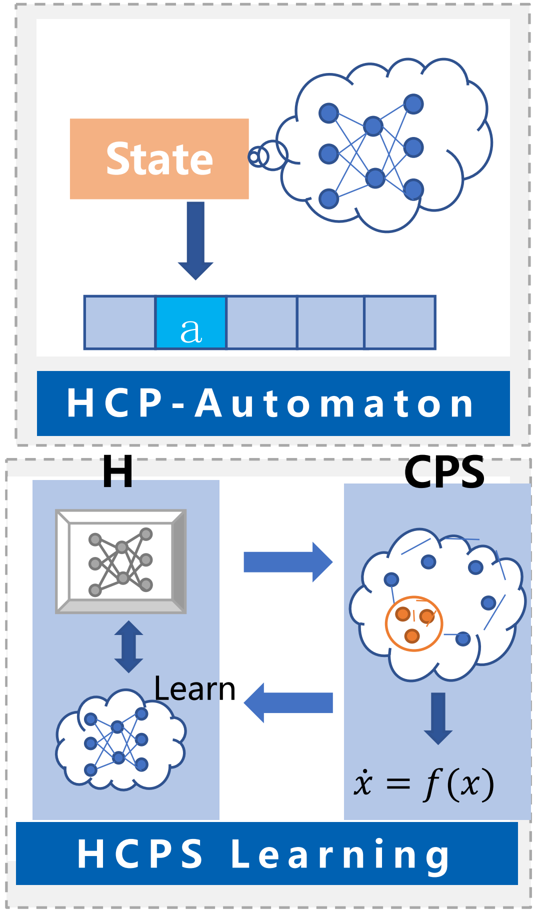
- Model human behavior as an Oracle
- Human and CPS interaction, in a closed loop
- Human intelligence – tasks-/processes-specific

## Develop an HCPS learning framework

- Oracle continuous learning for model refinement
- Abstraction and representation of H-C-P interaction information
- Single- and multi-agent learning algorithms
- Timed and probabilistic behavior

## Computability and complexity study

- Relative complexity



# HCPS Architecture Modelling

**Questions** | **1. Unified meta semantic theory; 2. Model blackbox integration**

## Propose an HCP interface contract model

- Discrete interface operations/events & continuous signals
- Discrete state and continuous state variables
- Static type, interaction type and behaviour type
- Incrementally define timed and probabilistic behaviour

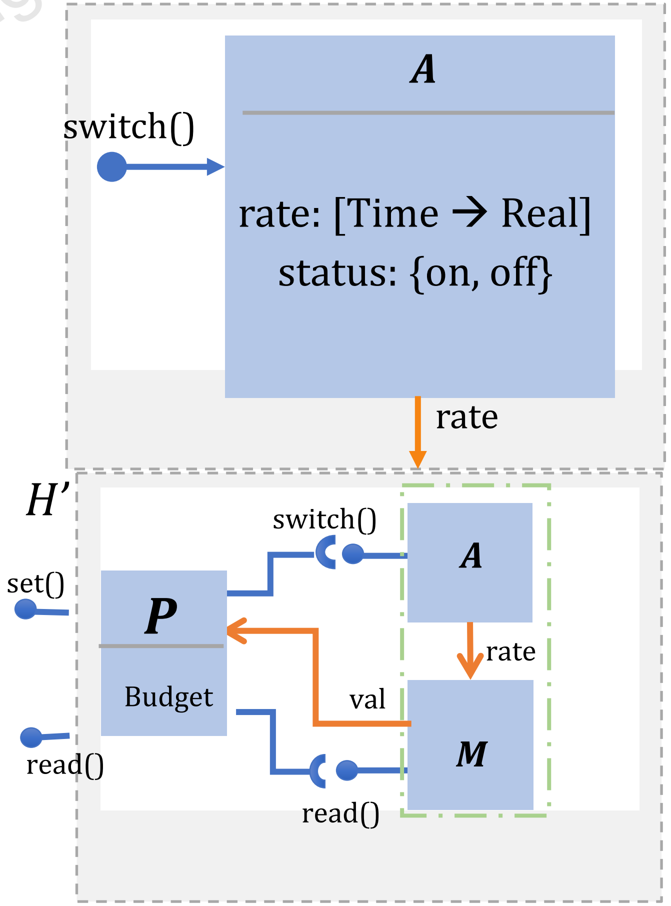
## Define composition and refinement

- Support top-down development & bottom-up integration
- Blackbox integration

## Compositional verification and correct by construction

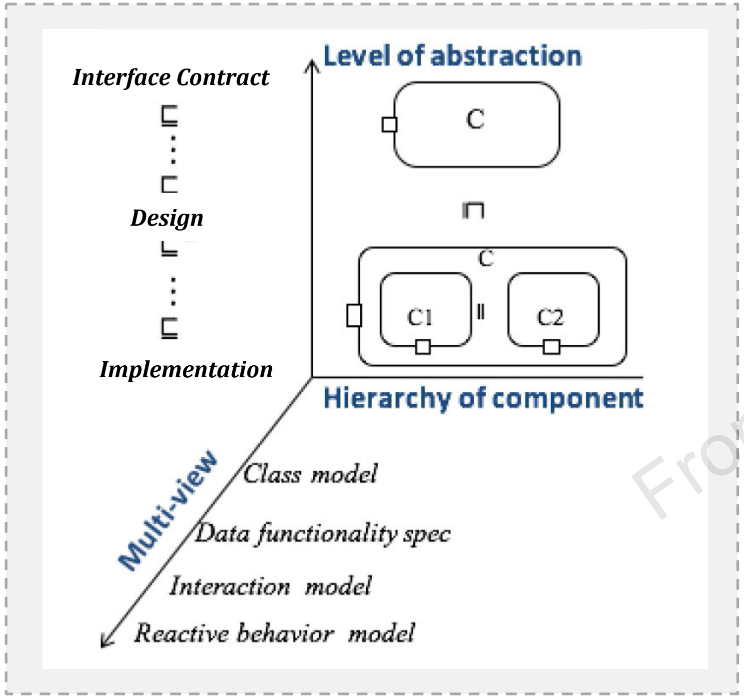
$\because\ P \vDash \phi_1, A \vDash \phi_2, M \vDash \phi_3$

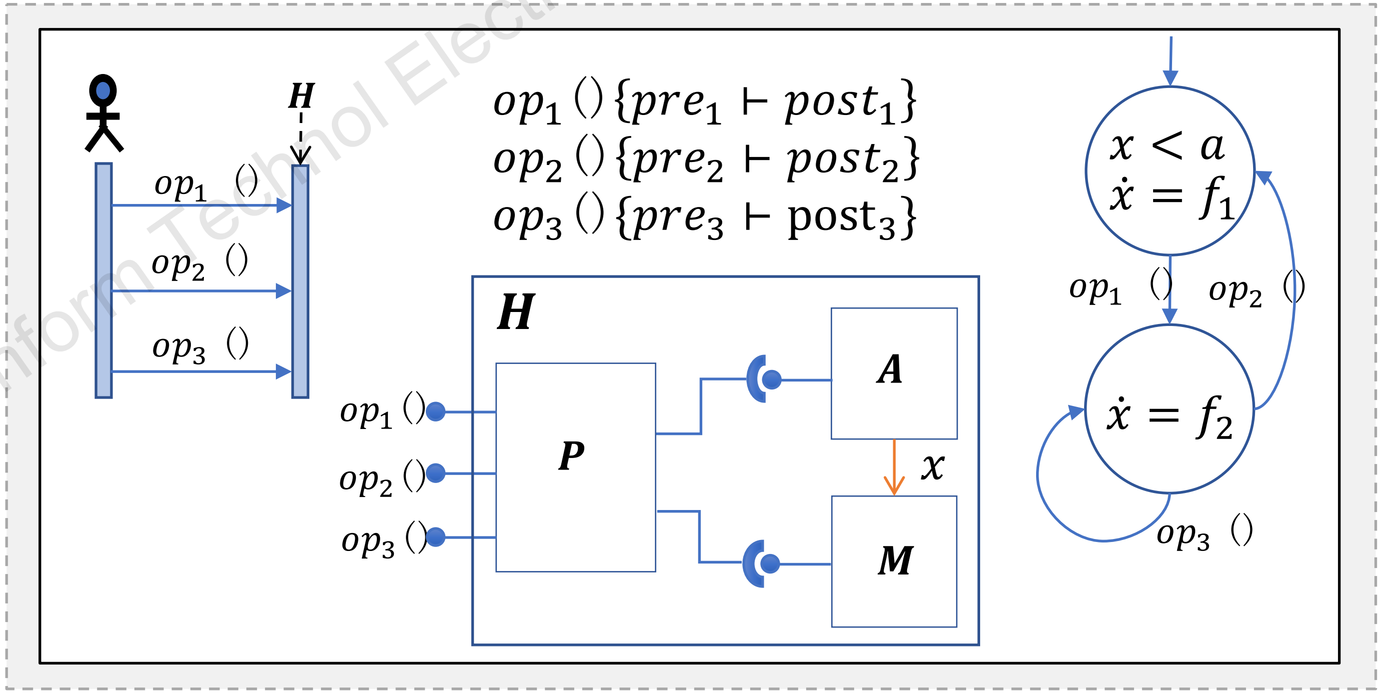
$\therefore H \vDash \phi$



# Required Features of the Modelling Theory

- Multi-dimensional abstraction, interfaces contracts of different granularities
- Information hiding and blackbox integration
- Multi-view & multi-notation modelling




UTP, institutions & rCOS for linking and unifying different syntaxes and semantics

# Software-Defined HCPS

## Principles of Software-Defined Systems

- Through abstractions of hardware and equipment, separate the laws of control from the physical hardware
- Separation use/specification of functionalities resources from their implementations, through APIs
- Higher-level business services and processes are realised through coordination and orchestration of those in the level below
- **The general form of programs in SD systems is APIs + Control Program**

## Well-known SD Paradigms

- Programmable logic controller
- OO programs: ClassDefinitions + Main Program
- Service-based programs: WSDLSpec + BPEL Program
- Workflow programs



## Challenges in SD-HCSP

- Difficult to have uniformed API definitions of heterogeneous resources, human, software, networks, physical processes …
- Hierarchical layered control and management of resources

# Relations Among Three Research Directions

- **HCPS Architecture Modelling aims at a rich semantic model of HCPS architectures**
- **HCPS Architecture Modelling and Design is based on the Theory of HCP Computation**
  - The blackbox semantics of the interfaces HCPS components are defined based on the model of HCP automata
  - The blackbox semantics of HCPS compositions are defined based on the composition of automata
- **These are like how programs are based on automata, distributed software based I/O automata, real-time systems based on timed automata, etc.**

- **The programming model of SD-HCPS is based on the architecture model**
  - Specification and programming language are defined based on the structure and semantics of the HCPS architecture model
  - Semantics of APIs and their compositions are defined based on the interface contracts of HCPS

# Brief Introduction to the Authors

Zhiming LIU received his MS degree in Computing Science from Software Institute of CAS in 1988 and PhD degree in Computer Science from University of Warwick in 1991. He worked in three universities in the UK during 1988–2005 and 2013–2015, and the United Nations University - International Institute for Software Technology (Macau) during 2002–2013. In 2016 he joined Southwest University in Chongqing as a full-time professor, leading the development of the University Centre for Research and Innovation in Software Engineering (RISE). He is an editorial board member of *Frontiers of Information Technology & Electronic Engineering*. He has been working in the area of software theory and methods, and is known for work on transformational approach to fault-tolerant and real-time systems, probabilistic duration calculus for system dependability analysis, and the rCOS method for object-oriented and component-based software.



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