The next generation of Cyber-Physical Systems

Cyber Physical Systems (CPS)s are physical, biological and engineered systems whose operations are monitored, coordinated, controlled and integrated by computing and communication core.

CPSs represent a new technological revolution, they are more than Networking and Information Technology, the Information and Knowledge in action are integrated on physical objects: they are manifested from the nano-world to large-scale wide-area systems of systems and at multiple time-scales. By, integration the most important attributes of intelligence like: perception, communication, learning, planning and behavior generation, reasoning and so on into CPS, we have to develop a new generation of intelligent and autonomous systems.

As computers become ever-faster and communication bandwidth ever-cheaper, computing and communication capabilities will be embedded in all types of objects and structures in the physical environment.

Computation/Information and Knowledge processing and physical processes are so tightly integrated that it is not possible to identify whether behavioral attributes are the result of computations, physical laws or both working together. CPSs allow individual machines to work together to form complex systems that provide new capabilities, make systems safer and more efficient. We believe that the Cyber-Physical systems of tomorrow will far exceed those of today in terms of adaptability, autonomy, efficiency, functionality, safety and usability. New generation of CPSs promise to transform our world with systems that respond more quickly, are more precise, work in dangerous or inaccessible environments, provide large-scale distributed coordination, are highly efficient.

These advanced capabilities will give a new impulse to develop science and technology with real impact on our daily life. These new facilities will be developed by deeply embedding computation intelligence, communication, control, and new mechanisms for sensing, activation and adaptation into physical systems with active and reconfigurable components.

We must develop principles, methodologies and tools to construct this new generation of CPSs, where physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities and interacting with each other in myriad of ways that change with context.

The complexity of current systems, the disparate and incommensurate formalisms and tools used and the limited ability to deal with uncertainty, whether arising from incidental events during operation or induced in systems development, impose the development of cross-cutting fundamental scientific and engineering principles and methodologies that will be required to create the future systems upon which our very lives will depend. The next generation of CPSs will transform how we interact with the physical world just like the internet transformed how we interact with one another. We must develop a better understanding coupling and interaction between computation and physical processes, the integration of the discrete with the continuous and the synchronous with the asynchronous. Rethinking the fundamental concepts and tools for cyber-physical systems will lead to new possibilities and facilities for new systems that cannot be developed or envisioned using today’s methods and technologies.

We need a new complex systems theory, new methodologies to analyze and design adaptive complex systems considering computing capabilities, communication facilities, advanced control strategies and dynamics of physical processes and integrate all of them. Our current technology cannot provide predictability for partially compositional properties, which is a common situation in all large-scale system development.

A new science of Cyber-Physical Systems design will allow us to create new machines with complex dynamics and high reliability and to apply the principles of CPS to new innovative industries.

This new science of CPS will allow us to design systems more economically by sharing both abstract knowledge and concrete tools.

For the creation of this new science and technology of CPS we must have in mind some major challenges:

- Realign abstractions layers in design flows–Computational abstractions must include physical concepts, such as time and energy and abstractions developed for describing physical dynamics should be extended with network delays, finite length and round-off errors. The changes in abstraction layers will allow synthesis of computations with physical properties and physical system dynamics will be robust against uncertainties.

- Develop semantic foundation for comparing heterogeneous models and modeling long describing different physics and logics. A new mathematical framework that makes semantics explicit, understandable and practical for system and tool developers

- Develop new understanding of compositionality in heterogeneous systems taking into account both physical and computational properties. This view will allow to create large, networked systems that satisfy physical properties and desired functionality in a reliable and safe way

- Develop a new technology for achieving predictability in partially compositional properties of CPSs

- A new science and technology foundation for system integration model-based, precise and predictable

- Develop new open architectures for CPSs that will allow us to build national-scale and global-scale capabilities easily adapted to different operational conditions. We need new architectures and tools that allow us to build reliable CPSs from unreliable components.

- We need to create new theories and methods for compositional certification of components and systems into large heterogeneous systems.

The next generation of CPSs will integrate hardware and software designed by integration of dynamical properties of the physical objects and advanced control strategies or even intelligent hybrid methodologies. The change in conception of CPSs will create new architectures of large intelligent cyber-physical systems with new capabilities and improve the quality of production and life.

In this framework, will must develop a workforce with new skills that are adapted to cyber-physical systems where the traditional disciplinary boundaries need to be redefined in all levels of training and education. We must create and develop a new concept of agile design automation of CPSs with integration of concurrent engineering concepts.

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