# Computational Self-awareness: Challenges in Cyber-physical Systems

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Cyber-physical systems (CPS) are spatially-distributed, time-sensitive, and multi-scale networked embedded systems, bringing the physical and the cyber world together through sensors and actuators. Consequently, the actions of CPS often have *physical* effects on us and our environment.

CPS are usually not single individual systems but a composition of various sensors and actuators on individual networked embedded systems. These individual systems come together to interact with each other and with their environment to achieve their own as well as common goals [1]. This gives rise to various technical and scientific challenges that require the CPS to exhibit capabilities in order to deal with those challenges autonomously during runtime. Computational self-awareness is a new paradigm, allowing individual systems to learn and reason about themselves and their environment and consequently overcome some of these challenges [4], [3].

**Heterogeneity:** Embedded systems composing a CPS are often interacting due to their common location and/or their common goals. However, these systems are usually not inherently designed to interact with each other and hence are often completely heterogeneous. This heterogeneity may originate from different sources such as unsynchronised clocks, differing processing power, memory, and capabilities altogether. While this can be of great potential [5], systems need to be aware of their own possible differences towards one another. Otherwise exchanged information between interacting systems may not reflect the same state of the environment or themselves. This can be due to a difference in local clocks affecting the time-stamp of acquired information, different granularity in sensing, or diverging internal models of the world, to name just few. In optimal cases, at least one embedded systems of an interacting pair is able to adapt to another system in order to achieve a meaningful result in their interaction. While this might not always be possible, systems have to be at least able to communicate and identify their differences and interpret received information accordingly. In any other case, interaction between systems might be counter-productive.

**Uncertainty:** The dynamic environment brings about constant uncertainty which the CPS has to deal with. On one hand, the CPS may not be able to cover the entirety of the environment and has to make certain assumptions about it. Whether this is at the spatial domain, due to sparsely distributed sensors, at the time domain, when a sensor misses an event, or at the granularity domain, where the sensor is simply not sensitive enough or the event to large for the sensor to detect. On the other hand, this might also be accounted for by the constantly ongoing dynamics of the environment. Events that are not expected and situations that have not been experienced before may occur at any time. While self-aware capabilities are not able to neutralise uncertainty, they need to support the system in identifying and handling potential uncertainties by adjusting the sensors and actuators accordingly. Additionally, appropriate adaptation of used models and developing new ones at runtime allow to represent the dynamic environment and novel information.

**Autonomy:** Future CPS inevitably require individual embedded systems to feature some kind of autonomy. Having a huge number of systems in the near future requires approaches which allow the individual devices to operate autonomously without the interaction of an operator. These capabilities include self-localisation, self-organisation, self-configuration, self-healing, self-adaptation, and self-optimisation. While an individual device may only have very limited abilities, in combination with other devices the entire CPS is expected to exhibit a more rational behaviour. The heterogeneous mix of abilities allows to cope with different problems and select the most appropriate ones for the given situation without wasting valuable resources [2].

In order to overcome the challenges to exploit the potential of heterogeneity, overcome the inherent uncertainty of the environment, and collaborate in a meaningful way autonomously, individual embedded systems within a CPS need to become aware of their own resources and capabilities, the immediate environment, and other systems to cooperate with. Computational self-awareness will be a key element to achieve this.

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