Self-awareness and Decision-taking in Socio-Cyber-Physical Systems
An Architectural Perspective

Ada Diaconescu, Télécom ParisTech, LTCI, FR **Jeremy Pitt, Imperial College London, UK**

This research aims to investigate the following question, from an architectural perspective: what *knowledge* is necessary for taking *decisions* that impact both i) the local goals of a particular sub-system; and ii) the coordination among sub-systems for reaching global system goals? In other words, what is the necessary self-awareness level and scope for taking a decision (optimally or satisfactorily), both locally and globally?

For instance, when is local knowledge sufficient to take local decisions? or, when does global system knowledge help optimise and coordinate local decisions? Does global knowledge suffice for taking global decisions impacting all sub-systems? Should global decisions constrain local decisions, or should they represent mere global indicators, or recommendations, when taking local decisions? These are architectural questions impacting large-scale cyber-physical systems, which are necessarily poly-centric in terms of awareness and control. Identifying the best solution for each kind of system is a key research problem, in our view.

There are two key considerations differentiating global and local knowledge. Firstly, system *scale* imposes that global knowledge of an entire system is *less detailed* than the local knowledge about each sub-system. This is because any system's resources are limited. Secondly (especially in social systems), global knowledge relies on collecting local knowledge encoded in some representation; rather than on first-hand experience, or perception. This incurs additional information loss since no representation, and no communication, is perfect.

Hence, there is lack of knowledge at both levels: the local level has the details but only on a limited scope; the global level has the overall view but no details. The key question is, *what is the best trade-off between knowledge scope and knowledge detail, when it comes to various decision types*? And following up from that, in which cases should global decisions override local ones, e.g., to help coordinate sub-systems, and to ensure overall coherence and optimisation? And, in which cases should global decisions be mere guidelines for local optimisation and decentralised coordination among sub-systems?

For instance, in social insect colonies (e.g. ants) individuals take local decisions based on their own knowledge and on some aggregate knowledge stored in the local environment (e.g. pheromone traces); there is *no* master decision taker that uses the global knowledge only. Similarly, within single organisms (e.g. humans), central control (central nervous system) may take global decisions based on global knowledge (e.g. where to go next), but some sub-systems cannot be directly controlled by such decisions (e.g. one can hardly stop their endocrine system from secreting a hormone just by thinking about it). Still, in most human organisations, global decisions constrain, or override, local decisions (e.g. a federal government's decree overrides provincial laws; global trade agreements constrain local markets). Indeed, while global knowledge and decisions help coordination and global coherence, they may also overlook key local details, hence imposing unsustainable conditions at the sub-system level. This may in turn jeopardise the stability and sustainability of the entire system.

While the "big picture" vs. "fine details" dichotomy is generally not new, our focus is on the architectural issues in terms of the distribution of knowledge and decision centres and of their interrelations. These questions are both timely and highly relevant for cyber-physical systems, most of which are actually *socio*-cyber-physical systems – e.g. smart homes, buildings, cities, vehicular networks and electric grids. Importantly, the autonomic control of such systems may be seen as a purely technical issue, yet the choice of management policies for such autonomic controllers are rather social or political issues (e.g. in a smart grid, should surplus energy production be distributed equally among consumers, or depending on the criticality of their demands, or based on a bidding process?). Since most cyber-physical systems are large-scale and/or connected to other cyber-physical systems, leading to ever larger-scales, seriously considering the distribution and authority interrelation among decision and knowledge management centres becomes rather urgent.