On some theoretical issues of interaction with socialized and personalized cyber-physical systems

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Abstract: The paradigm of cyber-physical systems (CPSs) is changing in our days. While a decade ago they were regarded as technical systems, they are now intellectualized as socially deeply embedded and behaviorally personalized systems. This has influence on the manifestations of CPSs and on the interaction with these systems. First, the paper casts light on the drivers of the development of social-cyber-physical systems. Then, it investigates the influence of socialization and personalization of cyber-physical systems on interaction. The last part of the paper looks into theoretical issues of interaction, such as coping with the interaction profile of cyber-physical systems, combining the intellectual domains of interaction, and interaction on various intentional levels.

1 Introduction: Seeing the big picture with the mind

Beginning at the end of the 1700s, the ‘first industrial revolution’ mechanized the industrial creation processes by using water and thermal energies. The ‘second industrial revolution’, which commenced at the beginning of the 1900s, exploited fossil and electric energies in production and transportation processes, and led to a widespread use of electromechanical systems in many application fields. Starting at the beginning of the 1950s, the ‘third industrial revolution’ introduced electronics in industrialized processes and fostered the proliferation of automation. The ‘fourth industrial revolution’ which was triggered by the emergence of digital computing and technologies at the midst of 1980s, introduced the use of computing in everyday working and living processes, and made the human societies information and service orientated. The change caused by the ever-growing large-scale application and sophistication of digital computing is often called ‘intelligence revolution’.

Gradually replacing the work performed by human brain with work by machine brain and knowledge, the intelligence revolution has been made possible by the evolution of advanced computing and networking paradigms and technologies. As shown in Figure 1, there have been four significant shifts in the paradigm of digital computing in the last 60 years. The currently manifested paradigm, cyber-physical computing, is still differently interpreted by various research communities and has for this reason multiple different definitions. However, there seems to be an agreement on that cyber-physical systems

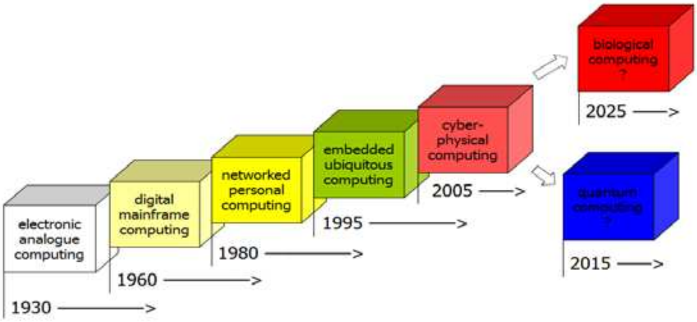


Figure 1: Shifting paradigms of computing

(CPSs) are confluences of knowledge and technologies of computing and informing, and knowledge and technologies of physical artefacts and engineered systems towards situated intelligent operation and servicing as actors in human and social contexts. There is a synergic relationship between the physical constituents and the cyber constituents of CPSs, and they are typically deeply embedded in their surrounding environments.

What the above overview indicates is that there is a continuous increase in the functional and structural complexities of engineered systems over time. The complexity of current large-scale CPSs (e.g., Internet) approaches the level of complexity of natural systems and thus they perform some sort of 'self-behavior' and evolution. Together with complexity, their heterogeneity is also increasing due to the number and interconnections of the involved material, energy and information flows and transformations [HE96]. The boundaries of complex systems are getting blurred, whereas the number and kinds of relationships that they have with other systems and their environments are non-linearly increasing. It has been argued by various complexity theories that complexity lends itself to emergence, dynamics, non-linearity and other forms of behavior that are not present in the constituents. In addition, CPSs are getting more socialized and personalized, therefore they raise new challenges for interoperation, interaction and interfacing, no matter if other systems, human individuals, or communities are concerned [BS14].

2 The influence of socialization and personalization of cyber-physical systems on interaction

The classical definitions of technical systems are not able to capture the essence of current complex engineered systems. The paradigm of CPSs goes beyond the paradigm of technical systems. The main constituents of CPSs are categorized as: (i) analogue hardware, (ii) digital hardware, (iii) control software, (iv) application software, (v) alphanumeric dataware, and (vi) semantic knowledgeware. Their major functions can be categorized as: (i) interfacing, (ii) sensing, (iii) searching, (iv) communication, (v) networking, (vi) computation, (vii) reasoning, (viii) conversion, (ix) control, (x) powering, and (xi) actuation. CPSs achieve a much higher integration and synergy of hardware, software and knowledgeware functionalities, technologies and components than any other type of systems ever before. Many CPSs are distributed and tightly

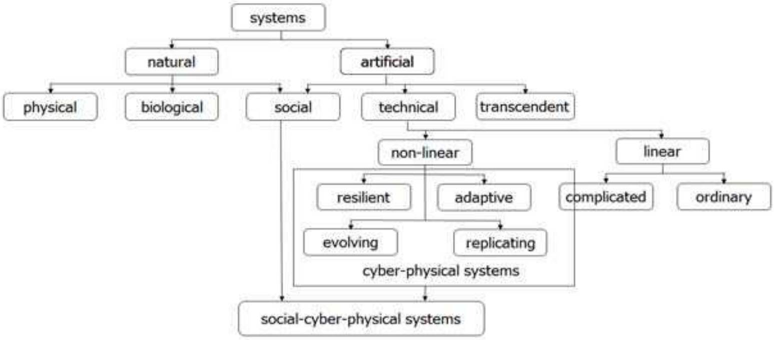


Figure 2: The position of SCPSs on the landscape of systems

interacting with the natural and engineered environments, but also penetrating into the cognitive domains of humans, and strongly influencing their social life and business.

It seems in these days that the recently emerged paradigm of CPSs is already going through a metamorphosis. Driven by the strive for system characteristics such as non-composite, openness, intelligence, autonomy, agency, resilience, adaptability, evolution and replication, the technology-driven system paradigm of CPSs is gradually transformed into a system paradigm that implies socially deeply embedded, cognitively aware, environment conscious, and partially autonomous systems. Therefore, we have proposed to consider future CPSs as social-cyber-physical systems (SCPSs) [HO13]. Figure 2 shows the position of SCPSs on the landscape of systems. Obviously, we still need to work out the knowledge that facilitates their proper intellectualization, design, implementation and application. We also need to develop those design and implementation principles that guarantee interoperation and interaction with these systems, which fulfil a kind of problem solving actor role, as opposed to the Internet of Things systems, which primarily play the role of infrastructural platforms.

When applied to living organisms, the term social refers to a set of characteristics of populations of humans or animals. It regards the interaction of organisms with other organisms and their collective co-existence, irrespective of whether they are aware of it or not, and irrespective of whether the interaction is voluntary or involuntary. In the context of cyber-physical systems, socialization means that they become able to establish

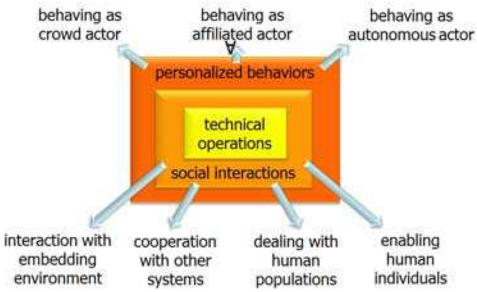
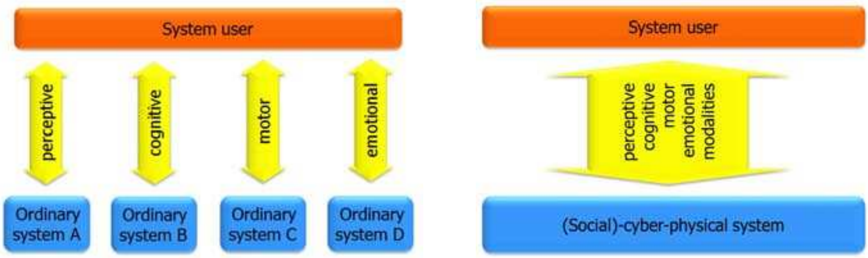


Figure 3: Dimensions of interactions and behaviors of current CPSs

an extensive range of non-technical relationships. As indicated in Figure 3, these relationships extend to: (i) the connections with natural and engineered environments, (ii) cooperation with other engineered systems, (iii) dealing with human populations in social contexts, and (iv) enabling humans by penetrating into their intellectual domains. Socialization also involves the increase of context awareness and the enhancement of social problem solving capabilities of SCPSs. Personalization means that the behavior of the system as a whole, or the constituents of it, will resemble the behavior of some natural agents [ZL96]. This natural agent-like operation can be achieved by designing system actors that are capable to behave as: (i) one of the actors in a crowd, (ii) affiliated individual actor, or (iii) fully autonomous actors. We are rapidly moving towards the situation when synthetic actors (agents) will be trusted near-peer teammates in SCPSs.

3 Some theoretical issues of interaction with socialized and personalized cyber-physical systems

The interaction profile of cyber-physical systems is rather complex. Not only human-system interactions, but also system-system interactions should be considered concurrently. The interaction can be looked at from perspectives such as the modality of interaction and the objective of interaction. It is well known that interaction with systems can in principle happen in four intellectual domains of humans, namely, in the motor, perceptive, cognitive and emotional domains. In case of interaction with conventional systems, we can typically identify a dominant modality (domain of interaction), which is accompanied by certain activities in the other domains (Figure 4.a). For instance, watching at a photo viewer (ordinary system A) is dominantly a perceptive interaction, but switching the device on or activating the software includes elements of both cognitive and motor interaction. Playing a computer game (ordinary system B) is based on a dominant cognitive interaction, but operating the game console needs motor interaction, viewing the game visuals needs perceptive interaction, and solving a Sudoku game needs cognitive interaction [GM05]. Steering and speeding a car (ordinary system C) is based on motor interaction that, however, is interwoven with perceptive and cognitive interactions. As a last example, being proud of the brand of a smartphone (ordinary system D) has effects on both the frequency and the way of using it (motor interaction), which in turn has effects on the perceptive and cognitive interaction.



a b

Figure 4: Interaction: (a) with ordinary systems, (b) social-cyber-physical systems

However, in the case of a social-cyber-physical system, interaction in the four domains is usually needed simultaneously and in a well-balanced manner. As an example, let us think of a cyber-physical stroke rehabilitation system. In this case, the physical rehabilitation involves motor interaction with various rehabilitation devices, such as assistive robotics-based exoskeletons. In combination with this, various cognitive exercises are also conducted in order to regenerate or enhance the mental capabilities of the patient based on dedicated cognitive interactions. In addition, various perceptive treatment exercises, including e.g. visual, audio, tactile interaction, are enforced in order to regain or enhance the lost perceptive capabilities of the patient. Simultaneously with these, the long term and short term engagement and motivation of the patient are triggered and maintained by emotion stimulating exercises and interaction. As indicated in Figure 4.b, these modalities blends into a hybrid interaction modality, the support of which is not easy and is still in its infancy.

Another issue is the level of interaction that is needed and can be realized between actors. Based on the information theory of Gitt, W., five levels of interaction can be identified [GI09]. As shown in Figure 5, low level interaction can be based on statistical or syntactic processing actions. On statistical level, physical signals and distribution patterns, while on syntactic level grammar and codes are the mediators of interaction. These make transportation and presentation of (physical) effects possible, but interpretation should be involved if comprehension of the meaning of the actions and communications plays a role in the interaction. It can be assumed that the actor is always pursuing a goal. While on semantic level it is achieving a shared meaning, on the pragmatic level of interaction the goal is the expected completion, and the concern is the way of executing the intended actions. Finally, on the level of apobetics, the intended purpose, the achievement of results, and the raised reflections are the concern of interaction. In other words, the latter means that if apobetic interaction is targeted, then the desired success and the objective of satisfaction should also be planned or designed.

We immediately face an inherent complexity if we combine the modalities/domains of interaction (motor, perceptive, cognitive or emotional) with the objectives of interaction (syntactic, semantic, pragmatic or apobetic), since each modality/domain can in principle be combined with each of the objectives shown on the right side of Figure 5. Current literature does not explain how these objectives can be considered and realized in the

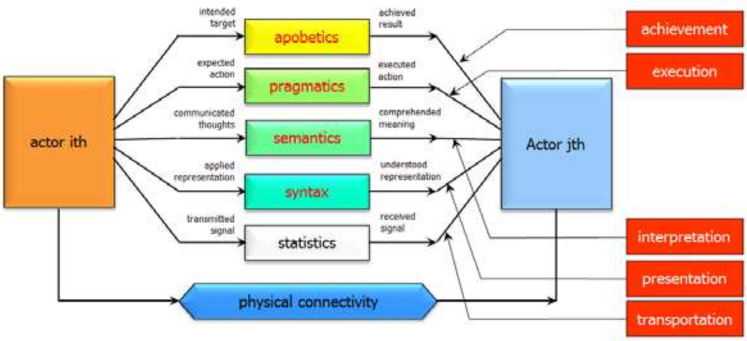


Figure 5: Levels of interaction between humans, agents and systems

case of the various modalities. Further research is needed in order to understand how the objectives can be realized in the case of a hybrid-modality-demanding interaction.

Interaction with behaviorally non-linear systems is another theoretical issue with significant implications on practical solutions. Resilient complex systems adjust and optimize their dominantly non-linear behavior to varying operational conditions without functional or structural adaptation. Adaptive complex systems change their structure, functionality and behavior at run-time as a response to changing objectives, environments and contexts that are unknown at design-time. In response to their perception of the environment and the systems themselves, evolving complex systems develop new configuration, functionality and behavior incrementally at run-time towards changed objectives or new opportunities based on learning. Replicating complex systems reproduce themselves in alternative manifestations based on system and environmental resources and according to non-evolutionary reproduction plans. The main challenge in the case of these systems arises from the fact that their long term operation cannot be exhaustively forecasted, and this causes indeterminism and uncertainties in designing the interactions. In addition, other practical issues can emerge due to the distributed and decentralized nature of SCPSs and from the fact that the zone of interaction between the system boundary and the environment boundary may be blurred and highly permeable.

Conclusions

In addition to addressing the role of complexity in the context of CPSs, the objective of this paper was to bring socialization and personalization of these systems in the focus, and to address some theoretical issues of interaction that need further attention in research and development. As theoretical issues: (i) the interaction profile, (ii) the multitude of interaction modalities, (iii) the intended objectives/levels of interaction, and (iv) the non-linear system behavioral were addressed with the goal of fostering further empirical research based on various SCPSs case studies and application contexts.

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