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Towards Hybrid and Diversity-Aware Collective Adaptive Systems

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Abstract. The physical and virtual dimensions of life are becoming more and more deeply interwoven. Society is merging with technology, giving rise to a global socio-technical ecosystem. In a society comprising people and machines as actors we often see people-to-people interactions mediated by machine and machine-to-machine interaction mediated by people. The speed and scale of this change and the differences in culture, language and interests make the problem of establishing effective means of communication and coordination increasingly challenging. Our vision, embodied in the *SmartSociety* project[1], is that a new generation of systems, hybrid (i.e., including humans and artificial peers, as well as social groups), distributed, open and large-scale, is needed to tackle these issues. In such systems, multitudes of heterogeneous peers will produce and handle massive amounts of data; peers will join/leave the system following unpredictable patterns with no central coordination and will interoperate at different spatial and temporal scales. Aware of the ethical issues, and by identifying the right incentive schemes and privacy levels, these systems will assist individuals and collectives in their everyday activities, coping with the diversity of the world and working in the presence of incomplete and incorrect information.

The vision

Research in collective adaptive systems (CAS) [1] has mostly focused on providing or imposing some form of harmonization or lightweight coordination of meaning and actions, where machines do most of the computation and humans mostly act as service/data consumers. Even systems that involve so-called *human-based computation*, and in which human intelligence [2] is used to execute computational tasks, are usually handcrafted to satisfy a specific application objective and lack a solid engineering design methodology. In these settings, collectives are generally homogeneous and are orchestrated to achieve a common global goal with limited or no knowledge adaptation. Our goal is to move towards a *hybrid* system, where people and machines work together tightly to build a smarter society. In these systems humans and machines *compose* to synergistically complement each other, thus bridging the semantic gap between the low-level machine interpretation of data and the high-level human one. In particular human capacity to make sense of the open-ended nature of context and its role human understanding plays a key bridging role here. In such systems, humans and technologies interoperate collectively to achieve their possibly conflicting goals at individual, organizational and societal levels. This approach is based on the assumption that there are tasks humans are better than machines at [6]. For instance, while machines are very effective in computational tasks, they cannot compete with humans in creativity, making judgments, expressing subjective opinions, abstract thinking and scientific reasoning. Operationally, peers in the system will implement a continuous unbounded cycle in which data is sensed, interpreted, shared, elaborated and acted upon. Actions are taken on the basis of system suggestions and the way humans react to them. Actions generate new data, thus driving the adaptation and evolution of the system. By overcoming current limitations of CAS in terms of quantity and heterogeneity of agents and data that can be managed, these systems offer the ability to *scale up* to the Internet scale. While massive-scale current Web systems (e.g., Google, Facebook) are already managing global user communities of hundreds of millions of users, they are only able to support only rather 'crude' machine-human interactions, such as data entry, search, and offline data analysis. They are instead unable to combine heterogeneous complex interactions in an adaptive, diversity-aware fashion.

[1] http://www.smart-society-project.eu/

An application scenario – beyond Smart Cities

In order to alleviate traffic jams and pollution in cities we could envision a system in which pervasive sensors continuously monitor, elaborate and record data about traffic conditions and air quality levels. Each driver has (local, personal) objectives that could include journey time, journey cost, environmental impact, pleasure in the trip etc. While policy makers - given precise national directives - have the (global) goal to guarantee a certain level of air quality as well as the non-functional requirement to make citizens, including drivers, happy. Using the drivers' history of responses to situations, hybrid algorithms involving humans and machines have understood the driving population's response to situations and how their driving behaviour responds to incentives (e.g. free refreshment at the next service station, a change in road pricing, new cost estimate of the trip, a faster route given the blockage etc.).
From the analysis of sensor data, machines can "understand" (from low-level analysis) that a critical traffic situation has arisen. This initiates a hybrid computation that calculates the best incentives to offer different strata in the driving population in order to align driver behaviour with global policy objectives. This computation might involve polling of a "pilot population" or expert decisions, or econometric simulations in some combination. Once users receive the notification, they may communicate further to the system providing high-level interpretation that allows refinement of the incentive offers. As the incident proceeds the CAS can adjust incentive offers depending on the driver response. Citizens will be notified through their mobile phones so they can: avoid areas presenting high pollution levels, avoid presenting at accident and emergency units with minor problems, give blood for specific rare groups and so on. Incentives will be given to appropriate target groups depending on their needs and expectations. People can ignore such suggestions and decide autonomously on what they believe is best for them. The system will be flexible enough to react in real time by recording decisions taken by users (data produced by actions) in order to recalibrate incentives offered to citizens.

Key notions and research agenda

The hybrid systems we envision in SmartSociety will be based on the core ideas of *compositionality* and *diversity*:

- **Compositionality**: humans and machines cooperate seamlessly by leveraging their respective strengths. People produce and manipulate their data by providing individual/local implicit or explicit semantics. Machines *compose* and adapt to people because they learn from people and in turn help them to achieve their local and global goals. This does not necessarily mean that these systems are able to reach global consensus (in terms of semantics and action), but they rather aim to offer the ability to interoperate by means of emerging *good enough social semantics* and collective (not necessarily collaborative) action by means of *good enough coordination*. These systems adapt their behaviour continually - evolving to meet the needs of the diverse society they are embedded in.
- **Diversity**: the ability to cope with the heterogeneity of agents, roles, possibly conflicting goals, data sources, language and semantics [3]. This requires effective design to support diversity-aware data and operation profiling, data and knowledge representation schemes, and interaction strategies.

Reaching this ambitious goal requires interdisciplinarity. Ethics is fundamental to the governance of smart societies and the definition of their design principles, including novel techniques for ensuring privacy by design in their application. Data and knowledge representation and human computer interaction are fundamental in determining the underlying diversity-aware data model and the mechanisms supporting the incremental construction of the shared semantics as well as achieving interoperability between peers. Agent systems will have to focus on reasoning and decision making about interaction situations [4] and be able to make *good enough* decisions fast, and support methods to combine human and machine computation [5]. ICT in general is fundamental for the development of the infrastructure supporting the overall system.

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