Toward Sociotechnical Urban Superorganisms

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Sooner or later, we'll all become part of an urban superorganism, putting our ICT devices and unique human capabilities to use for the good of both ourselves and society.

In recent years, researchers have made considerable progress in the areas of mobile and ubiquitous computing. At the same time, a wide range of smart portable sensing and actuating ICT devices, especially smartphones, have penetrated both the consumer and industrial markets.

These developments are paving the way for innovative services to perceive detailed information about the surrounding physical and social world (A. Schmidt, M. Langheinrich, and K. Kersting, "Perception beyond the Here and Now," *Computer,* Feb. 2011, pp. 86-88) and interact with it (M. Conti et al., "Looking Ahead in Pervasive Computing: Challenges and Opportunities in the Era of Cyber-Physical Convergence," *Pervasive and Mobile Computing*, Feb. 2012, pp. 2-21).

In addition, new technologies are emerging to engage large numbers of people in location-based collaborative activities to solve problems, via crowdsourcing, or simply to socialize, as in flash mobs and mobile gaming (F. Zambonelli, "Pervasive Urban Crowdsourcing: Visions and Challenges," *Proc. 2011 Int'l Conf. PerCom Workshops*, IEEE, 2011, pp. 578-583).

The confluence of these trends promises to radically transform the nature of cities and how we live in them. As Table 1 shows, human sensing, computing, and actuating capabilities complement ICT devices' capabilities. This makes it beneficial to integrate humans and ICT devices into a single infrastructure, letting them work in an orchestrated and adaptive way toward specific urban-level goals—much like the organisms of a superorganism.

FROM BIOLOGICAL TO SOCIOTECHNICAL SUPERORGANISMS

A group of organisms forms a superorganism when it exhibits intelligent and adaptive collective behavior. The emergence of a superorganism typically involves putting individual sensing, cognitive, and actuating capabilities at the service of the group and closing them in a feedback loop.

The classic examples of biological superorganisms are colonies of social insects such as ants, honeybees, and termites (B. Hölldobler and E.O. Wilson, *The Superorganism: The Beauty, Elegance, and Strangeness of Insect Societies,* W.W. Norton, 2009). For example, a single ant has very limited and local sensing and actuating capabilities, and little or no cognitive capability. Yet, ants can indirectly coordinate their movements by spreading and detecting pheromones, and in so doing they collectively display powerful sensing (finding food in the environment), computing (finding the shortest path from the food back to the nest), and actuating (carrying large amounts of food to the nest) capabilities. These capabilities make the overall colony behave in a seemingly intelligent and highly adaptive way in its foraging activities.

In future urban environments, networks of sociotechnical entities—ICT devices and citizens—will continu-

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ously and perhaps invisibly cooperate in highly decentralized and participatory sensing activities. The real-time sharing of the results of such activities at city scale will enable a shared understanding, via computing and thinking, of urban issues and their dynamics. This in turn will make it possible to plan and direct responses or fix problems with specific collective actions, as Figure 1 shows.

A CHANGING URBAN EXPERIENCE

Urban superorganisms' features likely will first emerge in the area of mobility control, drawing on the extensive infrastructure already in place.

Video cameras, motion detectors, and other sensors are widely deployed in many cities to monitor vehicular and pedestrian traffic. In addition, many urban dwellers have GPS-enabled smartphones, tablets, and in-car navigation systems that could be used to easily track their location and those of their vehicles, as well as to detect the overall density of people and vehicles. Users could also contribute to sensing activities by posting additional information about surrounding events on social networks.

All of this information could be exploited to improve traffic flow or help people avoid crowds in city regions. In-car navigation systems, digital traffic lights, and digital signage could form an integrated traffic control system, while public displays as well as smartphones could deliver directions to pedestrians. In addition to dramatically reducing the stress and danger of urban mobility, such actions could induce a paradigm change from sensing mobility patterns and adapting services to them, to planning services and adapting mobility patterns accordingly.

A future urban superorganism could also improve energy awareness and efficiency. Real-time sensing of energy consumption data—gathered through various sensing devices—could enable on-the-fly computing of carbon footprints at different levels of granularity. Large public displays as well as smartphones and other personal devices could convey this information to citizens, perhaps with individual contributing factors, to provide immediate feedback on the effects of their own behaviors, and thus motivate individuals as well as the community at large to follow greener practices.

The same sensing-understanding-acting dynamic could also help make cities safer and cleaner. For example, if a camera mounted on a traffic light detects a child having trouble crossing a busy intersection, nearby citizens could be alerted via their handheld devices to lend a hand. Likewise, waste management services could be notified about litter observed on the street.

However, the promise of urban superorganisms goes beyond the facilitation of measurably useful objectives. In fact, by providing feedback on all the ways we relate to our environment and one another, urban superorganisms could make city life more pleasant and rewarding as well as promote stronger citizenship—qualities that traditional metrics cannot capture.

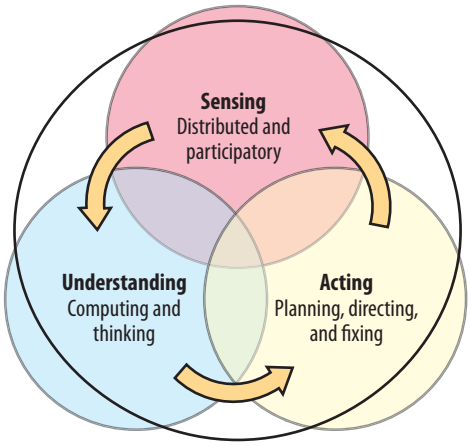

Figure 1. Conceptual structure of urban superorganisms. Intelligent, coordinated responses to city-scale problems emerge from a closed feedback loop involving collective sensing activities, understanding and sharing of ideas, and collaborative actions.

Table 1. Complementary ICT and human capabilities.

Scenario	ICT capabilities	Human capabilities
Sensing	Sensor networks, camera networks, RFID tags, opportunistic access to smartphone sensors	Five human senses; posting of facts, opinions, and feelings on social networks; proactive use of smartphone sensors
Computing	Data analysis, data aggregation, basic situation recognition	Pattern analysis, advanced situation recognition, emotion recognition
Actuating	Traffic control; digital signage; personal displays and navigation systems; critical infrastructure such as water distribution, energy grid, and so on	Physical movement of individuals and manned vehicles, physical actions, social persuasion

CHALLENGES

To fully realize the vision of urban superorganisms, researchers must overcome many theoretical and technological challenges.

Innovative coordination models and software infrastructures are

needed to facilitate spontaneous and effective interactions in large-scale systems at both the ICT and human level. These technologies should enforce a large variety of situated "sociotechnical business processes" involving numerous heterogeneous components and people, while preserving the immediacy and simplicity of current collaboration tools such as Twitter and Facebook. In addition, they should seamlessly blend human and ICT services in a way similar to Amazon Mechanical Turk yet adapt to support dynamic, location-based interactions. The EU's SAPERE project (www.sapere-project.eu) is exploring this issue in the context of *self-aware pervasive service ecosystems*.

The emergence of urban superorganisms will also require a better understanding of the complex interplay between ICT systems and people. The ultimate goal is to learn how to control such dynamics, at many spatial and temporal scales, to achieve specific urban objectives.

Finally, to promote participation, novel mechanisms are required to push interactions among diverse components and human agents. Researchers have proposed several ways to encourage the opportunistic sharing of sensing devices and of human capabilities, primarily through monetary incentives. However, emphasizing the social value of participation could be a more successful wide-scale inducement. For example, people could be publicly recognized with some kind of "citizenship score" for properly playing the urban superorganism game.

Despite the many challenges ahead, the future path seems clear. Sooner or later, we'll all become part of an urban superorganism, putting our ICT devices and unique human capabilities to use for the good of both ourselves and society.

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