1 When everything is connected

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1.1 Introduction

1.1.1 Mobile communication and the Internet

The Internet has created in only one decade a global information network that has become the platform for communication and delivering information, digital content and knowledge, enabling commercial transactions and advertising, creating virtual communities for cocreating and sharing their content, and for building various value adding digital services for consumers and businesses. The Internet phenomenon has been a complex development that has been influenced by several factors – an emerging culture that shares values that are brilliantly summarized by Manuel Castells [1]:

> The culture of the Internet is a culture made up of a technocratic belief in the progress of humans through technology, enacted by communities of hackers thriving on free and open technological creativity, embedded in virtual networks aimed at reinventing society, and materialized by money-driven entrepreneurs into the workings of the new economy.

The Internet can be characterized by four key elements: Internet technology and its standardization, open innovation based on various open source development tools and software, content and technology creation in various virtual communities around the Internet, and finally on business opportunities created by the Internet connectivity and access to the global information. The history and the origin of mobile communication are different and have been driven by the telecommunication operators and manufacturers. Digital mobile communication has focused on providing secure connectivity and guaranteed quality of voice and messaging services. The key driver has been connection, i.e., establishing a link between two persons. The global expansion of digital mobile phones and mobile network services has occurred in a short period of time, more or less in parallel with the Internet, during the last 10–15 years. Today there are roughly 3 billion mobile subscribers, and by 2010 nearly 90% of the global population will be able to access mobile voice and messaging services.

Mobile communication networks have also evolved from the original voice and text messaging services to complex data communication networks. The mobile phone

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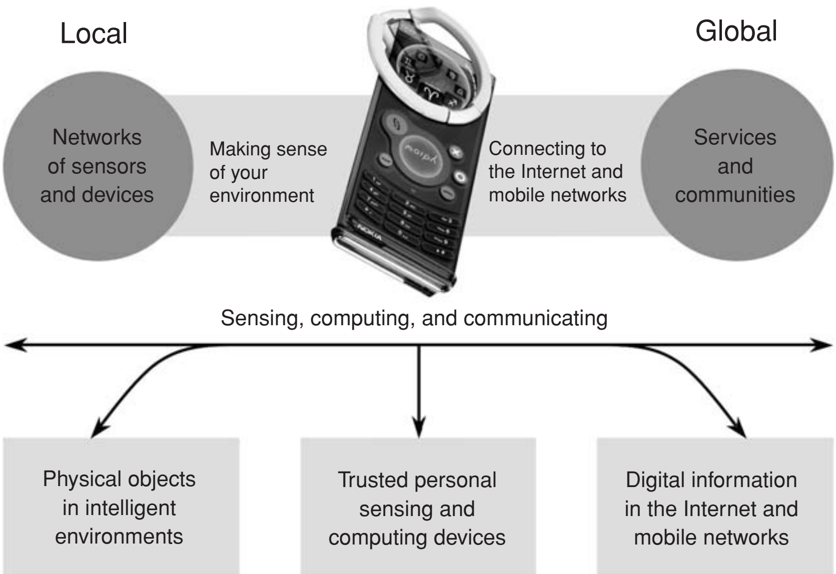

Figure 1.1 Mobile device as a gateway between local and global information and services.

has become a pocket-size mobile multimedia computer with various applications and capabilities to access networked services. The convergence of mobile communication and the Internet is one of the most signicant technology trends of our time with signicant social and economic impact. The mobile devices and networks are able to extend access to the Internet from homes and offices to every pocket and every situation in everyday life. Mobile phones outnumber personal computers by a factor of 5–10. In developing countries in particular, mobile phones are immensely important for accessing the Internet and its services as many people make their first connection to the Internet via a mobile phone.

It is very clear that the evolution of human society will be shaped by the global communication and information sharing networks. In this book we will discuss another important dimension that will bring the Internet and mobile communication even closer to human everyday life. We will discuss the new capabilities to master our interface to the physical world. The ability of human technologies to image, measure, and manipulate matter down to the molecular scale and to master the self-organizing structures of nature will extend our ability to invent new materials and manufacturing solutions, new energy, sensing, computing and communication technologies, and a deeper means to interact with living systems: our environment and our bodies. The aim of this book is to study these abilities in the context of the Internet and mobile communication and from the perspective of the era of the transformation of human society towards the new concept of seamless local and global interaction, illustrated in Figure 1.1.

1.1.2 Towards merging of physical and digital worlds

Mobile phones have already become an enabling platform for several digital services and applications. Mobile phones are now mobile computers with a wide range of multimedia functionality, e.g., imaging, navigation, music, content management, internet browsing, email, and time management. Increasingly they will have advanced multiaccess communication, information processing, multimedia, mass storage, and multimodal user interface capabilities.

Mobile phones are developing towards being trusted personal intelligent devices that have new fundamental capabilities, illustrated in Figure 1.1:

- to sense and interact with the local environment via embedded short-range radios, sensors, cameras, and audio functionality;
- to function both as servers for global and local internet services and as clients for global internet services;
- to serve as gateways that connect local information and global Internet-based services;
- to carry the digital identity of the user and to enable easy-to-use secure communication and controlled privacy in future smart spaces;
- to make sense of and learn from both the local context and the behavior of its user, and optimize its radio access, information transport, and device functionality accordingly.

Form factors and user interface concepts of mobile phones and computers will vary according to the usage scenario. The trend towards smaller and thinner structures as well as towards reliable transformable mechanics will continue. The desire to have curved, flexible, compliant, stretchable structures and more freedom for industrial design sets demanding requirements for displays, keyboards, antennas, batteries, electromagnetic shielding, and electronics integration technologies. Integrating electronics and user interface functions into structural components, such as covers then becomes a necessity.

The modular device architecture of mobile phones and computers consists of several functional subsystems that are connected together via very high-speed asynchronous serial interfaces [2, 3]. This modular approach enables the use of optimal technologies for particular functionalities, optimization of power consumption, and the modular development of device technologies and software. The same modular architecture can be extended from one device to a distributed system of devices that share the same key content, e.g., remote mass storage, display, or a printer.

A variety of new devices will be embedded in our intelligent surroundings. Ambient intelligence will gradually emerge from the enhanced standardized interoperability between different consumer electronics products and will extend into more distributed sensing, computing, storage, and communication solutions. The current communication-centric modularity will develop into content- and context-centric device virtualization.

The vision of ambient intelligence, in which computation and communication are always available and ready to serve the user in an intelligent way, requires mobile devices plus intelligence embedded in human environments: home, office, and public places. This results in a new platform that enables ubiquitous sensing, computing, and communication. The core requirements for this kind of ubiquitous ambient intelligence are that devices are autonomous and robust, that they can be deployed easily, and that they survive without explicit management or care. Mobility also implies limited size and restrictions on the power consumption. Seamless connectivity with other devices and fixed networks is a crucial enabler for ambient intelligence systems. This leads to requirements for increased data rates of the wireless links.

Intelligence, sensing, context awareness, and increased data rates require more memory and computing power, which together with the limitations of size lead to severe challenges in thermal management. It is not possible to accomplish the combination of all these requirements using current technologies. As we shall see in the rest of the book, nanotechnology could provide solutions for sensing, actuation, radio, embedding intelligence into the environment, power-efficient computing, memory, energy sources, human–machine interaction, materials, mechanics, manufacturing, and environmental issues.

1.2 Future devices, lifestyle, and design

1.2.1 Navigation in space and time

Early on the morning of Tuesday July 7, 2020, Professor Xi wakes up in her modern Kensington hotel room in London, still feeling tired after her long flight from Shanghai. Only a few years earlier she limited her traveling to the most important conferences and visiting lectureships. Her environmental ethics and the existence other means of communicating meant she preferred to stay mostly in her own university in Hangzhou. However, this invitation to give a series of lectures about Chinese innovation and environmental strategies to the MBA class of the London Business School gave her an opportunity to discuss both the history of innovation in China and its recent huge economical and technological advances.

After having breakfast Professor Xi decides to use the remaining hour before her meeting with Professor Williams to take a walk through a London park. It is a beautiful morning. Walking through the city, Professor Xi relies on her mobile device. Her thoughts return to her lectures. She opens her Morph device which shows her a map of the city, her location, and the route. She lifts the device, looks through it, and the device displays the street and the local information on services around her (see Figure 1.2). This is the modern equivalent of navigation, cartography, measuring of distances, and using a compass. All these ancient inventions of the Song dynasty are now encapsulated in this transformable piece of flexible and elastic material. She wraps the device around her wrist and walks on to her meeting, trusting in the instructions of her mobile personal device.

Professor Xi is moving through the streets of London that are depicted as a mixed experience of physical and virtual realities. At the same time she is able to find information about her environment that helps her to navigate towards her meeting. She is able to access local information about her surroundings – directly based on the local

Figure 1.2 A transparent and transformable user interface [4] for augmented reality experience.

short-range communication and indirectly using the global Internet-based knowledge relating to her location. Location-based information services have thus become an integral part of living in a physical space. This access to local knowledge enables her to interact with the people, commerce, history, and the aspirations of the immediate community of what otherwise would remain merely a nondescript street to her. It helps her to link her current physical location to her personal world map.

Her personal mobile wearable device is a physical expression of the *timeless time* and the *spaces of flow* [1, 5, 6]. The device connects her to her physical location but at the same time also to the global information that describes and defines her location. The space and time of her experience have become much more complex and nonlinear. However, she also has a physical meeting to attend, and the device gives her instructions for how to get there in time.

1.2.2 Transformable device

A transformation is defined in mathematics as a process by which a figure, an expression, or a function is converted into another that is equivalent in some important respect but is differently expressed or represented. In a similar way a transformable device has its own character but its functional and morphological appearance can be adjusted according to the context. In Figure 1.3 Professor Xi's mobile device, the Morph, presents a potential future map with navigation functionality. The same device can be opened to form a flat touch display that shows a dynamic and context aware map of the environment. The dynamic map combines space and time, it can relate current events and the history of its local surroundings, guiding us through space and time. The same device can be folded into a handheld communication tool that enables us to easily find the people and things that we need in our current situation. Furthermore, the device can be wrapped around the wrist so that it becomes a simple street navigator guiding us to our goal.

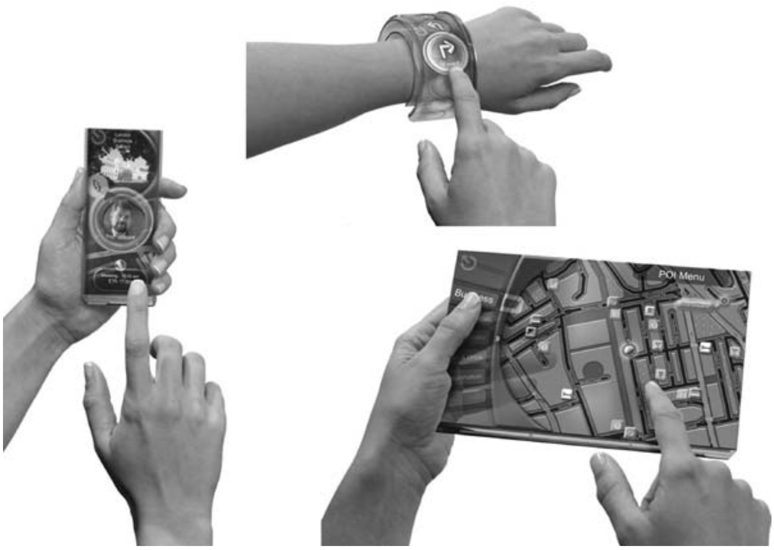

Figure 1.3 A future guide could be a device that transforms from a wearable navigator to a touch-sensitive map.

Morph has some new capabilities that are not possible with existing technologies: it is a flexible and stretchable device made of transparent materials with embedded optical and electronic functions. To achieve this we need:

- a transparent device with display capability;
- flexible and partly stretchable mechanics with nonlinear spatial and directional control of elasticity embedded into the materials themselves and even rigid-on-demand actuators;
- distributed sensors and signal processing in the transparent structures, e.g., pressure and touch sensor arrays;
- transparent and flexible antenna, electronics, and energy storage;
- externally controllable and dynamic surface topography and roughness;
- multifunctional, robust surface coatings providing protection of device functionality, dirt repellence, antireflection, etc.;
- transformability and conformability with intelligence that can extract conformation and context and adjust the functionality accordingly.

The Morph device can essentially be transformed in many different ways: e.g., into a graphical user interface, or a mechanical configuration to increase the availability of applications and services. The user interface of the device can adapt to the needs of the user in terms of both its functionality and its appearance. Transformability can be used to enable ease of use of the device, applications, and services. The Morph device is transformable in both its form and its conformation. The Morph is a cognitive user interface, capable of sensing both the user and the environment, making decisions based on this information, adapting to the context and giving feedback to the user. The Morph can learn about its user and can become a trusted personal companion.

The transformable compliant mechanisms need to be built deep into the material solutions of the device. In it, complex mechanical and electromagnetic metamaterials and artificial nanoscale material structures enable controllable flexure and stretch in the macroscopic mechanisms creating the desired functions. One of the key challenges is how to freeze the conformations and how to allow the right level of flexibility in various parts of the device. Can nanostructured functional materials be arranged into macroscopic structures according to the device functionality? We need to learn how to build a bridge between the nanoscale properties of the materials and the manufacturing of a macroscopic object.

1.2.3 Fashion and expression

The mobile device has already become a personal device that is used to express personal identity. New materials, integration technologies, modular architectures and tools of customization will affect the way people can design and tailor their devices – according to the desired functionality and the look and feel. The personalization of mobile devices and the integration of some of their functions, such as display and sensors, in clothing will create new opportunities for fashion designers.

Nanotechnologies will enable the integration of electrical and optical functions into fabrics. We are not speaking only about integration of components into wearable objects but also of embedding functions into the materials that are used in clothes and other wearable objects. Manufacturing solutions, such as ink jet printing and reel-to-reel fabrication, have already been used in the textile industry. As electronics manufacturing is beginning to use similar methods, the integration of electronics and optics will become feasible on large scale in textiles and other materials will be used for wearable objects.

New engineered materials and structures could be used to create artificial, functional, and biocompatible systems. For example, early prototypes of artificial skin with integrated sensors have been developed [7, 12]. Artificial sensors can be integrated into the human nervous system. This kind of functional system will be complex and expensive but it is possible to create low-cost functional systems with sensing and actuation: materials that react to temperature, humidity, and touch by changing their properties, such as surface roughness, perforation, color, and reflectivity. Many phenomena that exist in nature could be mimicked by future clothing and wearable devices.

Fashion is used as a way to express both being part of a community and individuality. In the future fashions will also enable us to express our feelings and adapt dynamically to our surroundings. At the same time, our personal, wearable objects will become intelligent and networked to the surrounding virtual and physical worlds.

1.2.4 Lifestyle and the mobile device (global knowledge, local view)

Mobile phones and mobile communication have also had significant impact on human culture. Mobile communication has created the capability for simultaneous social interaction at a distance in *real time*. Mobile connectivity has increased the efficiency of different professionals on the move. Social networks, including the family, are reshaping based on pervasive connectivity. Several public services, e.g., remote health care, can be provided using mobile-communication-based technologies. Mobile phones have created youth cultures: peer groups with a collective identity, strengthened personal identities expressing creativity and fashion, and new patterns for consumption of entertainment, games, and media. Mobile communication can be used to improve the safety and security of people; however, the risks and fears of misuse of the technologies are real: the security and privacy of individuals are also threatened by omnipresent communication technologies.

Internet connectivity and mobile communication have had a great influence on human social and cultural development. At the deepest levels our concepts of space and time are changing. Mobile networks and pervasive connectivity are enablers for commercial transactions and advanced services, even production and manufacturing will become geographically distributed globally. Mobile communication is a most advanced technology that will enable this kind of global network society [6]. Human society is becoming more dependent on knowledge generation and global flows of information than on the physical locations in terms of not only economies, but also cultural trends. Information networks and mobile connectivity are also beginning to affect the physical environments of human beings, our urban planning, and the architecture of our buildings and cities [8]. The capability to connect local and global information in the same physical location are changing our concept of distance and the location itself.

The concept of time has varied throughout history. Contemporary societies are driven by the concept of clock time that is a result of the industrial age. During this era of Taylorian concepts time was modeled as linear, irreversible, measurable, and predictable. The profound transformation of the concept of time in the globally networked society is based on instant information accessibility and interactions that lead to emerging, random, nonlinear, and incursive phenomena that shape the life and economics of the people. Manuel Castells has named this emerging era the timeless time [5]. The timeless time concept can be seen in several current phenomena. The ability of global markets to work *in real time* with transactions occurring at immense speed creates the need for more flexible management processes in networked enterprises in order to make their decisions *in real time* based on understanding complex emerging situations. The increasing speed of the economic activities influences the patterns of work and free time. Even social interaction and social networks obey more complex causalities – the emergence and exponential growth of online communities, such as Facebook, Twitter, and LinkedIn, are reflections of the future of social networks.

Our concepts of macroscopic space and time are changing, and at the same the human capability to study, image, and manipulate matter at a molecular scale is expanding our scale of impact. Nanoscience and nanotechnologies are creating possibilities for developing new functional materials, new sensing and computing solutions, and technologies for environmental and medical engineering. Nanotechnologies are enabling integration of new functionality into mobile communication and the Internet. The Internet will become connected to our physical environment.

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Excerpt
More information

Figure 1.4 Professor Xi waits for the ambulance with her father. She is in a visitor room at the London Business School and he is at home in Shanghai. Their communication is provided by their Morphs and the nearby screens. The prewarning via the Morphs leads to quick preventative action by medical personnel and keeps relatives informed.

1.3 Trusted personal device becomes a cognitive interface

1.3.1 Assisted living and remote health care for the elderly

Professor Xi is drawn from her mental preparations for her lectures by an insistent alarm signal from her Morph. It takes her a moment to realize the cause: the Morph is notifying her that her father in Shanghai is showing signs of potential heart failure! Quickly she uses her Morph and the largest wall screen in the visitor room of the London Business School to make a virtual connection to her father (see Figure 1.4). She and her father feel as if they are in the same room, even though he is in Shanghai. He is not in any pain and so they talk for the 5 minutes it takes for the ambulance to arrive. During the ambulance trip, and in the hospital, Professor Xi continues to reassure her father via their Morphs. Soon after his arrival at the hospital it is clear that her father is not in immediate danger but the hospital wishes to keep him in for several hours for observation. A relieved Professor Xi closes the connection and tries to continue her preparations. She feels grateful that her father's health monitoring system, combined with the quick reactions of the health system, has saved her father from serious harm.

Technologies for assisted living and remote health care for the elderly are urgently needed. With such systems, the increasing elderly population can receive care while staying in their own home and so maintaining social independence. This preventative system could allow significant savings in public expenditure on health care. As the population profiles are changing, we face a truly global challenge in China, Japan, North America, and Europe. The same technologies need not be used solely for the remote monitoring of the elderly, e.g., they could monitor pilots during flights or monitor anybody's wellness, e.g., the amount and quality of sleep, level of physical activity and exercising, or health markers such as cholesterol levels.

Several kinds of user interfaces are needed in assisted living concepts, and privacy is extremely important. The person to be monitored needs a wearable user interface that does not reveal information to others. The user interfaces and devices need to be truly *personal*. The user interface needs to be either compatible with clothing or an integrated part of it, and it must be connected to other devices, such as a mobile device that provides the global connectivity. People with the right to use the information, like near relatives and professional caregivers, could access the information via their mobile devices. Healthcare professionals would benefit from a combination of mobile and stationary devices that enable them to continuously monitor their patients.

In developing the future personal trusted mobile devices the meaning of trust has specific significance in the context of medical applications. A failure in the operation of the device could result in tragic consequences. The secure operation of devices over the Internet and through mobile communication requires intelligent algorithms embedded in devices, networks, and services. The end-to-end solution (according to Figure 1.1) must be able to monitor its own integrity and give warning of possible failures. The devices and the solutions need to pass the specific tests and regulations required for medical equipment. For fitness, wellness, and preventative healthcare purposes the requirements are somewhat less demanding. In addition to diagnosis, active treatments inside the human body are being developed based on bionanoscience. A good example of this is the controlled release of drugs for targeted or long-term delivery.

1.3.2 Integrated cognitive systems

Energy-efficient implementation of artificial sensors on mobile devices and in intelligent environments will enable the recognition of people, objects, chemicals, radio traffic, sounds, speech, touch, and the overall context around the devices. These embedded capabilities and increased artificial intelligence could bring communication, applications, and Internet-based services to a new level with only imagination as the limiting factor.

Integrated cognitive systems and processes are capable of perception, cognition, learning, and actuation in real time in real physical environments. Ultimately these artificial cognitive systems will seamlessly integrate with human cognitive processes and behavioral patterns. Thus the first requirement for embedded intelligence is efficient interaction with humans – the users.

Solutions for artificial classification of sensory information, mechanisms for decision making driving the device's actions, and processes for learning and adaptation need to be implemented in devices with different levels of complexity. If the device can understand the context, behavioral patterns, gestures, and moods of the user, then future devices and user interfaces can change and adapt their operations to support their user accordingly. Going beyond this, embedded intelligence could support us in presenting options, remembering, and even decision making.

Based on efficient human interaction and context awareness the cognitive user interface of our devices could create an enhanced new linkage for everyone to the merged