Chapter 2
Ambient Intelligence: A New Computing Paradigm and a Vision of a Next Wave in ICT

2.1 Introduction

AmI has emerged in the past 15 years or so as a new computing paradigm and as a vision of a next wave in ICT. It postulates a paradigmatic shift in computing and offers a vision of the future of technology—with far-reaching societal implications, representing an instance of the currently prevailing configuration of social-scientific knowledge and thus a cultural production and historical event. AmI is a multidisciplinary field where a wide range of scientific and technological areas and human-directed sciences converge on a common vision of the future and the enormous opportunities and immense possibilities such future will open up and bring, respectively, that are created by the incorporation of machine intelligence into people's everyday lives and existing environments. In other words, AmI is said to hold great potential for engendering drastic social transformations. As such, it has increasingly gained legitimacy as an academic and public pursuit and discourse in the European information society: scientists and scholars, industry experts and consortia, government S&T agencies, S&T policymakers, universities, and research institutes and technical laboratories are promoting, and making significant commitments to, AmI as advances in S&T.

However, by virtue of its very definition, implying a certain desired view of the world, AmI represents more a vision of the future than a reality. And as shown by and known from preceding techno-visions and forecasting studies, the future reality is most likely to end up being very different from the way it is initially predicted. Accordingly, realizing the AmI vision may turn out to be very different from what it was envisioned a decade and a half ago. In fact, techno-visions seem to face a paradox, in that they fail to balance between innovative and futuristic claims and realistic assumptions. This pertains to unreasonable prospects, of limited modern applicability, on how people, technology, and society will evolve, as well as to a generalization or oversimplification of the rather specific or complex challenges involved in enabling future scenarios or making them for real. Also, crucially,

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techno-utopia is a relevant risk in such a strong focus on ambitious and inspiring visions of the future of technology. Techno-utopian discourses surround the advent of new technological innovations or breakthroughs, on the basis of which such discourses promise revolutionary social changes. The central issue with techno-visions is the technologically deterministic view underlying many of the envisioned scenarios, ignoring or falling short in considering the user and social dynamics involved in the innovation process.

Furthermore, yet recent years have—due to the introduction of technological innovations or breakthroughs and their amalgamation with recent discoveries in human-directed sciences—witnessed an outburst of claims for new paradigms and paradigm shifts, in particular in relation to a plethora of visions of next waves in ICT, social studies of AmI include—a kind of new paradigm and paradigm shift epidemic. Several authors and scholars have a tendency to categorize AmI—as recent techno–scientific achievements or advances in S&T—as a paradigm and paradigm shift in relation to computing, ICT, society, and so on. In fact, there has been a near passion for labeling new technological visions as paradigms and paradigm shifts as a way to describe a certain stage of technological development within a given society. While such visions emanate from the transformational effects of computing, predominately, where paradigm and paradigm shift actually hold, they still entail a lot of discursive aspects in the sense of a set of concepts, ideas, claims, assumptions, premises, and categorizations that are historically contingent and socio–culturally specific—and generate truth effects accordingly. The underlying assumption is that while AmI, as new technological applications, is the result of scientific discovery or innovation, it is still directed toward humans and targeted at complex, dynamic social realities made of an infinite richness of circumstances, and involving intertwined factors and situated social dynamics. In other words, AmI has been concerned with people–centered approaches in the practice of technological development. Accordingly, it can be argued that there is a computing paradigm profile relating to AmI as to ubiquitous computing—which constitutes one of AmI's major visions, but there is no paradigm in society—nor should there be. In all, AmI as a technological vision involves paradigmatic, non-paradigmatic, pre-paradigmatic, post-paradigmatic, and discursive dimensions.

However, at the technological level, AmI is characterized by human-like cognitive and behavioral capabilities, namely context awareness, implicit and natural interaction, and intelligence (cognitive, emotional, social, and conversational). By being equipped with advanced enabling technologies and computational processes and what this entails in terms of miniature smart sensors, sophisticated data processing and machine learning techniques, and hybrid modeling approaches to knowledge representation and reasoning, AmI should be capable to think and behave intelligently in support of human users, by providing personalized, adaptive, responsive, and proactive services in a variety of settings: living spaces, workspaces, social and public places, and on the move. With the progress in the fields of microelectronics (i.e., miniaturization and processing power of sensing and computing devices), embedded systems, wireless and mobile communication networks, and software intelligent agents/user interfaces, the AmI vision is evolving into a deployable and achievable computing paradigm.

The aim of this chapter is to give insights into the origin and context of the AmI vision; to shed light on the customary assumptions behind the dominant vision of AmI, underlying many of its envisioned scenarios, and provide an account on its current status; to outline and describe a generic typology for AmI; to provide an overview of technological factors behind AmI and the many, diverse research topics or areas associated with AmI; to introduce and describe human-directed sciences as well as artificial intelligence and their relationships and contributions to AmI; and to discuss key paradigmatic, non-paradigmatic, pre-paradigmatic, and post-paradigmatic dimensions of AmI. Moreover, this chapter intends to provide essential underpinning conceptual tools for exploring the subject of AmI further in the remaining chapters.

2.2 The Origin and Context of the AmI Vision

Much of what characterizes AmI can be traced back to the origins of ubiquitous computing. AmI as a new computing paradigm has evolved as a result of an evolutionary technological development, building upon preceding computing paradigms, including mainframe computing, desktop computing, multiple computing, and ubiquitous computing (UbiComp). As a vision of a next wave in ICT, a kind of shift in computer technology and its role in society, AmI became widespread and prevalent in Europe about a decade after the emergence of the UbiComp vision in the USA, a future world of technology which was spotted in 1991 by Mark Weiser, chief scientist at the Xerox Palo Alto Research Center (PARC) in California, when he published a paper in Scientific American which spoke of a third generation of computing systems, an era when computing technology would vanish into the background. Weiser (1991) writes: ‘First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives. Alan Kay of Apple calls this “Third Paradigm” computing’. So, about 25 years ago, Mark Weiser predicted this technological development and described it in his influential article “The Computer for the 21st Century” (Weiser 1991). Widely credited as the first to have coined the term ‘ubiquitous computing’, Weiser alluded to ir as omnipresent computing devices and computers that serve people in their everyday lives, functioning unobtrusively in the background of their consciousness and freeing them from tedious routine tasks. In a similar fashion, the European Union’s Information Society Technologies Advisory Group (ISTAG) used the term ‘ambient intelligence’ in its 1999 vision statement to describe a vision where ‘people will be surrounded by intelligent and intuitive interfaces embedded in everyday objects around us and an environment recognizing and responding to the presence of individuals in an invisible way’ (ISTAG 2001, p. 1). In the European vision of AmI (or the future information society), ‘the emphasis is on greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions' (ISTAG 2001, p. 1). Issues on key difference between the two visions and concepts are taken up in the next section.

The research within UbiComp and the development of the vision in the USA has been furthered in concert with other universities, research centers and laboratories, governmental agencies, and industries. Among the universities involved include MIT, Berkeley, Harvard, Yale, Stanford, Cornell, Georgia Tech's College of Computing, and so on. As an example, MIT has contributed significant research in the field of UbiComp, notably Hiroshi Ishii's *Things That Think* consortium at the Media Lab and Project Oxygen. It is worth pointing out that research undertaken at those universities has been heavily supported by government funding, especially by the Defense Advanced Research Projects Agency (DARPA), which is the central research and development organization for the Department of Defense (DoD), and the National Science Foundation (NSF) as an independent federal agency. Many other corporations have additionally undertaken UbiComp research, either on their own or in consortia with other companies and/or universities. Among which include: Microsoft, IBM, Xerox, HP, Intel, Cisco Systems, Sun Microsystems, and so forth.

Inspired by the UbiComp vision, the AmI vision in Europe was promoted by certain stakeholders—a group of scholars and experts, a cluster of ICT companies, research laboratories, governmental agencies, and policymakers. AmI was originally developed in 1998 by Philips for the time frame 2010–2020 as a vision on the future of ICT (consumer electronics, telecommunications, and computing) where user-friendly devices support ubiquitous information, communication, and entertainment. In 1999, Philips joined the Oxygen alliance, an international consortium of industrial partners within the MIT Oxygen project. In 2000, plans were made to construct a feasibility and usability facility dedicated to AmI. A major step in developing the vision of AmI in Europe came from the Information ISTAG, a group of scholars and industry experts who first advanced the vision of AmI in 1999. In this year, ISTAG published a vision statement for the European community Framework Program (FP) 5 for Research and Technological Development (RTD) that laid down a challenge to start creating an AmI landscape. During 2000, a scenario exercise was launched to assist in further developing a better understanding of the implications of this landscape as a collaborative endeavor between the Joint Research Center's Institute for Prospective Technological Studies (IPTS-JRC) and DG Information Society, and the development and testing of scenarios involved about 35 experts from across Europe. In parallel with the development of the AmI vision at Philips at the time ISTAG working group was chaired by CEO of Philips Industrial Research Dr. Martin Schuurmans, a number of other initiatives started to explore AmI further with the launch of and the funneling of expenditure in research projects. ISTAG continued to develop the vision under the IST program of the European Union (EU) FP6 and FP7 for RTD. It has since 1999 made consistent efforts for ICT to get an increased attention and a higher pace of development in Europe (Punie 2003). Indeed, it is a strong promoter of, and a vocal champion for, the vision of AmI. With ISTAG and the EU IST RTD funding program, huge efforts have been made in the EU to mobilise research and industry towards laying the foundation of an AmI landscape and realizing the vision of AmI.

There has been a strong governmental and institutional support for AmI. AmI has been embedded in one of the funding instruments of the European Commission (EC), notably under its FP5, FP6, and FP7. EC is a key player in the further development of the AmI vision; it used it for the launch of its FP5 and FP6, following the advice of ISTAG. In particular, AmI was one of the key concepts being used to develop the Information Society aspects of the EU's RTD FP 6. The association of AmI with the European policies towards the knowledge society and the financial backing in the FP IST research programs contributed to make AmI a very active research topic. European industry, consortiums, universities, research institutes, and member states have also been mobilized to contribute to the realization of the AmI vision, by devoting funds to AmI research (e.g., Wright 2005).

As a result of many research initiatives and endeavors, the AmI vision gained a strong footing in Europe. This has led to the establishment of roadmaps, research agendas, projects, and other endeavors across Europe, spanning a variety of domains, such as context awareness computing, multimodal communication modeling, micro-systems design, embedded systems, multimedia, service provisioning, privacy and security, affective computing, and so on. Virtually all European AmI projects have been undertaken by consortia, which typically comprise partners from different countries and different sectors, especially universities and industry (Wright 2005). The increase of AmI projects and research activities has been driving up the EC budget, apart from the heavy investment undertaken from and the huge funding spent by many European corporations, companies, universities and other involved stakeholders from different sectors in the EU. In addition, in the aftermath of the first European symposium on AmI (EUSAI) that took place in 2004, many conferences and forums have been and continued to be held across Europe to-date, addressing a range of topics within AmI research and practice. The goal of all these efforts and stakeholder motivation is to spur innovation and the S&T knowledge base for well-being, competitiveness, and growth in the future European information society (Punie 2003), by unlocking the transformational effects of ICT. AmI can be used as a medium to achieve innovation (Aarts 2005). AmI has a great potential to lead to 'radical social transformations' and new ICT to 'shape Europe's future' (ISTAG 2003, 2006). Innovation has long been recognized as a vehicle for societal transformation, especially as a society moves from one technological epoch to another.

2.3 The Current Status, Unrealism, and Technological Determinism of the AmI Vision

Notwithstanding the huge financial support and funding provided and the intensive research in academic circles and in the industry, coupled with the strong interest stimulated by European policy makers, the current state of research and development shows that the vision of AmI is facing enormous challenges and hurdles in its progress towards realization and delivery in Europe. Demonstrably, the 'AmI

Space' has not materialized as foreseen or envisaged 15 years ago—by ISTAG. No real breakthrough in AmI research is perceived and achieved thus far, although AmI environments are intelligent and AmI applications and services make the life of the people better. It is argued that among the causes why AmI environments have not broken through into the mainstream are the prevailing assumptions in the vision of AmI, underlying many of the envisioned scenarios pertaining to the pre-configuration of users in, and the kind of society envisaged with, AmI—i.e., unrealism and technological determinism. Like preceding techno-visions, by virtue of its very definition, implying a certain desired view on the world, AmI represents more a vision of the future than reality. And as shown by and known from forecasting studies, the future reality is most likely to end up being very different from the way it is initially envisioned or predicted. Indeed, techno-visions appear to face a paradox, in that they fail to balance between innovative and futuristic claims and realistic assumptions. This pertains to unreasonable prospects, of limited modern applicability, on how people and technology will evolve, as well as to an over-simplification of the rather complex challenges involved in enabling future scenarios or making them for real. Also, techno-utopia is a relevant risk in such a strong focus on such aspiring and inspiring visions of the future of technology. Techno-utopian discourses are common with the advent of new technological innovations or breakthroughs, on the basis of which these discourses promise revolutionary social changes. The central issue with techno-visions is the technologically deterministic view underlying many of the envisioned scenarios. However, techno-visions seem to fail to deliver what they promise or to realize their full potential, regardless of the extent to which visionaries, research leaders, and policymakers build expectations, mobilize and marshal R&D resources, and inspire and align strategic stakeholders towards the realization and delivery of such visions. The main reason for this phenomenon lies in the difficulty of avoiding unrealism and technological determinism.

A key implication of technological determinism is overlooking the user and social dynamics and undercurrents involved in the innovation process. This implies that techno-visions only look at what is technologically feasible and have a one-dimensional account of how social change occurs (Burgelman 2001). This may involve the risk of people becoming disinclined to accept, absorb, or adapt to technological innovation opportunities and the promised radical social transformation consequently becoming a fallacy. Similarly, one of the ramifications of unrealism—e.g., a design process grounded in the unrealistic assumptions pervading (user) scenarios—is the irrelevant and unrealistic systems and applications that no one will use, adopt, or benefit from. What is needed is to 'better understand what people want, how they take advantage of available devices, and how to craft devices and systems in ways that *intelligently* inserts them into ordinary everyday affairs—not just the affairs of one individual at a time, but into the ordinary interactions found in group activity or social settings more generally' (Gunnarsdóttir and Arribas-Ayllon 2012, p. 32). In light of this, if no real breakthrough in AmI research and development is perceived, it would be mainly because of the prevailing vision of user participation (see Criel and Claeys 2008), in addition to ignoring what recent history of ICT and social studies of new technologies have shown in terms of the importance of social innovation as an ingredient in technology innovation and the central role of multiple methods of participative design as innovation instruments, as well as failing to make explicit the consideration for human values and concerns in the design choices and decisions that will shape AmI technology. Seeing the user as a shaper of technology, these views call upon a more active participatory role in technology innovation and design, and thereby challenge the passive role of the user as a mere adopter of new technologies (e.g., Alahuhta and Heinonen 2003).

Furthermore, putting emphasis on the user in AmI innovation research plays a key role in the development of related applications and services. However, it is unquestionable that the current or dominant user-centered design approaches—albeit originated from participatory design—place the user at such a central stage as they often claim, which goes together with the vision of AmI (e.g., Criel and Claeys 2008). As to the humanistic philosophy of technology design, experiences have shown that it is very challenging to give people the lead and consider their values and concerns in the ways systems and applications are developed and applied. In other words, the difficulty with human-centered design approach is that it is far from clear how this can be achieved due to the availability of little knowledge and the lack of tools to integrate user behavior as a parameter in system design and product and service development (Punie 2003; Riva et al. 2003). As to social innovation, while it is considered decisive in producing successful technological systems as well as in the acceptance of new technologies, it is often seen to be very challenging as well as too costly and time consuming for technology creators to take onboard. Regardless, in reference to the AmI vision, Aarts and Grotenhuis (2009) underscore the need for a value shift: '…we need a more balanced approach in which technology should serve people instead of driving them to the max'. This argument relates to social innovation in the sense of directing the development of new technologies towards responding to users' needs and addressing social concerns. In other words, technological development has to be linked with social development. The underlying assumption is that failing to make this connection is likely to result in people rejecting new technologies and societal actors in misdirecting and misallocating resources, e.g., mobilization of professionals, experts, companies, and technical R&D.

Nevertheless, as many argue, visions of the future of technology are meant to provoke discussion or promote debate and depict plausible futures or communicate possible scenarios, adding to mobilizing and marshalling resources and inspiring and aligning key stakeholders into the same direction. As Gunnarsdóttir and Arribas-Ayllon (2012, p. 30) point out, '[t]he AmI vision emerges from a pedigree of expectations about the future of computing…The original scenarios are central to making up new worlds and building expectations around prospective lifestyles and users. Rhetorically, they contribute to conditions that make visions of AmI seemingly possible. But they also engender capacities to investigate what is actually possible. Incorporating new challenges and anticipating problems modulates the course of expectations… New visions are adapted to accommodate contingent futures—uncertainties about design principles, experiences, identities and preferences… Visionaries and research leaders continue to imagine new socio-technical arrangements in which…experiences are profoundly changing. The new interaction paradigm between people and technology will be embedded in an ecological utopia…based on values associated with intimate connections between people and things… [A] greater vision needs to be cultivated to sustain both research and…funding interests.'

With the purpose of reflecting on what it 'means for the AmI vision, and its foundational role for AmI at large' to 'move from visionary perspectives of the future to a new focus on the challenge of actually being able to deliver real value today', José et al. (2010, p. 1480, 1482) suggest 'that it is time for the AmI field to move beyond its founding vision and embrace important emerging trends that may bring this field closer to realization, delivery and real social impact' and that revolve 'around some of its core concepts, more specifically the notion of intelligence, the system view and the requirements process. The main motivation is to search for alternative research directions that may be more effective in delivering today the essence of the AmI vision, even if they mean abandoning some of the currently prevailing approaches and assumptions'.

2.4 AmI Versus UbiComp as Visions

AmI and UbiComp share many similar assumptions, claims, ideas, terminologies, and categorizations. They depict a vision of the future information society where everyday human environment will be permeated by computer intelligence and technology: humans will be surrounded and accompanied by advanced sensing and computing devices, intelligent multimodal interfaces, intelligent software agents, and wireless and ad-hoc (a system of network elements combined to form a network entailing no planning) networking technology, which are everywhere, invisibly embedded in human natural surroundings, in virtually all kinds of everyday objects in order to make them smart. This computationally augmented everyday environment is aware of people's presence and context, and is adaptive, responsive, and anticipatory to their needs and desires, thereby intelligently supporting their daily lives through providing unlimited services in new, intuitive ways and in a variety of settings. In other words, smart everyday objects can interact and communicate with each other and other people's objects, explore their own environment (situations, events, locations, user states, etc.), and interact with human users, therefore helping them to cope with their daily tasks in a seamless and intuitive way.

While AmI and UbiComp visions converge on the pervasion of microprocessors and communication capabilities into everyday human environments and thus the omnipresence and always-on interconnection of computing resources and services, AmI places a particularly strong focus on intelligent interfaces that are sensitive to users' needs, adaptive to and anticipatory of their desires and intentions, and responsive to their emotions. Philips has distinguished AmI from UbiComp as a related vision of the future of technology, by characterizing the AmI vision as a seamless smart environments capable of anticipating and intelligently responding to people's needs and motivations, and acting autonomously on their behalf (Gunnarsdóttir and Arribas-Ayllon 2012). ISTAG (2003) claims that AmI emerged in parallel with UbiComp but is different from it, in that AmI is concerned more with the use of the technology than basic technology: what characterizes this difference particularly are the focus (users in their environment versus next-generation computing technology) and the orientation (user-pull versus technology push) of technology (Ibid). Weiser (1993, p. 75) wrote: 'Since we started this work at PARC in 1988 a few places have begun work on this possible next-generation computing environment in which each person is continually interacting with hundreds of nearby wirelessly interconnected computers. The goal is to achieve the most effective kind of technology, that which is essentially invisible to the user. To bring computers to this point while retaining their power will require radically new kinds of computers of all sizes and shapes to be available to each person. I call this future world "Ubiquitous Computing"'. At the core of the AmI vision, on the other hand, are three technologies: ubiquitous computing, ubiquitous communication, and intelligent user-friendly interfaces. Ubiquitous computing means integration of microprocessors into everyday objects, ubiquitous communication enables these objects to communicate with each other and human users by means of wireless and ad-hoc networking, and intelligent user-friendly interfaces allow the inhabitants of the AmI environment to interact with the environment in a natural and personalized way (Riva et al. 2005). Accordingly, AmI stems from the convergence of these three key technologies.

To a large extent, the distinctive characteristics have been largely set by the ISTAG reports on AmI: according to the vision statement, 'on convergence humans will be surrounded by intelligent interfaces supported by computing and networking technology which is everywhere, embedded in everyday objects… AmI implies a seamless environment of computing, advanced networking technology and specific interfaces. It is aware of the specific characteristics of human presence and personalities, takes care of needs and is capable of responding intelligently to spoken or gestured indications of desire, and even can engage in intelligent dialog. AmI should also be unobtrusive, often invisible: everywhere and yet in our consciousness—nowhere unless we need it. Interaction should be relaxing and enjoyable for the citizen, and not involve a steep learning curve' (ISTAG 2001, p. 11; ISTAG 2003, p. 8). In other words, AmI can be described as the merger of two important visions: 'ubiquitous computing' and 'social user interfaces': 'It builds on advanced networking technologies, which allow robust, ad-hoc networks to be formed by a broad range of mobile devices and other objects (ubiquitous computing). By adding adaptive user-system interaction methods, based on new insights in the way people like to interact with computing devices (social user interfaces), digital environments can be created which improve the quality of life of people by acting on their behalf. These context-aware systems combine ubiquitous information, communication, and entertainment with enhanced personalization, natural interaction and intelligence' (Riva et al. 2003, p. 63). In all, AmI is a vision in which ICT and its applications and uses are widened and deepened—a drastic shift in the users of the technology, its incorporation into diverse spheres of living and working, and the applications (Punie 2003).

In fact, the vision of the future of technology is reflected in a variety of terms that closely resemble each other, including, in addition to AmI and UbiComp, pervasive computing, ubiquitous networking, everywhere computing, sentient computing, proactive computing, calm computing, wearable computing, invisible computing, affective computing, haptic computing, the Internet of Things, Things that Think, and so on. These terms are used by different scholars and industry players to promote the future vision of technology in different parts of the world. For example, AmI is used in Europe, and the term was coined by Emile Aarts of Philips Research in 1998 and adopted by the European Commission. Its equivalent in the USA is UbiComp; Marc Weiser was first credited for dubbing the term in the late 1980s, during his tenure as a Chief Scientist/Technologist at the Xerox Palo Alto Research Center (PARC). He wrote some of the earliest papers on the subject, largely defining it and sketching out its major concerns (Weiser 1991; Weiser et al. 1999). Ubiquitous networking is more prevalent in Japan. Essentially all these terms mean pretty much the same thing: regardless of their locations, researchers are all investigating and developing similar technologies and dealing with similar challenges and problems (see Wright 2005).

2.5 AmI Versus UbiComp as Concepts

AmI as a concept is similar to UbiComp—intelligence everywhere. Similar to the vision, however, views from the European scholarly community argue that they differ in some aspects. AmI and UbiComp as concepts can still imply a slightly different focus. AmI is the direct extension of the concept UbiComp, but it is much more than this, as the AmI system should be adaptive and responsive to the user's needs and behavior (Riva et al. 2003; ISTAG 2001). The term AmI has a recent provenance and is not clearly discerned from earlier concepts, such as UbiComp (ISTAG 2003). Indeed, to the set of core system properties initially proposed by Weiser (1991) two additional ones have been added: computers (1) can operate autonomously, on behalf of the user or without human intervention, be self-governed, and (2) handle a multiplicity of dynamic interactions and actions, governed by intelligent decision making and interaction, which involves artificial intelligence techniques (Polsdad 2009). Weiser (1991) suggested three main internal properties in order for the UbiComp systems to be interleaved into the world: (1) computers need to be networked, distributed, and transparently accessible, as wireless communication network and Internet were far less pervasive; (2) HCI needs to be hidden (implicit) for it was overly intrusive, and (3) computers need to be aware of the context of physical and human environment in order to operate in their physical and human environment in an optimal way. According to Polsdad (2009), different types of UbiComp systems have been proposed based upon merging different sets of core properties, including ubiquity and transparency; distributed mobile, intelligence, augmented reality; autonomy and iHCI; AmI; and so forth.

2.6 UbiComp and AmI: Definitional Issues

In general, the term ‘ubiquitous’ means omnipresent: appearing or existing everywhere. Combined with computing, it forms the term ‘ubiquitous computing’, which was introduced by Marc Weiser in early 1990s, and denotes that technology in all its forms—computing, communication, and networking—will permeate everyday human environment. It is a concept in computer science wherein computing can occur using any device and system, in any location and co-location, and in any design format, enabling the human user to interact with such diverse forms of computers, as laptops, smart cards and devices, tablets, and terminals in everyday objects. UbiComp is a way to describe computers that ‘fit the human environment instead of forcing humans to enter theirs’ (York and Pendharkar 2004, pp. 773–774). In more detail, UbiComp entails sensing and computing devices (and related services) being omnipresent, situated in physical and human world environment, and functioning unobtrusively in the background while being intuitive to human usage to such an extent that users are not even aware of their presence or sense their interaction—i.e., the UbiComp devices disappear into the environment and from the perception of users in such that the latter can engage many (hidden) devices simultaneously without necessarily being aware of doing so, simply using them unconsciously to accomplish everyday tasks in a variety of settings. UbiComp is about technology vanishing, being invisibly woven, into the fabric of everyday life and being massively used by people (Weiser 1991).

Thus far, there is no canonical definition of AmI, although many attempts have been, over the last 15 years, undertaken to define the concept of AmI. AmI is a difficult concept to define precisely; hence, it has been used in multiple ways. Definitions are fundamental to, and lay the foundation of, the understanding of AmI as a new concept, as they illustrate the properties of AmI and elucidate the term in relation to related terms. What is common to all definitions in the literature on AmI is that it is conceived as distributing computation in the environment and a novel approach to HCI—i.e., human-centric or social user interfaces. The most basic prerequisite of AmI is that it is focused on the human actor and thus concerned with people-centered practice of technology development. Indeed, most attempts to define and redefine the notion of AmI by most studies that flooded after the publication of the ISTAG reports on AmI in 2001 and 2003 emphasize this shared characteristic—AmI denotes a shift towards ‘human-centered computing’ (e.g., Aarts et al. 2002). AmI claims to place the user at the center of future design and development of technologies and provides guiding principles for how this should be accomplished. In AmI, technologies should be designed and developed for people rather than making people adapt to technologies. Iterating the ISTAG's (2001, p. 11) description of AmI for clarification purposes, '…humans will be surrounded by intelligent interfaces supported by computing and networking technology which is everywhere, embedded in everyday objects… AmI… is aware of the specific characteristics of human presence and personalities, takes care of needs and is capable of responding intelligently to spoken or gestured indications of desire, and even can engage in intelligent dialog. AmI should also be unobtrusive, often invisible: everywhere and yet in our consciousness nowhere unless we need it. Interaction should be relaxing and enjoyable for the citizen, and not involve a steep learning curve'. This description points out some of the most fundamental ideas underlying the AmI concept: 'the idea of a radical and technology driven change to existing environments and people's lives; the view of networked devices strongly embedded into the environment; the idea of transparent systems that do not need to be noticed by people; the anticipatory and proactive nature of the system that frees people from manual control of the environment; and intelligent interfaces that will be able to understand and adapt, not only to the presence of people, but also to situations of everyday life, including people's moods, activities or expectations' (José et al. 2010, p. 1481). In a nutshell, AmI is an adaptive, responsive, and proactive technology that is omnipresent.

Other attempts to define AmI revolve essentially around the same set of constructs. Gill and Cormican (2005, p. 3) define AmI as 'a people centered technology that is intuitive to the needs and requirements of the human actor. They are non-intrusive systems that are adaptive and responsive to the needs and wants of different individuals'. AmI is described as technology that is capable to automate a platform embedding the required devices for powering context-aware, personalized, adaptive and anticipatory services (Arts and Marzano 2003). AmI is lauded to be 'a new paradigm in information technology, in which people are empowered through a digital environment that is aware of their presence and context, and is sensitive, adaptive, and responsive to their needs, habits, gestures and emotions' (Riva et al. 2003, p. 63). To Horvath (2002, cited in Gill and Cormican 2005), who advances the definition further in practical terms, AmI signifies that 'we will be surrounded by intelligent interfaces embedded in everyday objects… These interfaces register our presence, automatically carry out certain tasks based on given criteria, and learn from our behavior in order to anticipate our needs'. Delving more into the human actors' interactions with AmI systems, Lindwer et al. (2003, cited in Gill and Cormican 2005, p. 3) describe AmI as a technology that is 'invisible, embedded in our natural surroundings, present whenever we need it,' the technology is easily 'enabled by simple and effortless interactions,' that are 'attuned to all our senses, adaptive to users and context and autonomously acting'.

2.7 More to the Characterizing Aspects of AmI

AmI has recently been adopted as a concept to refer to a multidisciplinary subject, which embraces a variety of pre-existing fields, such as computer science, engineering, cognitive neuroscience, human communication, and so on. Fundamentally, multiple definitions and descriptions emerge when dealing with multidimensional concepts or investigating new emerging multifaceted phenomena. AmI is an evolving socio-technological phenomenon for which there is no clear and widely acknowledged definition. The research within AmI is ambiguous and vast, which makes it difficult to delineate the concept of AmI, although defining concepts is a fundamental step in doing scientific research. This has indeed an implication for understanding the concept and hampering the advance of AmI. AmI as a new paradigm in ICT is ill-defined, which is at present hindering its development (Gill and Cormican 2005). The scholarly literature on AmI is as almost heterogeneous as the approaches into the conceptualization, modeling, design, and development of AmI systems within a variety of application domains. This has generated and led to a profusion of definitions. There is a cornucopia of applications in the domain of AmI supporting (or combining) different sets and scales of core properties (e.g., context awareness, implicit interaction, intelligence; and distribution,) to different degrees, various types of settings (e.g., home, learning, social, and work environment) to different degrees; multiple forms of computing (smart) devices (e.g., various types of sensors, MEMS, NMES, VLSI Video, and RFID); and a vast range of combination possibilities of multiple systems to form interacting systems of systems, and so forth. For example, on smart sensor technologies, Lindwer et al. (2003, cited in Gill and Cormican 2005, p. 3) highlight there is a 'large difference in abstraction level between the thinking about Ambient Intelligence systems and the micro-, nano-, and optoelectrical components needed to implement those systems'. This makes the definitions of AmI not that useful to AmI designers and developers

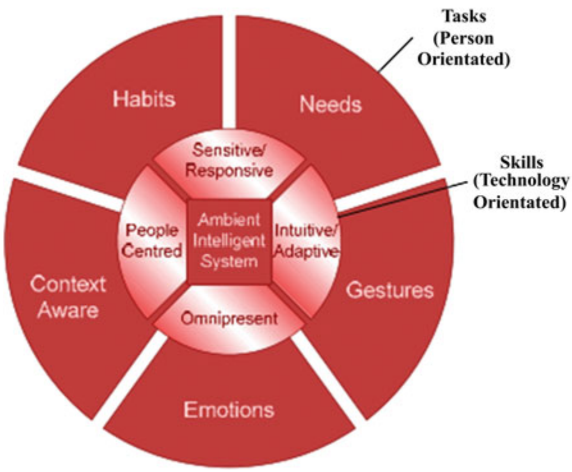

Fig. 2.1 Ambient intelligence system. *Source* Gill and Cormican (2005)

as a research community. This substantiates that definitions of AmI need something extra to assist AmI engineers in the creation and development of AmI systems—e.g., generic typologies or frameworks. However, the extension of computing power into everyday life scenarios in the context of AmI certainly requires advanced knowledge from diverse human-directed disciplines beyond the proper ambit of computing, such as cognitive psychology, cognitive science, neuroscience, social science, behavioral science, linguistics, communication, and philosophy, to name a few. This makes it certainly overwhelming to understand the concept and philosophy of AmI. Adding to the lack of an agreed-upon definition is the alphabet soup of metaphors created by computer scientists and ICT industry designers and experts that commonly fall under the technology of the future, as mentioned earlier. This has generated a cacophony leading to an exasperating confusion in the field, including the elusiveness of new concepts. In all, AmI defies a concise analytical definition, although one can often point to examples of application domains that entail specific technological dimensions. However, while most definitions tend to capture key shared characteristics of AmI as a new computing paradigm (or a metaphor depicting a vision of a next wave in ICT), a generic typology can still be useful in understanding this paradigm. A typology can better facilitate an understanding of the AmI concept and philosophy (Gill and Cormican 2005).

2.8 Typologies for AmI

A generic topology for AmI can improve its definition and reduce or remove the ambiguity surrounding what constitutes it and thereby assist in the development of AmI systems. While typologies are not panaceas, a generic one for AmI systems is necessary, as it helps to define what AmI is and what it is not and assists the designers and developers of AmI systems and applications, by having a better understanding of AmI as a new computing paradigm (Gill and Cormican 2005). A typology commonly refers to the study and interpretation of types or a taxonomy according to general type. It is thus grouping models or artifacts describing different aspects of the same or shared characteristics. There exist various approaches to AmI typology, involving technological or human views or a combination of these and supporting different characteristics pertaining to computational tasks and competencies depending on the application domain, among others. There exist many theoretical models in literature (e.g., Arts and Marzano 2003; Hellenschmidt and Kirste 2004; Riva et al. 2005; Gill and Cormican 2005) that look at technological dimensions as to what enables or initiates an AmI system or take a combined view of the characteristic of what an AmI system should involve, that is, what constitutes and uniquely distinguishes AmI from other computing paradigms or technologies. Based on the foundational tenets of AmI as a paradigm that builds upon people-centered philosophy, Gill and Cormican (2005) propose an AmI system typology based on a combined perspective—technological and human side of the AmI—involving tasks and skills as two main areas that together define what an

AmI system should entail—what is and what is not an AmI system. As illustrated in Fig. 2.1, the outer ring represents the tasks that the AmI system needs to recognize and respond to and the inner ring represent the skills that AmI system should encompass. The authors stated that the tasks: habits, needs, gestures, emotions, and context are human-orientated, in that they represent the human characteristics that the AmI must be aware of, whereas the skills: sensitive/responsive, intuitive/adaptive, people-centered, and omnipresent, are technology-orientated, in that they represent the technology characteristics that the AmI must have or inherently accomplish as abilities to interact with the human actors. They also mentioned that the link between the two areas is of an inseparable, interlinked, and interdependent nature.

To elaborate further on the link between the tasks and skills, the AmI system needs to take care of needs, be sensitive to users, anticipate and respond intelligently to spoken or gestured indications of desire, react to explicit spoken and gestured commands, support the social processes of humans and be competent agents in social interactions, engage in intelligent dialog or mingle socially with human users, and elicit pleasant user experiences and positive emotions in users. AmI thus involves supporting different kinds of needs associated with living, work, social, and healthcare environments. These needs differ as to the necessity level—i.e., either they improve the quality of people's lives or sustain human lives. For AmI technology to be able to interact with the human actor—what it must innately accomplish as its aptitudes—and thus provide efficient services in support of the user, it has to be equipped with such human-like computational capabilities as context awareness functionality (see Chap. 3), natural interaction and intelligent behavior (see Chap. 6), emotional and social intelligence (see Chap. 8), and cognitive supporting behavior (see Chap. 9). These computational competencies enable AmI systems to provide adaptive, responsive, and anticipatory services. Responsiveness, adaptation, and anticipation (see Chap. 6 for a detailed account and discussion and Chaps. 8 and 9 for application examples) are based either on pre-programed heuristics or real-time learning and reasoning capabilities. However, according to Gill and Cormican (2005, p. 6) for an AmI system to be sensitive/responsive, it 'needs to be tactful and sympathetic in relation to the feelings of the human actor, has to react quickly, strongly, or favorably to the various situations it encounters. In particular, it needs to respond and be sensitive to a suggestion or proposal. As such, it needs to be responsive, receptive, aware, perceptive, insightful, precise, delicate, and most importantly finely tuned to the requirements of the human actor and quick to respond'. For AmI to be adaptive, it 'needs to be able to adapt to the human actor directly and instinctively. This should be accomplished without being discovered or consciously perceived therefore it needs to be accomplished instinctively i.e., able to be adjusted for use in different conditions. The characteristics it is required to show are spontaneity, sensitivity, discerning, insightful and at times shrewd' (Ibid). And for AmI to be anticipatory and proactive, it needs to predict the human actor's needs and desires and pre-act in a way that is articulated as desirable and appropriate and without conscious mediation. It is required to think on its own, make decisions based on predictions or expectations about the future, and act autonomously so the human actor does not have to work to use it—the AmI system frees people from manual control of the environment. As such, it needs to be predictive, aware, knowledgeable, experienced, and adaptively curious and confident. This characteristic is, according to Schmidhuber (1991), important to decrease the mismatch between anticipated states and states actually experienced in the future. He introduces the concept of curiosity for intelligent agents as a measure of the mismatch between expectations and future experienced reality.

Considering the sprouting nature of AmI paradigm, any proposed typology for AmI normally result from and build on pervious, ongoing, and/or future (theoretical and empirical) research in the area of AmI, thereby evolving continuously with the purpose of improving definitions and reducing the ambiguity around what constitutes AmI. Indeed, since the inception of AmI, a number of typologies have been, and continue to be, developed, revised, refined, restructured, expanded, or adapted to reflect various renditions pertaining to the amalgamation of computational tasks and competencies—how they have been, and are being, combined in relation to various application domains (e.g., ambient assisted living, smart home environment, workspace, healthcare environment, social environment, etc.) as to what they entail in terms of the underlying technologies used for the implementation of AmI systems (e.g., capture technologies, data processing methods, pattern recognition techniques, modeling and reasoning approaches, etc.) and in terms of the nature of intelligent services to be provided. Therefore, typologies constantly evolve as new research results transpire and knowledge advances. This process will continue as AmI evolves as a computing paradigm and become more established and popular as an academic discourse.

However, the existing literature on AmI remains heavy on speculation and weak on empirical evidence and theory building—extant typologies, frameworks, and models have poor explanatory power, and the applications and systems that have been developed in the recent years are far from real-world implementation, i.e., generally evaluated and instantiated in laboratory settings. This concerns more the vision of 'human-centric computing', as most of the many concepts that have already been tested out as prototypes in field trials relate more to the vision of UbiComp. Hence, thorough empirical and theorizing endeavor is necessary for AmI as both a new computing paradigm and a vision of a next wave in ICT to have strong academic buy-in and practical relevance in relation to the future form of the kind of technological development in the information society. At present, the growth of academic interest in AmI as a 'paradigmatic shift in computing and society' (Punie 2003) is such that it is becoming part of mainstream debate in the technological social sciences in Europe.

2.9 Paradigmatic, Non-paradigmatic, Pre-paradigmatic, and Post-paradigmatic Dimensions of AmI

For what it entails as a metaphor depicting a future vision of technology, AmI involves aspects, or represents an instance, of both a new computing paradigm as well as a vision of a next wave in ICT (or a new paradigm in ICT of a loose profile nature) with societal implications. This is because AmI characterization involves merging two major trends: (1) ubiquitous computing and communication, distributing computation in everyday human environment or integration of microprocessors and networked sensors and actuators in everyday objects, and (2) social and human-centric user interfaces as a novel approach to HCI, which entails a transformation of the role of ICT in society and eventually of how people live and work. Issues relating to AmI as a paradigmatic shift in computing are also discussed here given their relevance. Before delving into the discussion of AmI as a new computing paradigm and a paradigmatic shift in computing, it may be useful to first look at some key concepts that make up this discussion, namely 'ICT', 'computing', 'paradigm', and 'paradigm shift'.

2.9.1 ICT and Computing

Abbreviated for information and communication technology, ICT is an umbrella term that describes a set of technologies used to access, create, store, retrieve, disseminate, exchange, manage, and transmit information in a digital format. ICT involves computing systems (e.g., laptops, wearable computers, smart mobile phones, augmented-reality devices, Internet network, telecommunication systems, sensors and actuators, etc.) and the associated innumerable software applications and services. ICT applications span over a myriad of domains and are integrated in almost all sectors of society. It is often spoken of based on the context of use, e.g., living, smart homes, learning, healthcare, energy efficiency, and so on. ICT is commonly synonymous with information technology (IT), the engineering field that deals with the use of information and communication systems to handle information and aid its transmission by a microelectronics-based combination of computing, networking, and telecommunications, as well as with the knowledge and skills needed to use such systems securely and intelligently within a wide spectrum of situations of use. The Information Technology Association of America (ITAA) defines IT as 'the study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware' (Veneri 1998, p. 3).

ICT has been used interchangeably with computing, but there is a distinction between the two concepts, in that computing theory is concerned with the way computer systems and software programs are created and function, and ICT theory deals with the application of ICT in and its effects on society. Generally, computing can be defined as: ‘any goal-oriented activity requiring, benefiting from, or creating computers. Thus, computing includes designing and building hardware and software systems for a wide range of purposes; processing, structuring, and managing various kinds of information; doing scientific studies using computers; making computer systems behave intelligently; creating and using communications and entertainment media; finding and gathering information relevant to any particular purpose, and so on. The list is virtually endless, and the possibilities are vast’ (ACM, AIS and IEEE-CS 2005, p. 9).

2.9.2 Paradigm and Paradigm Shift

According to Kuhn (1962, 1996), a paradigm denotes the explanatory power and thus universality of a theoretical model and its broader institutional implications for the structure, organization, and practice of science. A theoretical model is a theory or a group of related theories designed to provide explanations within a scientific domain or subdomain for a community of practitioners—in other words, a scientific discipline- or subfield-shared cognitive or intellectual framework encompassing the basic assumptions, ways of reasoning, and approaches or methodologies that are universally acknowledged by a scientific community. A comprehensive theoretical model involves a conceptual foundation for the domain; understands and describes problems within the domain and specify their solutions; is grounded in prior empirical findings and scientific literature; is able to predict outcomes in situations where these outcomes can occur far in the future; guides the specification of a priori postulations and hypotheses; uses rigorous methodologies to investigate them; and provides a framework for interpretation and understanding of unexpected outcomes or results of scientific investigations. Kuhn’s notion of paradigm is based on the existence of an agreed upon set of concepts for a scientific domain, and this set forms or constitutes the shared knowledge and specialized language of a discipline (e.g., computer science) or sub-discipline (e.g., artificial intelligence, software engineering). This notion of paradigm: an all-encompassing set of assumptions resulting in the organization of scientific theories and practices, involves searching for invariant dominant paradigm governing scientific research. And ‘successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science’ (Kuhn 1962, p. 12). This is what Kuhn (1962) dubbed ‘paradigm shifts’. A paradigm shift is, according to him, a change in the basic assumptions, thought patterns or ways of reasoning, within the ruling theory of science—in other words, a radical and irreversible scientific revolution from a dominant scientific way of looking at the world. This applies to computing, as I will try to exemplify below. In accordance with Kuhn’s (1962) conception, a paradigm shift in computing should meet three conditions or encompass three criteria: it must be grounded in a meta-theory, be accepted by practitioners of a scientific community, and have a body of successful practice. This is the case for AmI with regard to its UbiComp strand.

2.9.3 Computing Paradigm and AmI as an Instance of a New Computing Paradigm

Like all scientific paradigms, computing paradigm is based on the existence of a widely agreed upon set of concepts and theories, a theoretical model, based on computer science, computer engineering, IT, information systems, and software engineering. These five sub-disciplines constitute the field of computing (ACM, AIS and IEEE-CS 2005). As subdomains of scientific research, they have many overlaps among them in their theories, methodologies, and practices as they form the domain of computing. The focus here is on computer science and engineering given their synergy as well as their more relevance to the topic of paradigm. Computer science is concerned with the study of the theoretical foundations of information (e.g., structures, representation) and computation (e.g., mechanisms, algorithms) and the practical techniques and methods for their implementation in the designed computer systems. Computer scientists deal with the systematic study and creation of algorithmic processes that describe, create, and transform information and formulate abstractions (or conceptualizations) to model and design complex systems (Denning et al. 1989; Wegner 1976). Integrating several fields of computer science and electrical engineering (IEEE and ACM 2004), computer engineering is concerned with the study, development, and application of computer systems and applications, hardware and software aspects of computing, such as designing chips, sensors, actuators, information processing units, operating systems, and other hardware components and devices and software mechanisms and processes.

Broadly, research in computing entails two key dimensions: the first is based on broad types of design science and natural science research activities: build, evaluate, theorize, and justify, and the second is based on broad types of design research produced outputs: representational constructs, models, methods, and instantiations (see March and Smith 1995 for an overview). Design is at the core of computing. As a scientific paradigm, design science entails an agreed upon set of principles, rules, methods, and activities used to construct technological artifacts to achieve certain goals—intended uses. Design science has its roots in engineering and other applied sciences, which are important for technology development. There is a large body of work (e.g., Venable 2006; March and Smith 1995; Cross 2001) on meta-theory, a theory about computing theories, pertaining to engineering science and design science, which has engendered several theorems in relation to the field of computing. Indeed, theory and theorizing are important ingredients in the evolution and practice of computing as a field of research and development. Like in other scientific paradigms, theory in computing is a primary output and theorizing plays a central role in the advancement of engineering, design, and modeling of computing systems. The foundational tenets and practice of computing paradigm—conceptual and theoretical model and practical knowledge—are based on hard sciences, such as natural science and formal science which involve methodological rigor and legitimacy. 'Natural science is concerned with explaining how and why things are… Natural scientists develop sets of concepts, or specialized language, with which to characterize phenomena. These are used in higher order constructions—laws, models, and theories—that make claims about the nature of reality. Theories—deep, principled explanations of phenomena—are the crowning achievements of natural science research. Products of natural science research are evaluated against norms of truth, or explanatory power. Claims must be consistent with observed facts, the ability to predict future observations being a mark of explanatory success. Progress is achieved as new theories provide deeper, more encompassing, and more accurate explanations' (March and Smith 1995, p. 253). Formal sciences, which are concerned with formal systems, such as logic, mathematics, statistics, theoretical computer science, information theory, game theory, systems theory, decision theory, and portions of linguistics, aid the natural sciences by providing information about the structures the latter use to describe and explain the world, and what inferences may be made about them. Among the characteristics of hard science include: producing testable predictions; performing controlled experiments; relying on quantifiable data and mathematical models; a high degree of accuracy and objectivity; and generally applying a purer form of the scientific method (Wilson 2012; Lemons 1996; Rose 1997; Diamond 1987).

In light of Kuhn's notion of scientific paradigm, entailing UbiComp as one of its two main constituting paradigms, AmI represents a third computing paradigm (as opposed to keeping computation bottled in a desktop-bound personal computer (PC) and sharing mainframes by lots of people). AmI paradigm, the age of calm technology, posits that computing technology recedes or vanishes into the background of everyday life (e.g., Weiser 1991). This paradigm has also been referred to as invisible computing and disappearing computing. In AmI, many invisible distributed computing devices are hidden in the environment, and come to be invisible to common consciousness. The increasing, continuous process of miniaturization of mechatronic systems, devices, and components, thanks to micro-engineering, is increasingly making this computing paradigm deployable, resulting in processors and tiny sensors and actuators being integrated into more and more everyday objects, leading to the physical disappearance of computing technology into the environment. This rapidly evolving development exemplifies a 'successive transition from one [computing] paradigm to another via [technological] revolution' (Kuhn 1962), which represents a developmental pattern of computing as a mature science. This implies that the new theoretical model pertaining to computing embodies an explanatory power, which in turn has institutional implications for the structure and organization of computing as a scientific discipline. AmI represents an instance of this new computing paradigm with regard to the new ways of designing, developing, and building computing devices and systems; structuring, representing, processing, and managing various kinds of information associated with context awareness, natural interaction, and intelligence functionalities; making computing devices and systems behave autonomously and equipping them with affective and conversational capabilities; creating and using advanced (based on presence technology) computer-mediated human–human and human–agent communications; and handling and managing media; and so on. Gunnarsdóttir and Arribas-Ayllon (2012) found that AmI paradigm has even the generative and performative power to harness not only technological, but also 'social-psychological, cultural, political and moral imaginations into a collective quest for novel reconfigurations of human-world relationships', a feature which relates to AmI as paradigmatic shift in computing.

2.9.4 AmI as a Paradigmatic Shift in Computing

Following Kuhn's conception of paradigm shift—the element of a drastic break in intellectual and thus political practice, AmI assumes a paradigmatic shift in computing—in terms of UbiComp as a key constituent of AmI. With that in mind, UbiComp did herald a paradigm break with the post-desktop paradigm, shifting from computation bottled in desktop-bound PC to computation distributed in the environment. Weiser (1991) positioned UbiComp as embodied reality, where computers are integrated in the real-world, as opposed to virtual reality, putting human users in computer-generated environments. He wrote: 'The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it… This is not just a "user interface" problem… Such machines cannot truly make computing an integral, invisible part of the way people live their lives. Therefore we are trying to conceive a new way of thinking about computers in the world, one that takes into account the natural human environment and allows the computers themselves to vanish into the background. Such a disappearance is a fundamental consequence not of technology, but of human psychology'. Referring to AmI as a paradigmatic shift in computing (and society), Miles et al. (2002, pp. 4–9) state: 'It is probably one occasion where the overused phrase "paradigm shift" is appropriate because it implies a radical shift in such dimensions as the users of the technology, its incorporation into different spheres of living and working, the skills required, the applications and content provided, the scale and nature of the markets and the players involved'. However, the vision of AmI assumes many shifts, including 'in computing systems from mainframe computing (1960–1980) over personal computing (1980–1990) and multiple computing devices per person… (2000 onwards) to invisible computing (2010 onwards)', 'in communication processes from people talking to people over people interacting with machines to machines/devices/software agents talking to each other and interacting with people'; 'in using computers as a tool to computers performing tasks without human intervention'; 'a decoupling of technological artifact and its functionality/use to multi-purpose devices/services'; 'in accessibility and networking from on/off over may access points to always on, anywhere, anytime' (Punie 2003, p. 12). This paradigm shift 'has the objective to make communication and computer systems simple, collaborative and immanent. Interacting with the environment where they work and live, people will naturally and intuitively select and use technology according to their own needs' (Riva et al. 2003, p. 64).

More to Kuhn's (1996) conception of paradigm shift, AmI stemming from UbiComp is accepted by a community of practitioners and has a body of successful practice. As mentioned earlier, there is a strong institutional and governmental support for and commitment to AmI—industry associations, scholarly and scientific research community, and policy and politics. The research and innovation within AmI are active across Europe at the levels of technology farsightedness, science and technology policy, research and technology development, and design of next generation technologies (see Punie 2003; Wright 2005). They pertain predominantly to the areas of microelectronics (miniaturization of mechatronic systems, devices, and components), embedded systems, and distributed computing. In particular, the trends toward AmI are noticeably driving research and development into ever smaller sizes of computing devices. AmI is about smart dust with networked miniature sensors and actuators and micro-electro-mechanical systems (MMES) incorporating smart micro-sensors and actuators with microprocessors and several other components so small to be virtually indiscernible or invisible. The miniaturization trend is increasingly enabling the development of various types and formats of sensing and computing devices that allow registering and processing various human parameters (information about people) in an intrusive way, without disturbing users or actors (see Chap. 4 for more detail on miniaturization trends and related issues).

In the very near future, both the physical and human world will be overwhelmed by or strewn with huge quantities of tiny devices (e.g., active and passive RFID tags), entrenched into everyday objects and attached to people, for the purpose of their identification, traceability, and monitoring. Today, RFID tags are attached to many objects and are expected to be embedded in virtually all kinds of everyday objects, with the advancement of the Internet of Things. In recent years, efforts have been directed towards designing remote devices and simple isolated appliances—that might be acceptable to the users and consumers of AmI technology, which 'prepares the ground for a complete infiltration of our environment with even more intelligent and interconnected devices. People should become familiar with AmI; slowly and unspectacularly; getting used to handing over the initiative to artificial devices. There is much sensing infrastructure already installed for handling security… What remains to be done is to shift the domain of the intended monitoring just enough to feed the ongoing process of people getting used to these controls and forgetting the embarrassment of being permanently monitored, in other words—having no off-switch' (Crutzen 2005, p. 220). At present, the environment of humans, the public and the private, is pervaded by huge quantities of active devices of various types and forms, computerized enough to automate day-to-day decisions and thus act autonomously on behalf of human–agents. However, the extensive incorporation of computer technology into people's everyday lives and thus the inevitable employment of artificial intelligent agents to automate day-to-day decisions involve repercussions that are difficult to foresee. In fact, the question to be raised is whether people really want to live in a world permeated with computer devices that take on their routine decision-making activities.

2.9.5 Non-paradigmatic Aspects of AmI

AmI has been concerned with people-centered practice of technological development. This implies that AmI is (claimed to be) about technologies that are fully designed for and adapted to people (human cognition, behavior, and needs)—i.e., based on new insights in the way people like to interact with such technologies and their applications, smart environments can be created which improve the quality of their life. If the people are the principal actors in the AmI paradigm, the relevant socio-technological reality must be only of the people's own construction. Following this reasoning, how can there be a general AmI theory, let alone a paradigm? There can only be a scattered archipelago of local socio-technological perspectives pertaining to the incorporation of computer technology into people's everyday lives and environments and how this can bring them a better life—in other words, how the promises made by AmI concerning the transformation of the role of ICT in society can transform the way people live and work. In addition to this argument, AmI travels under many aliases—context-aware computing, situated computing, sentient computing, wearable computing, invisible computing, calm computing, pervasive computing, disappearing computing, affective computing, and so forth. Such scattering or dispersion of computing trends does not provide the conditions for, or facilitate, the generation of a coherent body of theory. In many cases, computing sources do not refer in any systematic way to one another, but keep on generating alternative labels with some of them even from the ground up, in the process reinventing the wheel or starting from scratch without zeroing in on generating 'expert opinion'. There are still further reasons why the notion of a paradigm (shift) may not apply to AmI in relation to society. One key consideration is that the elements of the AmI paradigm are contradictory. While AmI technologies should be designed for and adapted to people, the people who are to live in AmI and the IoT are not asked for their views as part of the design and innovation process. Another consideration is that AmI concern normative values and, thus, is concerned with various policy frameworks, rather than explanatory and meta-theoretical frameworks. It is more a vision of the future information society—and, to add, promoted by certain ICT companies, institutions, and policymakers for particular ends—than a reality. By virtue of its very definition, it is normative, signifying a certain desired view on the socio-technological world, and also serve political-economic purposes. Overall, AmI is not necessarily anti-theoretical but it is intellectually fragmented. The work of several AmI authors can be contextualized in terms of their institutional belonging, scholarly affiliation, social location, cultural inclination, ideological commitment, and socio-political status. In particular, institutional dimension entails that there are clear political advantages to a break with existing societal paradigm—which is not fully technologized, thereby AmI finding strong institutional (and governmental) support.

2.9.6 Pre-paradigmatic and Post-paradigmatic Aspects of AmI

Like all paradigms in (technological) social science, AmI being post-paradigmatic or, at least, non-paradigmatic—in relation to society—has to do obviously with not being grounded on a solid, meta-theoretical base that transcends contingent human actions—i.e., it lacks a theoretical model with an explanatory power and universal nature (and as taken to assume a paradigmatic shift in society, it does not demonstrate a drastic break in intellectual and thus political practice.

AmI is pre-paradigmatic because there is no scholarly consensus available in social sciences and humanities (and other human-directed sciences) upon which it is based. Human-directed sciences (see below for elucidation) involve volatile theories, pluralism of theoretical models, and a plethora of unsolved issues. Adding to this is the generally understood extraordinary complexity of social sciences (and humanities), as they involve social and political processes which are reflexive in nature (see Bourdieu and Wacquant's (1992) notion of reflexive sociology), i.e., social actors act upon theories themselves, which are hence adapted in action (see Bourdieu's (1988) analyses of social science in action). This is most likely to carry over its effects to the implementation of knowledge about cognitive, emotional, social, and behavioral processes of humans into AmI systems and thus their behavior. But the AmI vision continues to be performed to elucidate the role of paradigm-making to communicate complex problems and address multiple issues pertaining to how people would want what they want. In addition, as a new approach to HCI, AmI integrates a range of human-directed disciplines and sub-disciplines, including cognitive science, cognitive psychology, cognitive neuroscience, social sciences (e.g., anthropology, sociology, etc.), human verbal and nonverbal communication, linguistics, media and cultural studies, and philosophy, but to name a few. However, through identifying limitations, complications, and new possibilities, disciplinary (and sub-disciplinary) synergies further complicate the AmI vision (Gunnarsdóttir and Arribas-Ayllon 2012).

AmI is post-paradigmatic because the conditions of inquiry within the field reflects and acknowledges the gaps, risks, limits, and discontinuities that AmI paradigm (as called) fails to notice, especially AmI. Gunnarsdóttir and Arribas-Ayllon (2012, p. 16) point out, '[a] striking feature of the AmI narrative is continuous modulation of promises… But we also identify highly reflexive practices of anticipating possibilities, limitations and dangers, with which the future horizon is modified and adjusted. One is the unique strategy of deliberately complicating the expectations [as 'an innovation practice, subjecting AmI developments to an ever-growing number of disciplines and methodological approaches which require continuous experimentation, monitoring and reporting'] by aggregating disciplines to carefully explore the subtleties of ordinary reasoning, communication and interaction in everyday situations. Another strategy is the world-making that situates AmI in a social economy and a culture undergoing radical changes [i.e., '*accounting* for contingencies is a rhetorical strategy creating worlds in which AmI visions and technologies seek alignment with socio-economic and cultural imaginations, and respond to changes in the global environment)']. The third is to earnestly engage in the contemplation of futures to be avoided.' In line with this thinking, José et al. (2010, p. 1480) argue that the inspiring vision of AmI 'should no longer be the main driver for AmI research' and it is necessary to re-interpret its role; it is time for the AmI field to move behind its foundational vision and thus rethink its currently prevailing assumptions, claims, and approaches, by embracing important emerging trends, among other things. Regardless, even new trends are essentially subject to future interrogations—predicated on the assumption of the perennial changing nature of the configuration of scientific and social knowledge. All in all, in current usage, AmI paradigm (in society or in ICT) can be used in a loose sense of an 'intellectual framework', similar to discourse, and not in Kuhn's specific meaning of an explanatory and meta-theoretical framework. Here discourse refers to a specific, coherent set of concepts, ideas, terminologies, claims, assumptions, visions, categorizations, and stories that are constructed, reconstructed, transformed, and challenged in a particular set of social practices—in other words, that are socially specific and historically contingent and that generate (discursive) truth effects, e.g., meaning and relevance is given to social realities.

2.10 Technological Factors Behind the AmI Vision

The main goal of AmI is to make computing technology everywhere, simple to use and intuitive to interact with, and accessible to people with minimal technical knowledge. The AmI vision is evolving towards an achievable and deployable computing paradigm, thanks to the recent advances in embedded systems, microelectronics, wireless communication networks, multimodal user interfaces, and intelligent agents. These enabling technologies are expected to evolve even more. They are a key prerequisite for realizing the AmI vision, especially in terms of its UbiComp vision. This is about the technology necessary for turning it into reality, making it happen. AmI systems are increasingly maturing and proliferating across a range of application domains.

Embedded systems constitute one of the components for ambience in AmI. AmI is characteristically embedded: many networked devices are integrated into the environment. The recent advances in embedded systems have brought significant improvements. Modern embedded systems, which are dedicated to handle a particular task, are based on microcontrollers (i.e., processors with integrated memory and peripheral interfaces). An embedded system is a computer system with a dedicated task, often with reactive computing—hardware and software systems are subject to a real-time computing constraint, e.g., operational deadlines from event to system response (e.g., Ben-Ari 1990), and is *embedded* as part of a complete device often including electrical and mechanical parts—within a larger mechanical or electrical system. Further, there are different approaches to processors (e.g., general purpose, specialized, custom designed, etc.). Embedded systems differ in size and cost, reliability, performance, and complexity, depending on the type of the tasks they are dedicated to handle. As a common application today, many devices can be controlled by embedded systems.

The progress of microelectronics has altered the nature of computing devices. Advances in electronic components (increasing capacity of computing power and storage) every 18–24 months at fixed costs has significantly affected many aspects of computing capabilities, including processing power, computational speed, memory, energy optimization, performance, efficiency, and so on. This has made it possible to entrench computing devices in everyday objects, a trend which is rapidly evolving. In particular, miniaturization has been a key factor for incorporating multiple smart sensors and microprocessors in everyday objects. There is already a huge amount of invisible computing devices embedded in laptops, mobile phones, wearable computers, and various types of appliances. Sensors are increasingly being manufactured on a microscopic scale, and this will with AmI continue to increase exponentially. Computing devices are increasingly equipped with quantum-based processing capacity and linked by mammoth bandwidth wireless networks with limitless connectivity, ushering in the era of the always-on, interconnected computing resources. This also relates to the the IoT: the interconnection of uniquely identifiable embedded devices, physical and virtual objects, and smart objects, using embedded systems, intelligent entities, and communication and sensing-actuation capabilities to interact with each other and with the environment via the Internet.

Recent advances in wireless and mobile networking technologies have drastically improved the capacity (mega-bandwidth), speed, energy efficiency, availability, and proliferation of communication networks. The three decade development in these technologies has enabled the idea of the massively distributed, embedded computing devices characteristic to AmI computing to become networked or connected.

HCI has evolved over the last four decades, from an explicit timely bidirectional interaction between the human user and the computer system to a more implicit multidirectional interaction. The shift from explicit means of human inputs to more implicit forms of inputs implies supporting natural human forms of communication and thus natural interaction. In desktop applications, graphical user interfaces (GUIs) as commonly used approaches are built on event based interaction, a direct dialog which occurs as a sequence of communication events between the user and the system (Schmidt 2005). This explicit HCI approach works through a user conforming to static devices (e.g., keyboard, mouse, touch screen, and visual display unit) using them in a predefined way. Various types of explicit user interface can be distinguished, including batch interfaces, command line interfaces, graphical user interfaces (GUIs), Web user interfaces (WUI), natural-language interfaces, touch screen, and zooming user interfaces (see Chap. 6 for more detail). Common to all explicit user interfaces is that the user explicitly requests an action from the computer, the action is carried out by the computer, and then the system responds with an appropriate reply. In AmI computing, on the other hand, the user and the system are in an implicit interaction where the system is aware of the context in which it operates or is being used and responds or adapts its behavior to the respective context. This relates to iHCI: 'the interaction of a human with the environment and with artifacts' as a process which entails that 'the system acquires *implicit input* from the user and may present *implicit output* to the user' (Schmidt 2005, p. 164). Hence, iHCI involves a number of the so-called naturalistic user interfaces, including facial user interfaces, gesture user interfaces, voice interfaces, motion tracking interfaces, eye-based interfaces, and so on.

The intelligent agent as a paradigm became widely recognized during the 1990s (Russell and Norvig 2003; Luger and Stubblefield 2004), a period that marked the emergence of UbiComp vision. In computing, the term 'intelligent agent' may be used to describe a software agent that has some intelligence, a certain degree of autonomy, ability to react to the environment, and goal-oriented behavior. There are many different types of agents (see Chap. 6), but common to all of them is that they act autonomously on behalf of users—decide and execute tasks on their own autonomy and authority. Intelligent agents represent one of the most promising technologies in AmI—intelligent user interfaces—because they are associated with computational capabilities such as adaptation, responsiveness, and anticipation relating to service delivery. Accordingly, capture technologies, pattern recognition techniques, ontological and hybrid modeling and reasoning techniques, and actuators have attracted increasing attention as AmI computing infrastructures and wireless communication networks become financially affordable and technically matured.

In all, intelligent environments, in which AmI can exist, which involve the home, work, learning, and social settings, are increasingly becoming computationally augmented: equipped with smart miniature sensors and actuators and information processing systems. These intelligent environments will be commonplace in the very near future. This can be explained by the dramatic reduction in the cost and the advancement of computing, networking, and communication technologies, which have indeed laid the foundations for the vision of AmI to become an achievable computing paradigm. In sum, it can be said that AmI is primarily based on technological progress in the aforementioned fields. The required research components in which significant progress has to be made in order to further develop and realize the AmI vision include: in terms of ambient components, MEMS and sensor technology, embedded systems, ubiquitous communications, input and output device technology, adaptive software, and smart materials, and in terms of intelligence component, contextual awareness, natural interaction, computational intelligence, media handling and management, and emotional computing (ISTAG 2003).

2.11 Research Topics in AmI

2.11.1 Computer Science, Artificial Intelligence, and Networking

As a result of the continuous effort to realize and deploy AmI paradigm, which continues to unfold due to the advance and prevalence of multi-sensory, miniaturized devices, smart computing devices, and advanced wireless communication networks, all AmI areas are under vigorous investigation in the creation of smart environments, ranging from low-level data collection (i.e., sensing, signal processing, fusion), to intermediate-level information processing (i.e., recognition, interpretation, reasoning), to high-level application and service delivery (i.e., adaptation and actions), to networking and middleware infrastructures. As a multidisciplinary paradigm and a 'crossover approach', AmI is strongly linked to a lot of topics related to computer science, artificial intelligence, and networking.

In terms of computer science, artificial intelligence, and networking, topics include, and are not limited to: context-aware, situated, affective, haptic, sentient, wearable, invisible, calm, smart, mobile, distributed, and location computing; embedded systems; knowledge-based and perceptual user interfaces; microprocessors and information processing units; machine learning and reasoning techniques; ontological modeling and reasoning techniques; real-time operation systems; multi-agent software; human-centered software engineering; sensor systems and networks; MMES and NMES; multimodal communication protocols; wireless and mobile communication networks; smart materials for multi-application smart cards; embodied conversational agents; and so forth (Punie 2003; Bettini et al. 2010; Schmidt 2005; Oulasvirta and Salovaara 2004; Chen and Nugent 2009; Picard 2000; Senders 2009; Lyshevski 2001; Vilhjálmsson 2009).

To create AmI environments requires collaboration between scholars and experts from several research areas of AmI, which can be clustered into: ubiquitous communication and networking, context awareness, intelligence, and natural HCI. The first area involves fixed, wireless, mobile, and ad-hoc networking systems, discovery mechanisms, software architectures, system integration, and mobile devices. The second area encompasses sensors, smart devices, and software architectures for multi-platform interfaces, as well as capture, tracking, positioning, monitoring, mining, and aggregation techniques. The third area includes pattern recognition algorithms, ontological modeling and reasoning, and autonomous intelligent decision making. The last area involves multimodal interaction, hypermedia interfaces, and agent-based interfaces. These areas have some overlaps among them.

2.11.2 Middleware Infrastructure

In addition to the above is the research area of middleware architecture (e.g., Azodolmolky et al. 2005; Strimpakou et al. 2006; Soldatos et al. 2007). It is important to highlight the key role of middleware in AmI. (This topic is beyond the scope of this book.) Indeed, advances in middleware research are critically important, as middleware represents the logic glue: it connect several kinds of distributed components, in the midst of a variety of heterogeneous hardware systems and software applications needed for realizing smart environments and their proper functioning. Put differently, in order for the massively embedded, distributed, networked devices and systems, which are invisibly integrated into the environment, to coordinate require middleware components, architectures, and services. Middleware allows multiple processes running on various sensors, devices, computers, and networks to link up and interact to support daily activities wherever needed. It is the coordination and cooperation between heterogeneous devices, their ability to communicate seamlessly across disparate networks, rather than their wide spread presence that create AmI environments. These are highly distributed, heterogeneous, and complex, involving myriad computing devices whose numbers are set to continuously increase by orders of magnitude and which are to be exploited in their full range to transparently provide services on a hard-to-imagine scale, regardless of time and place. AmI infrastructures are highly dynamic, while featuring a high degree of heterogeneity (e.g., Johanson et al. 2002; Garlan et al. 2002), and middleware boosts interoperability, integration, cooperation, and dynamicity (e.g., sensors join and leave the AmI infrastructure in a dynamic fashion) necessary to support highly heterogeneous and distributed components (e.g., agents) and scalable systems.

Middleware components are intended to provide information on people and objects—to identify them and their behavior, activities, actions, and locations in the scope of multi-sensor indoor and outdoor infrastructures. Therefore, middleware is crucial for context representation, interpretation, and management. The amalgamation of sensing technologies, ubiquitous computing, and distributed middleware aims at creating a new generation of pervasive or AmI services. Distributed processing is empowered by middleware components for transfer of signals from various sources and for realizing information fusion from multiple perceptive components (Azodolmolky et al. 2005). Moreover, middleware can be used to support and deploy data-centric distributed systems, such as network-monitoring systems, sensor networks, the dynamic Web whose ubiquitous presence creates very large application networks that spread over large geographical areas. It is increasingly evident that intensive processing, the massive data dissemination, and intelligent fusion in order to build dynamic knowledge bases are becoming achievable, owing to the recent advances and innovation solutions to operating efficiencies, easing application and networking development; enhancing data management, and boosting interoperability between applications. Therefore, supporting AmI systems and applications necessitates a wide range of middleware components, especially components for context awareness for it relies on gathering a huge amount of implicit contextual information from distributed sensors.

Building middleware infrastructures of such magnitude, multi-layering, and complexity requires enormous research endeavor in design and engineering. Middleware is one of the main technical and engineering challenges, as AmI requires complex middleware components and architectures. There is a need to develop new middleware technologies for adaptive, reliable, and scalable handling of high-volume dynamic information flows for coping with the complexity of the unprecedented extensity and velocity of information flow, constantly changing underlying network connectivity, dynamic system organization, high sensitivity and real-time processing of data, and massive volatile and unpredictable bursts of data at geographically dispersed locations.

2.12 Human-Directed Sciences and Artificial Intelligence in AmI: Disciplines, Fields, Relationships, and Contributions

Directed at humans, AmI is moreover strongly linked to a number of fields and subfields related to human-directed sciences. These include, but are not limited to: cognitive psychology, cognitive science, cognitive neuroscience, human communication, linguistics, philosophy, sociology, and anthropology; a brief account of these disciplines is provided below. Especially, the class of AmI applications on focus in this book exhibits human-like understanding and intelligent supporting behavior in relation to cognitive, emotional, social, and conversational processes and behaviors of humans. The human-directed sciences are in AmI associated with modeling in terms of incorporating related knowledge into AmI systems to enhance their computational understanding and thus inform and guide their behavior, with design in terms of how AmI systems should be constructed to better suit implicit and natural forms of interaction with human users, and with, more broadly, HCI, which is highly interdisciplinary: it studies humans and computers in conjunction, and thus integrates a range of academic human-directed disciplines (see Chap. 5 for more detail).

2.12.1 Cognitive Psychology

Psychology is the scientific study of the processes and behavior of the human brain. Cognitive psychology is one of the recent psychological approaches and additions to psychological research. It is thus the subfield of psychology that studies internal mental information-manipulation processes and internal structures and representations used in cognition between stimulus and response (e.g., Galotti 2004; Passer and Smith 2006). The core focus of cognitive psychology is on how humans process information. Mental processes are the brain activities that handle information when sensing and perceiving objects and situations, storing information, solving problems, making decisions, learning, processing language, reasoning, and so forth. The school of thought derived from the cognitive approach is known as cognitivism, which is a theoretical framework for understanding the mind. Cognitivists argue that thinking is so essential to psychology that the study of thinking should become its own field (Lilienfeld et al. 2009). The cognitive approach has achieved a phenomenal success, which is manifested in its current dominance as the core model in contemporary psychology (e.g., Frijda 1986; Cornelius 1996; Scherer et al. 2001; Ortony et al. 1988; Russell 2003; Galotti 2004; Passer and Smith 2006). The information processing view is supported by many years of research. Additionally, cognitive psychology has fueled a generation of productive research, yielding deep and fertile insights into many aspects of cognition. Major research areas in cognitive psychology include: sensation (e.g., sensory modalities, sensory memory); perception (e.g., attention, pattern recognition); categorization (e.g., categorical judgment and classification, category representation and structure); memory (e.g., emotion and memory, working memory, short-term memory, long-term memory, semantic memory); knowledge presentation (e.g., mental imagery, propositional encoding); language (e.g., grammar, phonetics, language acquisition, language understanding and production); thinking (e.g., decision making, formal and natural reasoning, problem solving); emotion (e.g., cognitive appraisal processing, neuro-physiological arousal); but to name a few. There are numerous practical applications for cognitive psychology research, including ways to improve memory, how to stimulate creativity, how to enhance decision-making accuracy, how to facilitate problem solving, how to enhance learning, and so forth. Recently, cognitive psychology has started to focus on the study of the relationship between cognition and emotion, as perception grew among cognitive psychologists that cognition is impossible without emotion. Emotion studies have contributed to 'ground cognitive psychology—which has had a penchant for the abstract—in the real-world, uncovering important science behind' how people make decision in all walks of life (Lehrer 2007). Most of the above research areas are of interest to cognitive science research based on complex representations and computational processes.

2.12.2 Cognitive Science

Cognitive science is concerned with the interdisciplinary scientific study of cognition, intelligence, or mind as information processors. It thus draws on a number of research disciplines (analytical fields), embracing cognitive psychology, computer science, cognitive neuroscience, neurophysiology, linguistics, cognitive and cultural anthropology, philosophy (especially the philosophy of mind and language), communication, and so on. The shared concern is the quest for understanding the nature of the mind. Cognitive science investigates how information is sensed, perceived, represented, processed, stored, and transformed in the human brain or computer systems. It involves researchers from several fields exploring new areas of mind and developing theories based on human and computational complex representations and processes. Some cognitive scientists limit their study to human cognition, while others consider cognition independently of its implementation in human or computers: 'cognition, be it real or abstract, human or machine' (Norman 1981, p. 1). Given its interdisciplinary nature, cognitive science espouses a wide variety of scientific research methodologies, among which include behavioral experiments, brain imagery, and neurobiological methods, in addition to computational modeling or simulation. While cognitive science encompasses a wide range of subject areas on cognition, it does not deal equally with every subject area that might be relevant to the functioning of the human mind or intelligence. Among the topics, which normally cover a wide range of intelligent behaviors, include, but are not limited to, knowledge representation, knowledge and processing of language, learning, memory, formal reasoning, perception and action, and artificial intelligence.

2.12.3 Artificial Intelligence (AI)

AI is the branch of computer science (defined above) that is concerned with understanding the nature of human intelligence (e.g., cognitive intelligence, emotional intelligence, social intelligence, and conversational intelligence), and creating computer systems capable of emulating intelligent behavior. Cognitive intelligence as a general mental capability entail, among other things, the ability to make think abstractly, reason, comprehend complex ideas, learn from experience, plan, make decisions, and solve problems. For what emotional, social, and conversational intelligences entail in relation to AmI, see Chap. 1—introduction. AI also refers to the modeling of intelligent cognitive and behavioral aspects of humans into machines, such as learning, reasoning, problem solving, perception, planning, creativity, language production, actuation, and so forth. John McCarthy, who coined the term in 1956, defines AI as 'the science and engineering of making intelligent machines' (McCarthy 2007). Another common definition of AI is the study of intelligent agents, systems which perceive their environment and make decisions and take actions that increase their chances of success (see, e.g., Russell and Norvig 2003; Poole et al. 1998; Luger and Stubblefield 2004). In all, while there are many definitions of AI in the literature, a common thread running through all definitions is the study of cognitive phenomena or the simulation of human intelligence into machines. Implementing aspects of human intelligence in computer systems is one of the main practical goals of AI. In relation to AmI, to simulate intelligence into computers, that is, to enable AmI systems to emulate intelligent behavior, entails augmenting such systems with such capabilities as sensation, perception (recognition and interpretation), reasoning, decision making, actuation, and so on, as well as awareness of the cognitive, emotional, social, and environmental dimensions of the user context, adding to responsiveness to task commands transmitted through voice, facial expression, or gestures.

Research in AI is characterized by high specialization, deeply separated into dedicated subfields that often fail to connect with each other (McCorduck 2004). The lack of interdisciplinary and collaborative research endeavors is a major concern in the field of AI. McCorduck (2004, p. 424) writes: 'the rough shattering of AI in subfields-vision, natural language, decision theory, genetic algorithms, robotics…and these with own sub-subfield-that would hardly have anything to say to each other'.

AI has become an essential part of the ICT industry, providing solutions for the most complex problems encountered in computer science (Russell and Norvig 2003; Kurzweil 2005). Especially, AI systems have greatly improved for the last decade (Sanders 2009). It is decisive in AmI research and practice. Computer intelligence combines a wide range of advanced technologies, such as machine learning, artificial neural networks, multisensory devices, data fusion techniques, modeling techniques, context awareness, natural HCI, computer vision, intelligent agents, and so forth.

2.12.4 Relationship Between Cognitive Psychology, Cognitive Science, and AI

Cognitive psychology, cognitive science, and AI involve the study of the phenomenon of cognition or intelligence, with cognitive psychology focused on the nature of cognition in humans, cognitive science in both humans and computers, and AI particularly in machines and computers. With aiming and sharing the interest to understand the nature and organizing principles of the mind, they involve low-level perception mechanisms and high-level reasoning and what they entail, thereby spanning many levels of analysis. They all pride themselves on their scientific basis and experimental rigor. As contributors to the cognitive evolution, they are built on the radical notion that it is possible to study, with scientific precision, the actual processes of thought. Insofar as research methods are taken to be computational in nature, AI has come to play a central role in cognitive science (Rapaport 1996). And given its interdisciplinary nature, cognitive science espouses a wide variety of methodologies, drawing on scientific research methods from cognitive psychology, cognitive neuroscience, and computer science. Cognitive science and AI use computer's intelligence to understand how humans think. Computers as tools are widely used to investigate various cognitive phenomena. In AI, computational modeling makes use of simulation techniques to investigate how human intelligence may be structured (Sun 2008). Testing computer programs by how they can accomplish what they can accomplish is said, in the field of AI, to be doing cognitive science: using AI to understand the human mind. Cognitive science also provides insights into how to present information to or structure knowledge for human beings so they can use it most effectively in terms of processing and manipulation. In addition, cognitive science employs cognitive paradigms to understand how information processing systems such as computers can simulate cognition or how the brain implements information-processing functions. In relation to this, del Val (1999) suggests that in order for cognitive psychology to be useful to AI, it needs to study common-sense knowledge and reasoning in realistic settings and to focus on studying how people do well the things they do well. Also, analyzing AI systems provides 'a new understanding of both human intelligence and other intelligences. However, it is difficult to study the mind with a similar one—namely ours. We need a better mirror. As you will see, in artificial intelligent systems we have this mirror' (Fritz 1997). Moreover, both cognitive scientists and cognitive psychologists were the antagonists of reason and therefore tended to reinforce the view that emotions interfere with cognition, and now discovered, building on almost more than two decades of mounting work, that it is impossible to understand how we think without understanding how we experience emotions. This area of study has become of prime focus in AI—specifically affective computing—in the recent years (addressed in the previous chapter).

Furthermore, core theoretical ideas of cognitive science, of which psychology is the thematic heart, are drawn from AI; many cognitive scientists try to build functioning models of how the mind works. AI is considered as one of the fields (in addition to linguistics, neuroscience, philosophy, anthropology, and psychology) that contributed to the birth of cognitive science (Miller 2003). Cognitive science could be synonymous with AI when the mind is understood as something that can be simulated through software and hardware—a computer scientist's view (Boring 2003). AI and cognitive psychology are a unified endeavor, with AI focused on cognitive science and ways of engineering intelligent entities. Cognitive psychology evolved as one of the significant facets of the interdisciplinary subject of cognitive science, which attempts to amalgamate a range of approaches in research on the mind and mental processes (Sun 2008). Owing to the use of computational metaphors and terminology, cognitive psychology has benefited greatly from the flourishing of research in cognitive science and AI. One major contribution of cognitive science and AI to cognitive psychology is the information processing model of cognition. This is the dominant paradigm in the field of psychology, which is a way of thinking and reasoning about mental processes, envisioning them as software programs running on the computer as a human brain. In this account, humans are viewed as dynamic information processing systems whose mental operations are described in computational terminology, e.g., inputs, structures, representations, processes, and outputs, and metaphors, e.g., the mind functions as a computer. The cognitive revolution was, from its inception, guided by the metaphor that the mind is like a computer, and 'cognitive psychologists were interested in the software' programs, and this 'metaphor helped stimulate some crucial scientific breakthroughs. It led to the birth of AI and helped make our inner life a subject suitable for science' (Lehrer 2007). 'The notion that mental states and processes intervene between stimuli and responses sometimes takes the form of a "computational" metaphor or analogy, which is often used as the identifying mark of contemporary cognitive science: The mind is to the brain as software is to hardware; mental states and processes are (like) computer programs implemented (in the case of humans) in brain states and processes' Rapaport (1996, p. 2). All in all, advances in AI, discoveries in cognitive science, and advanced understanding of human cognition (information processing system) are, combined, generating a whole set of fertile insights and new ideas that is increasingly altering the way we think about how we think and how we should use this understanding to advance technology towards the level of human functioning. One corollary of this is the socio-technological phenomenon of AmI, especially the intelligent behavior of AmI systems associated with facilitating and enhancing human cognitive intelligence, thanks to cognitive context awareness and natural interaction.

2.12.5 Contributions of Cognitive Disciplines and Scientific Areas to AmI

One of the significant contributions of cognitive science and AI to computing is the creation and implementation of computer systems that are capable of emulating human intelligent behavior. AmI technology represents an instance of this wave of computing. In the recent years, the evolution of cognitive science and the advancement of AI have provided the ground for the vision of AmI to become a reality, enabling AmI systems to evolve rapidly and spread across a whole range of areas of applications. At present, tremendous opportunities reside in deploying and implementing AmI systems on different scales, intelligence, and distribution, thanks to AI. To iterate, AI has become an essential part of the ICT industry, providing solutions for the most difficult problems in computing (Russell and Norvig 2003; Kurzweil 2005). AmI systems are increasingly performing well towards emulating many aspects of human intelligence, by becoming highly intelligent entities due in large part to the advance and prevalence of AI techniques. The engineering, design, and modeling of such entities is made possible by simulating the human mind—as complex mental information-manipulation processes. The cognitive science view of humans as dynamic information processing systems whose mental operations are described in computational terminology (e.g., sensory inputs, artificial neural networks, knowledge representation, reasoning mechanisms, outputs, etc.) has led to simulating 'broad areas of human cognition' (Vera and Simon 1993)—i.e., implementing human cognitive models into computer systems, which has enabled the vision of AmI to become deployable and achievable as a computing paradigm.

Examples of AI processes and models which emulate human cognition as an information processing system, which have been utilized in AmI systems, include sensing (inspired by human sensory receptors), artificial neural networks (inspired by the structure of biological neural networks), reasoning/inference (inspired by the cognitive ability to connect concepts and manipulate them mentally to generate abstractions or descriptions), and perception and action (inspired by the ability of biological actuators that perceive a stimulus and behave in response to it). Human-made actuators are devices that receive signals or stimulus and respond with torque or force while biological actuators are based upon electro-magnetic-mechanical-chemical processes and accomplished through motor responses. Computer system outputs can be classified into different types of actuators.

AmI systems can perform in a human-brain like fashion and are even projected to perform more powerfully than humans—in some instances. One of the goals of AI is to develop complex computers that surpass human intelligence. Indeed, general intelligence (known as strong or classical AI), which matches or exceeds human intelligence continues to be among the field's long-term goals (Kurzweil 1999, 2005). While both AI and AmI face the challenges of achieving a human-level understanding of the world, Leahu et al. (2008) claim this is the reason why AmI is failing to scale from prototypes to realistic systems and environments. However, next-generation AI is aimed at the construction of fully integrated artificial cognitive systems that reach across the full spectrum of cognition, from low-level perception/action to high-level reasoning. At the current stage of joint research between AI and AmI, AmI systems seem to be able—in laboratory settings—to emulate many aspects of cognitive intelligence as a property of the mind, encompassing such capacities as to learn from and leverage on human behavior, to adapt, to anticipate, to perform complex inferences, to make decisions, to solve problems, to perceive and produce language (e.g., speech acts with prosodic features and facial gestures), and so on. This computational intelligence of AmI systems is being extended to include abilities of facilitating and augmenting cognitive intelligence in action, by understanding, a form of mindreading of various cognitive dimensions of the user context, and undertaking actions in a knowledgeable manner that support the user's cognitive needs. One key aim of AI is to use the computational power of computer systems to augment human intelligence in its various forms.

The complexity of AmI systems that results from their dynamic nature and the need to provide controllable environment for people constitutes a long-term opportunity for the application of AI research. In order to realize the idea of AmI, researchers must employ the state-of-the-art AI techniques. As regards the integration of AI with AmI with the aim to stimulate joint research among scholars working in the field of computer science, vigorous investigations are active on diverse computing topics, including design of smart and miniaturized sensing and computing devices, embedded and distributed computing, modeling formalism languages, knowledge representation and reasoning, service management, intelligent agent-based architectures, multi-agent software, real-time operation systems, naturalistic and knowledge-based user interfaces, natural language processing, speech and gesture recognition, computer vision, machine learning and reasoning, complex decision making, multimodal communication protocols, and so on. These topics constitute currently the focus areas within AI research.

Cognitive science is widely applied across several fields and has much to its credit, owing to its widely acknowledged accomplishments beyond AI and AmI. It has offered a wealth of knowledge to the field of computing and computer science, especially foundational concepts and theoretical models which have proven to be valuable and seminal in the design and modeling of computing systems—the way they cognitively function and intelligently behave (e.g., social intelligence, emotional intelligence, and conversational intelligence). Indeed, it is widely acknowledged that it is the major stride the cognitive science has made in the past two decades, coupled with recent discoveries in computing and advances in AI that has led to the phenomenon of AmI, a birth of a new paradigm shift in computing and a novel approach to HCI. In more detail, the amalgamation of recent discoveries in cognitive science—that make it possible to acquire a better understanding of the cognitive information processing aspects of human mind, and the breakthroughs at the level of the enabling technologies and computational processes and capabilities (e.g., context awareness, natural interaction, and intelligent behavior) make it increasingly possible to build ground-breaking intelligent (human-inspired) systems based on this understanding. This new development entails advanced knowledge in human functioning as to cognitive, emotional, behavioral, and social aspects and processes and how they interrelate, coupled with innovations pertaining to system engineering, design, and modeling. Moreover, the evolving wave of research in computing has given rise to, and continues to inspire, a whole range of new computing trends, namely, hitherto, context-aware, affective, haptic, situated, invisible, sentient, calm, and aesthetic computing. In particular, the interdisciplinary research approach increasingly adopted in the field of computing is qualitatively shaping research endeavors towards realizing the full potential of AmI as a computing paradigm. This approach has generated a wealth of interactional knowledge about the socio-technological phenomenon of AmI.

Cognitive science spans many levels of analysis pertaining to human mind and artificial brain, from low-level sensation, perception, and action mechanisms to high-level reasoning, inference, and decision making. This entails a range of brain functional systems, including cognitive system, neural system, evaluation system, decision system, motor system, monitor system, and so forth. One major research challenge in AmI is to create context-aware computers that are able to adapt in response to the human users' cognitive states and processes, with the aim to facilitate and enhance their cognitive intelligence abilities when performing tasks in a variety of settings.

2.12.6 Neuroscience and Cognitive Neuroscience

Neuroscience is the interdisciplinary scientific study of the nervous system; it collaborates with such fields as computer science, AI, engineering, mathematics, linguistics, psychology, philosophy, and so on. The neuroscience has made major strides in the past two decades with regard to advancing the understanding of neurological patterns underlying affect, emotion, attention, and behavior. Ontologies and knowledge from neurological disciplines are key components of AmI applications—the structure of ambient software and hardware design. Neurocognitive science is of particular relevance to presence technology covered in Chap. 9.

Cognitive neuroscience is the interdisciplinary scientific study of higher cognitive functions (e.g., object recognition, reasoning, language understanding, etc.) in humans and their underlying neural substructures (bases), neural substrates of mental processors as part of biological substrates. As an integrative field of study, it draws mainly from cognitive science, cognitive psychology, neuroscience, and computer science. It also has backgrounds in linguistics, philosophy, neurobiology, neuropsychology, bioengineering, and so on. In investigating how cognitive functions are generated by neural circuits in the brain, it relies upon theoretical models in cognitive science and evidence from computational modeling and neuropsychology. As its main goal is to understand the nature of cognitive functions from a neural perspective, it entails two strands of research: behavioral strand, using a combination of behavioral testing (experimental paradigm), and computational strand, using theoretical computational modeling. In all, the concern of cognitive neuroscience is to advance the understanding of the link between cognitive phenomena and the underlying neural substrate of the brain.

2.12.7 Linguistics: Single and Interdisciplinary Subfields

Linguistics is the scientific study of natural language, the general and universal properties of language. It covers the structure, sounds, meaning, and other dimensions of language as a system. Linguistics encompasses a range of single and interdisciplinary subfields. Single subfields include morphology, syntax, phonology, phonetics, lexicon, semantics, and pragmatics, and Interdisciplinary subfields include sociolinguistics, psycholinguistics, cognitive linguistics, and neurolinguistics (see Chap. 6 for a detailed account). It collaborates with AI, cognitive science, cognitive psychology, and neurocognitive science. Chapter 6 provides an overview addressing the use of computational linguistics: structural linguistics, linguistic production, and linguistic comprehension as well as psycholinguistics, neurolinguistics, and cognitive linguistics in relation to conversational agents and other AI systems.

2.12.8 Human Communication

Human communication is the field of study that is concerned with how humans communicate, involving all forms of verbal and nonverbal communication. As a natural form of interaction, it is highly complex, manifold, and dynamic, making humans the most powerful communicators on the planet. To communicate with each other and convey and understand thoughts, feelings, messages, opinions, or information, humans use a wide variety of verbal and nonverbal communicative behaviors. As body movements, such behaviors are sometimes classified into micro-movements (e.g., facial expressions, facial gestures, eye movement) and macro-movements (e.g., hand gestures, body postures/corporal stances), in addition to speech and its prosodic, paralinguistic, and extra-linguistic features. They have been under vigorous investigation in the creation of AmI systems for context-aware adaptive and responsive, dialog acts, and explicit natural (touchless) interactive services, as they can be utilized as both explicit and implicit inputs for interface control and interaction.

The human-directed sciences or disciplines covered thus far have been at the core of the study, design, development, and implementation of AmI systems. AmI represents a class of applications that is characterized by human-like cognitive, emotional, and behavioral (conversational and social) understanding, interacting, and supporting behaviors as computational capabilities. All in all, the aim of AmI as a novel approach to HCI is to come closer to the aim of creating interaction between humans and systems that is closer to natural and social interaction, by mimicking the most pertinent aspects and processes of human functioning.

2.12.9 Philosophy

In this context, philosophy is concerned with general and fundamental questions and problems associated particularly with reality, values, and language (see Teichmann and Evans 1999). Accordingly, reality is the conjectured state of technological artifacts and environments—human-like or intelligent interactive entities—as they in point of fact exist and will exist as well as some of their aspects that are or might be imagined in the inspiring vision of AmI—aspects of limited or no modern applicability with reference to intelligent interaction in both real and cyber spaces. This also includes re-imagining and rebuilding expectations about the potential and role that new ICT as smart artifcats and environments will have in shaping the everyday of the future and the way people construct their lives, in particular in relation to what the prevailing notion and assumption of intelligence in the vision of AmI stands for or can possibly stand for. Especially, AmI scenarios are constructed in ways that treat AmI as an 'imagined concept' (ISTAG 2003), and thus represent visions of lifeworlds inhabited by potential human users who are imagined. This pertains to what modern philosophers or thinkers refer to as thoughts of things that are conceivable as coherent abstractions but not real. As to values, AmI is associated with both human and ethical values in the sense that technologies may pose risks to such values. Human values, for which consideration are unlikely to be made more explicit, or which may not be taken into account, in the fundamental design choices that shape AmI technology can include hedonism (pleasure and aesthetics) and other high-level values such as self-direction (independent thought and action), creativity, ownership, freedom, togetherness, and so on. Ethical values are associated predominantly with privacy, trust and confidence, security (safety, harmony, and stability of self), and so forth. As philosophical fields, ethics (which is concerned with the concepts of ‘right’ and ‘good’ in relation to individual and social behavior) and aesthetics (which investigates the concepts of ‘beauty’ and ‘pleasure’—see Chap. 9 for a detailed account) form the field of axiology (e.g., von Hartmann 1908), which is the philosophical study of values. As regards to language, in the context of AmI, it pertains to the perceived ability of AmI systems to mimic verbal and nonverbal human communication behavior so to become able to engage in intelligent dialog or mingle socially with human users (see Chap. 7). Thus, philosophy of language in this context deals with such fundamental problems as the nature and origin of meaning—what it means to mean something and what underlies meaning, language use—understanding and producing speech acts, and the relationship between language and social reality—how it is used pragmatically and socioculturally in terms of situational and cultural context. And the philosophical perspective in this book is of a critical and analytical nature in the way of addressing the various problems in question.

2.12.10 Sociology and Anthropology (Social, Cultural, and Cognitive)

Sociology is the academic study of social behavior—i.e., behavior directed towards society, which in a sociological hierarchy is followed by social actions from people and directed at other people. Social processes as forms of social interactions and social relations come further along this ascending scale. It is concerned with such aspects of social behavior as development, structure, institutions, and roots. As a social science, it relates to AmI from the perspective of social change, social processes, social interaction, social structure, and so on. Drawing on social sciences and humanities, among others, anthropology is the scientific study of past and present humans. It entails social anthropology and cultural anthropology which emphasize, respectively, cross-cultural comparisons (e.g., relationships between the traits of a few societies) and examination of social context, and cultural relativism (e.g., others’ understanding of individuals’ beliefs and activities in terms of their own culture) and holism (e.g., viewing properties of social systems as wholes, not as sums or collections of parts), among others. As an approach within cultural anthropology, cognitive anthropology is concerned with the ways in which people perceive and think about aspects of the world, physical and social reality, seeking to explain patterns of shared knowledge (e.g., scientific discourse), cultural innovation (e.g., AmI, ICT, etc.), among others, using cognitive science methods and theoretical frameworks, coupled with insights from history, linguistics, ethnography, hermeneutics, and so on. Cognitive anthropology serves as a link between the material and ideational aspects of culture and human cognitive or thought processes

(D'Andrade 1995). Rooted in cultural relativism, it deals with the implicit knowledge of people from different groups and how such knowledge changes the way people perceive and connect with the world around them (Ibid). Both sociology and anthropology are social sciences. Social science is the academic study of society and the relationships among individuals that constitute part of society. In AmI, a multidisciplinary team of sociologists, anthropologists, cognitive psychologists, philosophers, designers, engineers, and so forth is required 'to represent realistically the complexities and subtleties of daily human living' (Hartson 2003).

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