Age in Ubiquitous Computing: A Thin Thread

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Abstract

Ubiquitous computing can significantly improve the general public's quality of life worldwide from birth to old age because it allows monitoring, awareness and support in many environments thanks to sensors, actuators, remote connections, and dedicated knowledge bases. However, ageing influences its usefulness and appropriateness due to growth and decline as well as changes in activities and uses of technology. We discuss potential dedicated services with smart spaces and wearable computers based on the cognitive, physical, physiological, and sensory characteristics of young people and older adults. Our main contribution is to show that existing services support few age-specific needs, and that designs miss age-appropriate techniques, taking into account the whole life span with personal, public and shared systems.

1. Introduction

Ubiquitous computing can significantly improve the general public's quality of life worldwide from birth to old age through support for everyday life. Specialists successfully developed useful services like infantry information systems but failed on life-long services for laymen due to excessive focus on young adults and on well-funded domains (e.g. health, military). To fix this lack, we highlight hereafter the needs in and benefits of ubiquity, with a focus on life-long improvements of quality of life and life-long uses of technologies.

Ubiquity relates to continuous contacts with computers that use sensors, actuators and networks. It covers *smart spaces* (aka *intelligent environments*), material environments like streets, offices and houses that react to people and events, as well as *wearable computers* (aka *wearables*), worn by users, embedded in e.g. earrings or clothes. Ubiquity relies on leading edge technologies to typically support health monitoring, communication and context-awareness.

Ubiquitous computing allows support for everyday life, which may improve quality of life. For the sake of simplicity, we will consider that quality of life is the level of objective satisfaction of human fundamental needs [1]. Human fundamental needs are universal but their expression varies due to personal experiences and abilities, culture, gender, and age. We focus first on age because it is usually neglected, because children increasingly access mobile devices (e.g. cellular phones), because elders become more numerous, and because growth and decline induce design complexities. Age influences (1) the nature of services useful to–or needed by–a given user, (2) appropriate designs, and (3) the potential for life-long use of technologies. We will consider other influences ulteriorly.

We first outline ageing in section 2 and evoke the reality of age-related ubiquitous services and of age-appropriate designs in sections 3 and 4. Then, we discuss life-long personal, public and shared ubiquitous services. Finally we conclude on critical research needs.

2. Human characteristics vary with age

Young people (0 to 20 years) and older adults (from 60 years) undergo important cognitive and bodily changes due to phylogeny and ontogeny, by phases for the former, continuously for the latter. For infants, children and adolescents, most changes are predictable because species-wide genetic schemes guide development. However, the abilities of elders change with a high *inter*- and *intra*-individual variability because personal history guides decline. For example, although blindness becomes more common, some people keep good eyesight; decline may plateau then accelerate, etc. Thus the world young population is homogeneous whereas the old one is heterogeneous, with problems emerging from concurrent disabilities.

According to Piaget [2], young people make systematic errors that accumulate and combine with each other due to their approximate understanding of reality. The widening gap between model and reality pushes them to transform their model and to advance through four stages (Table 1). During this progression, concept formation, egocentrism, memory, and world views are of particular interest.

Table 1: Characteristics of young people [2].

Stage	*Age*	*Main characteristics*
Sensorimotor	0-2 years	– Experience through senses, movements – Learning of object permanence
Preoperational	2-7 years	– Acquisition of motor skills – Animism – Centration[1] – Classification of objects – Egocentrism[2] – Use of symbols and words
Concrete operational	7-11 years	– Decentring[3] (end of centration) – Logical thinking about concrete events – End of egocentrism
Formal operational	11+ years	– Abstract reasoning

Concept formation is marked by 3 phases: syncretic heaps, complexes and concepts [3]. Complexes can be confusing as they rely on concrete factual bonds rather than abstract logical bonds; true concepts coexist with them from adolescence.

Egocentrism implies a low ability to distinguish between oneself and others, between what one knows and what others know. It leads to egocentric speech, which happens when a child engages in activities and shares thoughts as a monologue; it is depressed when the kid is alone or obviously not understood [3, pp233-234].

Young children do not understand the uniqueness of events: they retain generic temporal sequences but not event-specific information [4]. Age correlates with all aspects of remembering, and encoding relies on knowledge [5]; understanding, and thus memorization, is guided by children-parent interactions (e.g. follow-ins, *wh-* questions, associative talks, positive appraisals) [5].

Objects influence human development as they stimulate and allow tests about reality; computers may magnify this phenomenon because they can expose virtual worlds and exhibit complex behaviors. Children commonly consider robots, toys and computers as alive and intelligent, and express animism towards them [6]. Besides, things shape a kid's mind during her activities [3, pp39-40]; for example if a pencil breaks while drawing a car, the child may end up drawing a broken car.

Until adolescence, bodily development concerns physical growth, sensory-motor evolutions, and physiological adaptations. Growth, notably influenced by nutrition, can be assessed with references proposed by the National Center for Health Statistics and by the World Health Organization for people up to 20 years [7][8]. Sensory systems are mostly complete at birth (e.g. vestibular system) but some elements fully develop after years (e.g. the visual system matures until puberty [9]), and one must learn perceptual skills. Also, kids' physiology differs from adults': children are more sensitive to heat and cold [10, p659], sleep needs sharply increase during adolescence [11, p116], etc.

Older adults' cognitive abilities decline unequally, control decreases, fatigue increases, and perception and communication are hampered [12][13][14][15]. Their intellect is globally maintained but memory, learning, and attention are impaired. Motor abilities decrease, and physiology is perturbed. Visual and aural abilities decline due to degradations of natural "sensors" and associated processes. Finally, speech turns less distinct.

We encourage readers to consult [16][17] for more details on youth, and [17][18][19] for old age.

3. Existing services support few age-specific needs

Young and old people undergo different changes, with specific consequences on health and daily life. Ubiquity theoretically affords solutions for their problems but applications are limited by hardware issues, real-world complexity, lack of interest in some topics, and lack of psycho-social focus. A few notable realizations include *Lifebelt* [20], *Mamagoose* [21], *Dog@watch* [22], and the arctic suit [23]. *Lifebelt* is a garment that monitors fetal and maternal vital signs during pregnancy. *Mamagoose* is a pajama designed to prevent the sudden infant death syndrome. *Dog@watch* is a wrist-worn wearable that contains an alarm and a wireless communication and location system. The arctic suit warms up the user on demand.

[1] Centration: seeing problems from a single angle.
[2] Egocentrism: seeing things only from one's own point of view.
[3] Decentring: seeing problems from multiple angles simultaneously.

3.1. Physiological needs

Youth and old age impair the maintenance of homeostasis, notably in regard to body temperature. Kids mainly endure a limited tolerance to heat and cold stress but such dysfunctions induce in elders cardiovascular problems, diabetes and dementia. In theory, ubiquitous computers may monitor environment, body and lifestyles, detect behavioral or physiological changes, warm up or cool, and alert. However, in practice, temperature sensors fail because they do not provide inner-body data, monitoring algorithms fail due to real-world complexity, and energy lacks to support thermoregulation except for smart rooms. Alerting is most successful but false positives hamper long-term adoption.

Besides, ubiquitous services may monitor sleep patterns and habits (e.g. light exposition causing drifts of a biological clock) daily to inform medical doctors or advise, as sleep needs vary until adulthood and problems like sleep apnea prevail in elders. Smart spaces may monitor movements with cameras and apnea (marked by loud snoring) with microphones while wearables may exploit accelerometers, microphones, and specific sensors to monitor brain waves. However, such services lack outside hospitals because most people underestimate the importance of sleep.

Finally ubiquitous computers could detect allergens and pollution to limit negative influences on health and growth, and follow food intakes to propose personalized guidance aligning nutrition to growth needs. Allergens/pollution sensors would be most useful in wearables but are still too big to embed. Nutritional monitoring is also difficult because it requires complex data input in restaurants and at home to be reliable; as a consequence existing systems are well below the general public's expectations.

3.2. Safety needs

Infants instinctively explore environments and interact with objects, endangering themselves with risks of falling, drowning or getting burnt. On the contrary, elders know dangers but risks are magnified by loneliness and body condition; for example, falls are a critical risk [24][25] even for seemingly minor accidents:

"[Older people's] skin will just tear, it's like tissue paper. It loses elasticity as you get older, the slightest knock can tear it", ambulance crew [25].

With appropriate sensors (e.g. accelerometers, cameras) and personal data, ubiquitous services can detect dangers, and alert family members or emergency staff. This is the most researched age-related topic in ubiquity, and results are encouraging.

Besides, ubiquitous systems may assess users' evolution in everyday life, and favor growth or slow down decline through e.g. exposure to vocabulary, multimodal stimulations, games, or help to do usual tasks. As far as we know, investigations of such services are rare.

3.3. Belonging needs

During infancy, familial contacts are critical; the others are motivated years later, and social life remains limited due to egocentrism, which reduces the usefulness of ubiquity before 7-8 years. Smart spaces offer limited links in public due to privacy issues and outdoors due to lack of equipment but wearables offer permanent continuous links; the broad diffusion of cellular phones among kids shows little work is now *required* to maintain distant relationships, even during stressful separations. Besides, ubiquity may compensate for a lack of social contacts by providing appropriate artificial companions but much research is required to investigate their effects on human psyche at different ages.

Although still a significant need, elders' contacts rarefy due to reduced mobility, energy, memory, and communication abilities. Only systems such as *HAL* exoskeletons [26] increase mobility but smart spaces and wearables may all reduce the need itself with enhanced remote communication. Finally, ubiquitous services can already remind faces and names at appropriate moments thanks to cameras and RFIDs, but lack efficient algorithms to clarify discussions in real-time (e.g. noise filtering, transposition of frequencies, display of speech on screens).

3.4. Esteem needs

Successful achievement of various activities is critical for children to learn and to properly develop their personality. Ubiquitous services may provide knowledge required to understanding events and fixing memories in everyday life; smart spaces can provide more numerous and more relevant information about events but wearables can provide information more relevant to the user's specific abilities and knowledge. Although context-awareness has been much researched since 2000, such systems are apparently still missing.

In regard to self-esteem, elders' key concerns are to maintain or regain independence and freedom to take risks [25], and to avoid looking dependent or old [14]. Existing systems could supply information to reactivate memories and help complete tasks but elders reject them because bystanders may notice something, especially in public shared environments, which highlights the need for more social investigations.

3.5. Self-actualization needs

Finding one's (metaphorical) way is a core aspect of self-actualization. In theory, ubiquity can serve to continuously archive descriptions of events and help identify "best" activities on the long-run using e.g. emotional data acquired from physiological sensors or cameras. In practice however, efficiency requires notable advances in context-awareness and affective computing.

4. Age-appropriate designs lack

To design systems appropriate in youth and old age, designers must consider the specificities of ageing and their consequences. Young people and older adults share issues about safety, integration, variability, and perception. In addition, critical issues include thinking and learning for kids, and memory and acceptance of systems for elders. These elements provide a view on ageing in ubiquitous human-computer interaction without pretending to exhaustiveness. They are introduced in Figure 1, and their description below highlights that current techniques for ubiquity are unsatisfactory.

Safety depends on the equipment's form factor and components' weight and location, based on users' characteristics, and thus age. The systems should limit changes in body temperature, especially for kids due to their limited thermoregulation, as well as forces applied by e.g. wearable haptic devices due to growth (e.g. muscle development) then decline (e.g. weakness in limbs and joints). Mental safety will be of paramount importance for adoption and quality of life due to expected omnipresence and pro-activity. For instance, kids' systems should respect cognitive development, and elders' self-esteem through decline; however solid knowledge lacks for implementation. Similarly, the impact of virtual companions should be assessed. Finally, location queries to contact nearby people would benefit emergency services due to the limited abilities of kids and elders but current architectures lack such a feature.

Integration is important because body and mental schemes of young people quickly change, and because elders difficultly acquire automated responses. Stable or shared designs, standard metaphors and natural interactions would facilitate everyday life uses of new systems. Besides, permanent visual agents may serve as an anchor and provide an interface for help, notably when using unknown public (or friends') systems. The human-computer interaction community proposed such features for isolated standard computers but we ignore how to implement them in a complex and dynamic ecology of devices and services on a world scale.

Variability is generated by daily fluctuations in abilities and needs, especially in elders who are diabetic or quickly fatigue. It can be tackled with multiple activity levels based on multi-level interfaces, artificial

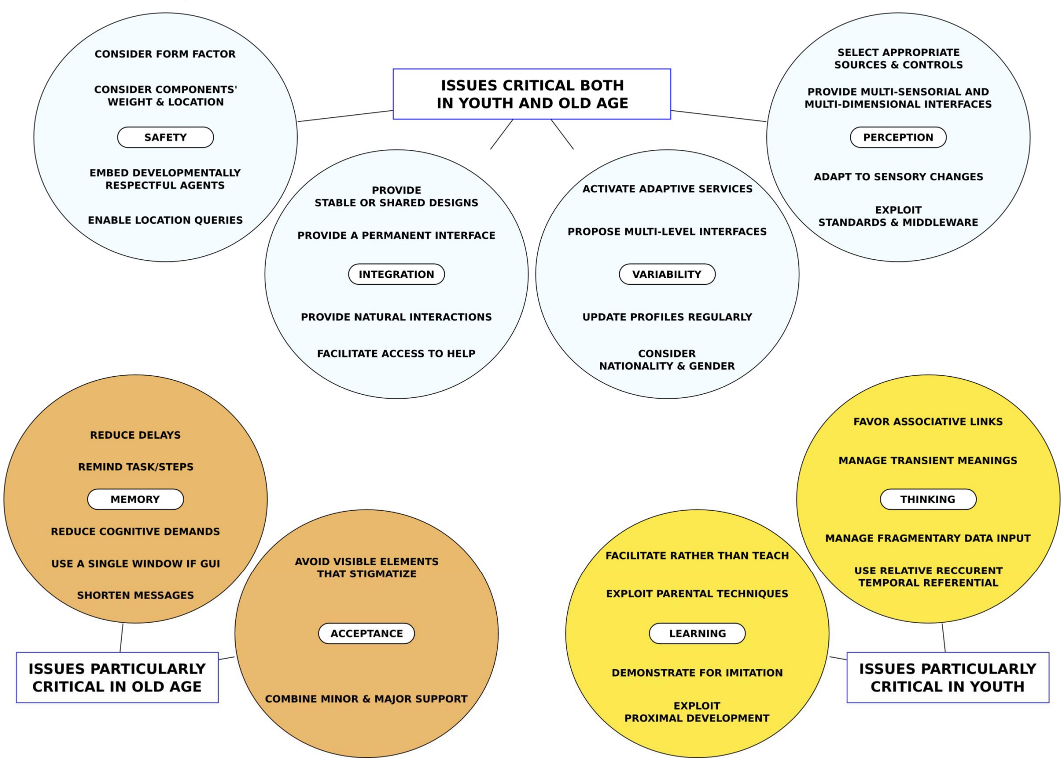

Figure 1: Critical design elements in youth and old age for information systems.

intelligence, or adaptation to users' states, maybe requiring up-to-date profile data about users. For instance, the interface of semi-transparent glasses may adapt to the user's current ability to focus and notice information; a wearable may avoid interrupting an elder with dementia to preserve working memory then remind of tasks during periods of lucidity. In spite of much work in context-awareness, appropriate sensors and algorithms lack for useful and reliable adaptations.

Perception differs between kids and elders, and among the latter. Systems for kids should integrate the limits of, and changes in, their sensory systems. For practical ubiquity, movement analysis may be most useful because children move much for games or by habit but bodily changes hamper the reuse of data; systems must therefore be flexible and maintain functionality through algorithmic and hardware upgrades, for instance using standards and middleware. Egocentric speech renders speech recognition attractive to identify kids' activities and problems but it requires powerful context-awareness systems and much personal knowledge. On the contrary to kids, elders often suffer from perceptual difficulties. For example, semi-transparent glasses loose usefulness as the importance of good lighting and contrast increase, speech output should be pre-recorded or provided by male operators because elders dislike synthetic voices and may miss high frequencies (e.g. female voice), and sensitive or small controls are invalidated by reduced dexterity. Finally, providing multi-sensorial (e.g. visual and aural) and multi-dimensional (e.g. color and size) output may counter varied effects of combined deficiencies.

Thinking issues mainly arise in youth because young people discover reality gradually and go through four phases of thinking. Kids use their own current meanings for words and symbols, which can confuse outsiders and inflexible language-based systems. Transient meanings should be reassessed regularly, and related processes (e.g. speech processing, vocabulary in interfaces, context-awareness) adapted to improve child-machine communication but such an approach is usually avoided due to complexity and lack of interest in young users. An additional difficulty is that centration and egocentrism lead to particularly fragmentary input of data before 8 years. Because children incorrectly understand relations and concepts, interfaces should stress associative links rather than abstract/logical links before puberty. Finally, management of temporal information by younger children requires recurrent relative referentials (e.g. winter, evening) rather than absolute ones (e.g. specific days and hours), which implies unusual means to explore temporal data.

Similarly, *learning* is mainly an issue during youth. Because learners actively acquire/create knowledge, systems should facilitate rather than teach; they may ask rather than tell, discuss rather than lecture, support rather than control, create a learning environment and follow children's interests rather than focus on curricula. Guidance for the acquisition of knowledge and memorization can benefit from techniques used by parents, such as *wh-* questions, associative talks, follow-ins, and appraisals. Because children also learn by imitation, animations of avatars may be provided in context; contrariwise attention should be paid to what is displayed. With help, young people can go beyond what they can learn alone; systems should thus evaluate and exploit this zone of proximal development but methods lack. As a first step, ubiquitous systems may learn which words the user acquired to adapt vocabulary used in interfaces and functions available.

Memory troubles influence numerous mental operations, and thus cognitive demands in elders should in general be reduced even at the detriment of other aspects. To compensate memory losses, several techniques are available: avoiding delays, shortening or removing textual and aural messages, using a single window for a given task, or reminding ongoing tasks and previous steps. These well known human-computer interaction techniques can easily be implemented.

Finally, *acceptance* of technologies by elders depends on aesthetics and social perception. Because they do not want to look old or dependent, systems should be designed without stigmatizing visible elements, and should deflect attention to the need for specific help. For example, elders may fear that bystanders will see information on screens in shared spaces or notice special parts of their devices. As a solution, minor functions may accompany major ones so that users can deny needing major support. Such social aspects of design for ubiquity may sound simple but tests and real-world deployments show the contrary.

4. Discussion

Our quick overview showed that important ubiquitous services are missing and that designs used are inappropriate due to ageing. However the importance of features varies with goals and use contexts of systems. We consider below three perspectives about age in ubiquity: life-long services, consecutive uses of public systems by people of varying age (e.g. terminals at train stations), and collaborative uses of shared systems within multi-generational groups (e.g. information providers at home within a family). We conclude that several investigations are critical to exploit ubiquity in everyday life, a need magnified for young and old users.

Human needs and abilities evolve through a lifetime from predictable to unpredictable. Useful services change with age, and often require sensors or algorithms beyond the state-of-the-art. Continuous monitoring is the main asset of ubiquity, potentially facilitating kids' learning, middle-aged persons' lifestyle management, and elders' memory support. Interfaces useful to kids change as cognition complements perception, factual bonds complement associative bonds, and the uniqueness of events complements patterns; later, one may benefit from adaptations to declining abilities. Personal profiles would be appropriate tools if updated regularly and if algorithms compensate for daily variations. The usefulness of services and their proper design influence long-term acceptance; data loss and security breaches may be disastrous for both users' life and for technological diffusion. Besides, middle-aged persons' views matter as they may choose systems for their kids and suggest those for their aged parents.

Unique static interfaces of public systems are bound to fail because users may differ greatly and have concurrent disabilities, especially in graying countries. Interfaces should adapt to the specificities of young and old users, especially to the knowledge of kids and to elders' memory as they may operate systems alone. Personal profiles can serve but standards lack, and data transmission raises significant privacy issues. Besides, adaptations to knowledge remain difficult as we ignore how to evaluate it reliably. Including anthropomorphic agents may facilitate interactions because they provide a natural reference for input and output.

Co-localized simultaneous (collaborative) use of a smart space by multi-generational users is difficult due to differences in abilities, which influence the exploitation of interaction means and of outputs. Wearables can solve the problem because they may communicate with smart spaces and provide personalized information to their wearer. Without them, designers may increase the density and diversity of sensors and actuators to provide more resources per user, alternative interaction (e.g. gaze, gesture) and alternative information access (e.g. display on screen, 3D sound) means; multimodality suits best various perceptual abilities and ways of thinking. Depending on equipment available, users and tasks, a smart space may provide a unified set of interactions and renderings for all users, or may exploit different renderings (e.g. different space of the screen) and interaction means for each user or cluster of users. The *collaborative work* community offers good bases but the state-of-the-art is insufficient to manage complex ubiquitous ecologies.

For life-long uses, the research community must investigate (1) data management when hardware/software is upgraded due to ageing or technical progress, (2) real-world complex context-awareness, (3) integration of systems with stable designs, and (4) long-term influences of ubiquity on human psyche, for example regarding animism and memorization. For public systems, integration with shared designs seems of paramount importance as users differ greatly in abilities and backgrounds; issues about acceptance of services are unclear. For collaborative uses also, integration with shared designs seems of paramount importance, but adaptations to knowledge or memory is less critical as other users may help. Besides, psycho-social factors are important to ensure that all users adopt a system, and do not reject it because e.g. it points out personal issues to friends or family members.

Unfortunately, most issues specific to children remain open because related research mainly concerned gaming and academic learning. There is a critical need for research about children because (1) we lack knowledge, especially about long-term impacts of technologies on physical and mental growth, (2) children already use proto-services in Japan and South Korea, (3) this research must be conducted over years due to growth phases, (4) ethics constrain this research and laws hinder varied large-scale investigations, and (5) results may differ with language and culture.

5. Perspectives

The specificities of worldwide young people and older adults induce needs and priorities different from those of "standard healthy adults", which affects the nature of ubiquitous services that can significantly improve quality of life, and impacts requirements for proper designs of systems, notably regarding safety, integration, variability, perception, thinking, learning, memory, and acceptance.

This study shows that most age-specific ubiquitous services are non-existent, that designs of existing systems are inappropriate for children and elders, and that research on critical issues is still at an embryonic stage.

The specificities of young people and older adults as well as their impact should be investigated in more depth, and the following questions must be answered by the research community: How may continuous use of ubiquitous systems influence growth and decline? Can systems featuring anthropomorphic agents compensate for a lack of social contacts? How can we provide systems that keep memory and functionality even through changes in hardware, software, and human needs and abilities due to ageing? What kinds of personal profiles would facilitate technological uses? Our group already investigates some of these questions but answers require concerted efforts with other groups due to the complexity and multi-disciplinary nature of ubiquity.

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