“Intelligent Spaces”

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1.0 INTRODUCTION

"A house is a machine for living in." Le Corbusier, 1921

Recent advances in digital modulation and transmission, signal processing, wireless access protocols, and IC technology have spawned many intelligent devices and objects. Seamless communications among such devices and possible processing centers can transform ordinary environments into intelligent spaces. The close coupling between physical and virtual spaces distinguishes intelligent spaces from virtual reality environments. Other attributes of intelligent spaces include ;

• System perception, cognition, analysis, reasoning, and prediction of users' status and surroundings. Situation awareness is the most fundamental form of such capabilities; the system should be aware of any information it can use to characterize an entity's situation—in other words, its context.

• High adaptivity to inhabitants' activities. This attribute contrasts with conventional computing environments centered at computers.

1.1 A Historical Perspective

Intelligent Buildings based on computer technology have been around in one form or another for over 20 years. Perhaps the most significant developments were the introduction to building control systems of embedded processors, dedicated networks and intelligent agent approaches. This view has led to proposing the following taxonomy for technologically based intelligent-buildings:

· First-generation Intelligent Buildings consist of numerous independent self-regulating (automatic) sub-systems. These sub-systems might be relatively sophisticated (e.g. HVAC or security systems), but they are essentially disconnected, and operate independently of each other.

· Second-generation Intelligent Buildings are formed when building control systems, are connected together via a network. By interconnecting them in this way, it becomes possible either to control them remotely (from a building services manager's office), or to facilitate some central scheduling or sequencing (such as securing areas, or turning systems on or off at specific times).

· Third-generation Intelligent Buildings have, in addition to the processors and networks of the first two generations, have the capability of learning about the building and its occupants, and hence adapting their control behavior accordingly. This functionality arises from the application of intelligent agent techniques (already widely used in other areas, such as robotics).

1.2 What is an intelligent space?

Intelligent spaces are physical spaces where access to other agents (human and artificial) is ubiquitous, the scale in terms of number of agents and amount of information is large, cognition is distributed, and computers are often invisible. The physical world in which people work and go about their daily activities is becoming increasingly intelligent. An increasing number of the objects that surround us (such as microwaves, VCRs, computers, answering machines, personal digital assistants, cell phones and security systems) have some level of intelligence; i.e., these devices are able to communicate, access, store, provide and/or process information.

Ubiquitous access means that technology will exist to enable all agents to access or provide information wherever, whenever, and to whomever it is useful thus remotely enabling other agents to act. Whether agents can exercise this ability will depend on the norms, incentives, privacy regulations, and security measures adopted by the group, organization, or society. In terms of scale, huge quantities of information will be automatically collected and stored and processed by a potentially ever-increasing number of agents. Information, access to information, and information processing and communication capabilities (i.e., intelligence and cognition) will be distributed across agents, time, space, physical devices and communication media (Hutchins, 1991; 1995). As computers are miniaturized, made more reliable, and increased in power and storage capability, we can expect more devices to become intelligent. This increases the number of agents, but it also starts making computers invisible. A further aspect of invisibility is that the interface between the digital world and the analog world will become seamless, this is the birth point of Ambient Intelligence (AmI). For example, speech recognition and synthesis software, automatic transcription software, face recognition software, all enable a more seamless interface between the digital and analog world. As spaces become intelligent there will be unprecedented increases in the size and complexity of the interaction and knowledge networks in which people (and other agents) are embedded and the size and mobility of their "infospheres". The term "infosphere" refers to the collection of remote instruments, appliances, computational resources (all of which may be artificial agents), as well as the agents (human and artificial) and information made accessible to a person by these systems from a person's working environment, such as the desk and office or the bridge of a ship. All agents have an infosphere; however, the size of that sphere may vary as the agents change physical location. The knowledge available in these infospheres includes what agents know, who they know, and what they know how to access. For humans, the size of their infosphere is largely determined by the type of immediately accessible technology. Thus, your infosphere generally becomes smaller as you move from your office, to your car, to the hallway, to a remote mountaintop. As spaces become intelligent, we expect two things to happen. First, infospheres will become larger. Indeed, there may be an increase in the complexity in individual's infospheres and the associated interaction, knowledge, and information networks well beyond people's ability to manage and monitor this space. Second, infospheres will become mobile. Thus, as the agents move from office to mountain top infospheres will degrade by choice, rather than access to technology. Moreover, technological change may lead to non-linear rates of change in these networks. For example, when one-to-one communication exists, even if every agent learns something new each time, the maximum number of new links in the knowledge network each time is N – the number of agents. In contrast, technologies which enable simultaneous many-to-many communication makes it possible for the maximum number of new links in the knowledge network to grow by N*(N-1). Technological change also may lead to fundamentally different structures (Barley, 1990; Kaufer and Carley, 1993). For example, databases enable teams to reach consensus by interacting with the database and so sharing knowledge off-line rather than reaching a shared understanding through direct interaction. As intelligent spaces alter the infospheres, the networks in which people are embedded, and those to which they have access to, are likely to respond dynamically and become potentially unbounded. The theory of bounded rationality suggests that limitations on humans determine the level of performance the organization can achieve. As these boundaries are eliminated then performance should improve. It is important to recognize that technology does not eliminate boundaries but moves them; i.e., in intelligent spaces cognitive, social and institutional barriers will still exist.

2.0 Ambient Intelligence (AmI)

In computing, ambient intelligence (AmI) refers to electronic environments that are sensitive and responsive to the presence of people. Ambient intelligence is a vision on the future of consumer electronics, telecommunications and computing that was originally developed in the late 1990s for the time frame 2010–2020. In an ambient intelligence world, devices work in concert to support people in carrying out their everyday life activities, tasks and rituals in easy, natural way using information and intelligence that is hidden in the network connecting these devices.

Ambient intelligence (AmI) is a new multidisciplinary paradigm rooted in the ideas of Norman and Ubiquitous Computing. AmI fosters novel anthropomorphic human–machine models of interaction. In AmI, technologies are deployed to make computers disappear in the background, while the human user moves into the foreground in complete control of the augmented environment. AmI is a user-centric paradigm, it supports a variety of artificial intelligence methods and works pervasively, non-intrusively, and transparently to aid the user. AmI supports and promotes interdisciplinary research encompassing the technological, scientific and artistic fields creating a virtual support for embedded and distributed intelligence.

AmI supports the design of the next generation of intelligent systems and introduces novel means of communication between human, machine, and the surrounding environment (man-made objects). It sets the principles to design a pervasive and transparent infrastructure capable of observing people without prying into their lives, adapting to the needs of the user. It builds upon ubiquitous computing and human-centric computer interaction design and is characterized by systems and technologies that are:

- Embedded: many networked devices are integrated into the environment
- Context aware: these devices can recognize you and your situational context
- Personalized: they can be tailored to your needs
- Adaptive: they can change in response to you
- Anticipatory: they can anticipate your desires without conscious mediation.

AmI is influenced by user-centered design where the user is placed in the center of the design activity and asked to give feedback through specific user evaluations and tests to improve the design or even co-create the design together with the designer (Participatory design) or with other users (End User Development). In order for AmI to become a reality a number of key technologies are required:

- Unobtrusive hardware (Miniaturisation, Nanotechnology, smart devices, sensors etc.)
- Seamless mobile/fixed communication and computing infrastructure (interoperability, wired and wireless networks, service-oriented architecture, semantic web etc.)

- Dynamic and massively distributed device networks, which are easy to control and program (e.g. service discovery, auto-configuration, end-user programmable devices and systems etc.).
- Human-centric computer interfaces (intelligent agents, multimodal interaction, context awareness etc.)
- Dependable and secure systems and devices (self-testing and self repairing software, privacy ensuring technology etc.)

The Social and Political aspects of Ambient Intelligence

The Information Society and Technology Advisory Group (ISTAG) suggests that the following characteristics will permit the societal acceptance of ambient intelligence:

- AmI should facilitate human contact.
- AmI should be orientated towards community and cultural enhancement.
- AmI should help to build knowledge and skills for work, better quality of work, citizenship and consumer choice.
- AmI should inspire trust and confidence.
- AmI should be consistent with long term sustainability - personal, societal and environmental - and with life-long learning.
- AmI should be made easy to live with and controllable by ordinary people

3.0 Systems within AmI

"An Intelligent-Building is one that provides a productive cost-effective environment through the optimization of four basic elements; systems, structures, services, management and the inter-relationship between them" [Robathan 89].

3.1 Responsive Architecture

Responsive architecture came to the fore in the late 1960s and early to mid 1970s when shortfalls within modern buildings led architects to question the design methodologies that were used within the profession. It was within this context that architects attempted to forge more appropriate forms of architecture and new, user-centered, design methodologies. Though the development of responsive architecture was first driven by shortfalls within practice, its successes were informed by three forward thinking ideas. These were: 1) that architects design systems, not just buildings, 2) that feedback could be used as an architectural form generator, and 3) that the profession of architecture must respond to the changes that surrounded its practice.

Only recently have the devices required been cheap, powerful and small enough to be economically used within buildings. So, after four decades since it began, responsive architecture has finally become a sensible topic for designers and architects to explore. As a background note it is worth mentioning that hybridized methodologies were developed when conventional programming techniques struggled to process environmental and user input in real-time. As such the development of responsive architectures strongly follow the development of robotic systems because each type of system must be capable of analyzing stimuli from numerous parallel systems quickly and accurately.

3.2 Context Aware Systems

Context-aware systems are computing systems that provide relevant services and information to users based situational conditions. Chen, Finin & Joshi at University of Maryland, Baltimore County (UMBC) are developing an agent oriented architecture called Context Broker Architecture (CoBrA) that aims to help devices, services and agents to become context aware in smart spaces such as an intelligent meeting room, a smart vehicle, and a smart house. Their research results show that building pervasive context-aware systems is difficult and costly without adequate support from a computing infrastructure. They believe that to create such infrastructure requires the following:

(i) *A collection of ontologies for modeling context*- In order to create computer systems that can "understand" and make full use of a context model, the contextual information must be explicitly represented so that they can be processed and reasoned by the computer systems.

(ii) *A shared model of the current context*- The shared model is a repository of knowledge that describes the context associated with an environment. As this repository is always accessible within an associated space, resource limited devices will be able to offload the burden of maintaining context knowledge.
(iii) *A declarative policy language that users and devices can use to define constraints on the sharing of private information and protection of resources*- that allows users and devices to define rules to control the use and the sharing of their private contextual information. Using this language, the users can protect their privacy by granting or denying the system permission to use or share their contextual information.

As a part of their long-term research plan, they are prototyping an intelligent context broker. Their goal is to create and deploy a pervasive context-aware meeting room in the newly constructed Information Technology and Engineering Building on the UMBC main campus.

3.3 Environment sensing and control

Sensors in architecture, consisting of distributed embedded agents, utilizes sensory information to learn to perform tasks related to user comfort, energy conservation, safety and monitoring functions. Sharples, Callaghan and Clarke show how these agents, employing a behavior-based approach derived from robotics research, are able to continuously learn and adapt to individuals within a building, whilst always providing a fast, safe response to any situation. Finally, they show how such a system could be used to provide support for older people, or people with disabilities, allowing them greater independence and quality of life.

In the context of a building, a system works by taking inputs from building sensors (light, temperature, passive infra-red, etc), and using this and other information to control effectors (heaters, lights, electronically-operated windows, etc). If this system is to be intelligent, an essential feature must be its ability to learn from experience, and hence adapt appropriately. Thus the notion of “autonomous governing” is important, as it implies a system which can adapt and generate its own rules (rather than being restricted to simple automation). “An Intelligent-Building is one that utilises computer technology to autonomously govern the building environment so as to optimise user comfort, energy-consumption, safety and monitoring-functions”. Work is concerned with utilising an intelligent embedded-agent approach (similar to the approach already taken in some areas of mobile robotics), to create an integrated and semi-autonomous building control system. Intelligent buildings are composed of numerous sensors, effectors and control units interconnected in such a way as to effectively form a machine.

By gathering information from its sensors over a period of time, the room-agent can notice how a particular person tends to react to particular circumstances, and can then learn to “mimic” or replicate that behavior itself. Because we are also using sensors to distinguish between different occupants, the system is able to learn different behaviours for different people. So for example, the system might learn that Person A, who is only partially sighted, prefers a higher level of light than Person B, whose sight is normal. It could then adjust the lighting level appropriately, according to who was in the room at that time.

The visual real-time interaction systems are all based on using motion of people to determine what is happening in the scene. The systems are self-calibrating wherever possible. In order to pick out motion from the background all images from XED cameras filter out the background by adaptively averaging the pixels so that an image of the background is built up over time. This image is not fully static as lighting may change, or furniture may be moved within the room. The background is then subtracted from the current image and usually this corresponds to where people are as people usually make motions at higher rates than the background adaptation.

3.4 Speech, behavior and expression recognition

Speech recognition is an important tool for developing natural interactions with Intelligent Environments (IE). Several agents comprise our current speech infrastructure. At the highest level, the Grammar Center agent exposes speech functionality to other agents in the system. An individual agent can register a grammar of phrases that it recognizes with the Grammar Center. In order to make use of existing speech technologies, all grammars are currently written in the Java Speech Grammar Format (JSGF). This speech system allows individual agents and applications to enable simultaneous, dynamically controlled speech input without having to directly interact with the underlying recognition technology.

Reactive behavior; at the ongoing context-aware Intelligent Room in MIT, are able to focus on constructing a representation for context and using that representation to understand user needs and expectations. Before the system can create this representation, it needs to collect data describing user actions and behavior. They rely on various components to detect this information: computer vision for head, arm, and person tracking; sensors for motion, location, pressure, and temperature sensing; and enhanced device controllers for device state detection. In short, they collect information about the current state of both the Room and the occupants within. The following three concerns describe ReBa, a "reactive behavioral" system that not only facilitates building a context representation, but also uses that knowledge to provide relevant services to the user. First, ReBa's basic representation of activity centric context. Next, how these basic building blocks are combined into more complex representations. Finally, the problem of conflicting behaviors arising from this architecture is identified.

3.5 Artificial intelligence

Artificial agents such as WebBot, robots, and electronic shoppers are joining humans and organizations in the ranks of the smart agents that "work" in and among organizations. Computers are coming to control, or are involved in the operation of, everything from the office and home environment to routine purchases to strategic organizational decisions. As computers become embedded in every device, from pens to microwaves to walls, the spaces around us become intelligent (Nixon, Lacey and Dobson, 1999; Thomas and Gellersen, 2000). Intelligent spaces are characterized by the potential for ubiquitous access to and provision of information among potentially unbounded networks of agents. Yet, we have little understanding of how to coordinate organizations in which humans and artificial agents work side-by-side, let alone how they work in these intelligent spaces. At least four paradigms in organization science speak to the potential impact of smart agents on new organizational form – structuralism, contingency theory, information processing theory, and social networks.

An exception here is some of the work on transactive memory which suggests that storing individual knowledge about who knows what in databases may have the same performance enhancing effects as when known directly by humans. Another exception is the work on information flow, which suggests that artificial smart agents change both the topology of the underlying networks, speeds the diffusion of information, and yet may maintain or exacerbate information inequalities. Collectively, this work leads to the conclusion that networks, cognition and the interaction among the two effect organizational performance.

Further, in intelligent spaces search is being conducted by smart agents, some of whom are artificial, who themselves are able to learn and where the direction of that search is enabled and constrained by the underlying networks. A consequence is that as the density of these networks change and as different types of agents populate these networks the time scarcity and competition among ideas begin to determine organizational outcomes. As the networks expand in both agents and ideas search effectively slows and organizational outcomes become a function more of order of learning. Organizational design is a complex system in which a large number of factors interact in non-linear ways to effect performance. Moreover, it is a dynamic system changing humans learn, as goals change, and so on. The presence of artificial smart agents in organizations adds further complexity by enabling greater quantities of information to be stored, meta-knowledge to be created, artificial agents to act on behalf of humans, more knowledge to be created, and so on. The effects of these changes are again non-linear.

Agents are intelligent if, in order to respond to a stimulus, they must engage in cognitive activity acting upon a body of information. Agents are adaptive if they change their behavior in response to changes in information. Agents are computational if they have the ability to do any of the following: acquire, process, store, interpret, or communicate information and the connections among pieces of information. Smart agents are agents that are intelligent, adaptive, and computational. Artificial smart agents are capable of working and communicating within and among organizations, on their own or with modest human intervention. As agents increase in the amount and type of knowledge that they attend to, increasingly considering real time situations, multiple agents, multiple goals, and historical situations the variety and type of responses available to them widens. As agents move from cognitively completely capable, the omniscient agent, to increasingly constrained agents, i.e. from the rational actor, to the boundedly rational actor, to the cognitive actor to the emotional cognitive actor they increase in their need for diverse actions.

As noted by Carley (1999) entity composed of intelligent, adaptive, and computational agents is also an intelligent, adaptive, and computational agent." Thus organizations are also smart agents; but unlike the individual agents we have been discussing they are synthetic. A synthetic agent is an agent synthesized out of multiple sub agents connected by a plethora of networks. This can enable a complex intelligent system at a meta-level where it becomes even greater than the inhabited or intelligence for the intended space.

3.6 Human Computer Interaction (HCI) and User Interface

Context management in HCI applications is a challenging problem. The complexity of maintaining contextual information is two-fold: first, in collecting the right information, and second, in knowing what to do with the information once you have it. Within intelligent spaces, there are three types of interactions: interactions between a space and users, between multiple spaces, and between multiple users. The first occurs when one or more users are in the room. Users can request a service from the room, or the room can react to users based on their current activity or other contextual information. Interactions between spaces occur when one space needs to request services from another space, such as a server room sending a request to a control room to lower the temperature. Interactions between users can be as local as talking face to face, or as remote as in chatting via personal digital assistants (PDAs). Finally, different combinations of these three types can occur.

The Intelligent Room project

The IRoom project is the component of MIT's Project Oxygen that seeks to construct IEs. The IRoom project has taken an agent-based approach to building and organizing the above components. For pervasive computing to be successful, they built interfaces that work the other way around, drawing the computer into our natural world of human discourse; computers will need to communicate using speech and vision just as humans do. Project Oxygen was started with these goals. One particular form that such human-centered technology can take is that of an IE, a physical space that is perceptually enabled, that is capable of natural human interactions, and that provides both proactive and reactive services to a community of users.

As discussed above, at the heart of an intelligent reactive behavioral system in Intelligent Room (IRoom) is a two-step process designed to assist users with their daily tasks: first, to understand the context of the current user- next, to adapt the

IRoom's response to that context. Six Design Principles proposed by Kulkarni while designing the Intelligent Room at Media Lab:

i) *React to user behavior within the current activity context*- the main problem of the rule based reactive system was its inability to understand that certain reactions apply in some contexts but not others. A better reactive behavioral system takes into account what the user is currently doing.

ii) *Each reaction should be encoded in a behavior; an activity-based module*- reactive behavioral system should not be specific to one particular space.

iii) *The system needs an organizing structure for all behaviors, and a layering one for active behaviors* - This principle specifies how to structure all the activated behaviors. In Subsumption, higher levels of behavior override lower levels. If we apply this idea to our "behaviors," we have a method of organizing the activated behaviors.

iv) *The reactive system should be customizable by a user.*

v) *Designing a new set of reactions should be easy.*

vi) *Adding a new behavior should not interrupt the system's operation.*

4.0 CONCLUSION

A large variety of disciplines can be grouped under the umbrella of AmI: distributed intelligence, data and information communication, software design, computer vision, speech recognition, robotics, information fusion, hardware design, computer wearables, social sciences, ethics, and law.

The current state of the art in information understanding and relaying will have to make huge steps forward to design algorithms capable of understanding and intuiting human actions and speech. Currently neither research nor technology are sufficient to implement AmI environments. Both are necessary to create the soul and body of a truly pervasive and distributed layer, capable of dealing with user requests, preempting the user and guiding the user in private and public enhanced spaces for our near future.

There seems to be a common consensus amongst the guidelines outlined by MIT IRoom and UMBC's Intelligent Meeting Room. These rules seem convincing at this time to achieve an intelligent space. But both these rooms have a mild difference in attitude. IRoom targets to deliver many needs of the user and achieve a fully multi-functional space. The meeting room intends to achieve optimization for its patent users and become sensitive to their needs. What should be the philosophical goal of these spaces is the question we need to ask now?

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