Ubiquitous Intelligence: The Intelligence Revolution

Interview to Prof. Jianhua Ma by Wise Media, March 2005

The merging of identification technologies, wireless communication and sensors allows the birth of a new vision: pervasive and unobtrusive intelligence embedded within the objects of the environment around us.

1) How will ubiquitous intelligence impact our world and our way of living?

Human being is a kind of the most well evolved things with the highest intelligence on earth. However, human has the various limitations on physical, perceptual, and many other capabilities. Lots of technologies, from the ancient time to the current modern era, have been aimed at making a variety of tools and machines for extending or overcoming the human limited capabilities. Electronic computers are the tools that are originally created to enhance the human computational capability and then increase the human information processing capability. We have seen the revolutionary changes of our world bought by computers and related IT technologies. Computers, ranging from stationary supercomputers/grids, clusters, workstations, servers and PCs to moveable laptops, PDAs, handhelds, etc., are getting more popular and more powerful with increasing intelligent functions. However, such popularity and powerfulness of computers as relatively independent individual machines/devices are not regarded as the ubiquitous intelligence.

It is fact that computers are becoming smaller and smaller, and can be attached, embedded or blended to almost all things from man-made to natural ones in the world. Computers become integrated parts of these things instead of independent individual artifacts. Due to the attachment/embedment/blending as well as emerging ubiquitous networks, ordinary things surrounding us are capable of (1) computing and communicating, (2) connecting and/or being connected to each other, and (3) behaving and acting rationally with some smartness or intelligence. Such kinds of things can be called smart or intelligent things or u-things including diverse objects, spaces/environments and systems. The world would evolve towards what we called the smart world pervaded with such smart or intelligent u-things. The pervasion of these smart/intelligent things or u-things in surroundings and the world is regarded as the ubiquitous intelligence.

Many things in the world have been revolutionarily changed due to integrated mechanical, electrical, and other capabilities. The most profound implication of the ubiquitous intelligence is to provide computational and informational capabilities to things surrounding us, and make them having various kinds and levels of intelligence. It may not be enough to describe the profound changes with the so called information revolution, and it would be appropriate to regard them as the intelligence revolution. With increasingly possible pervasion and ubiquity of intelligent things including popular everyday objects, countless changes will take place in the world, which will have great impact on almost all aspects of our living and working. Benefiting from the intelligence evolution, human life and working style are evolving towards more convenient, comfortable, and efficient.

2) In terms of applications, where do you foresee the vastest deployment of ubiquitous intelligence and emerging and disruptive technologies.

With the continuing miniaturization of IC chips, MEMS, NEMS, etc., any objects are possible to have attached/embedded IC chips, MEMS, NEMS, and/or other systems with the information possessing and the wireless communication ability so as to function smartly. In the long terms, the ubiquitous intelligence related technology can, theoretically, be deployed to anywhere having need of the smart or intelligent objects.

In practice, however, many factors affect deployment of the smart/intelligent objects in real application environments. One of them is the cost/performance concern of attachable/embeddable computers. Relatively small and cheap ubiquitous or pervasive devices such as some RFIDs and sensors, usually have limited computational power, memory capacity, and communication distance. The devices with better performance cost much higher and are in larger sizes. This factor makes the applications of ubiquitous intelligence, during a certain period, fall into the two streams. The one is to use cheap devices to offer limited specific but cost effective services, such as RFID-based card, goods/product management, and sensing appliances. The other is to use good performance devices in some environments that require relatively higher accuracy and better quality for kids care, for car safety, for health care, and so on.

Another factor in making acceptable ubiquitous intelligent applications is the privacy concern as well as related legal regulations and laws. The ubiquitous intelligence indeed can make our living more convenient and comfortable but also take us to some potential dangerous environments with the possibility of sacrificing privacy and the risk of out of control. Therefore, the potential applications of underlying ubiquitous intelligence would at first go to those environments where the privacy may not be a serious or sensitive issue to users or can be well under control. Along with the progresses of privacy protection technologies and laws, ubiquitous intelligent applications can be deployed to wider environments in practice. There are some other factors such as dependable, manageable, and trustable concerns are currently barriers of deploying ubiquitous intelligence.

3) Will advanced identification technologies like RFID play a major role in the construction of intelligent environments?

Absolutely, RFID will play an essential and indispensable role in the intelligent environments. The modern human society is organized based on the personal IDs including citizen number, insurance number, telephone number, credit card number, bank account number, driving license number, passport number, and many other numbers. It would be difficult or even impossible to effectively and efficiently manage the current human society if we had not these personal ID numbers.

In his book published in 1985, Prof. M. Minsky gave a scheme called “Society of Mind”, in which each mind is made of many smaller processes known as agents. The software agents can be embedded into real objects as so called objects’ minds that make the objects smart or intelligent. Any ubiquitous intelligent environment is a collection of smart/intelligent objects with minds, which form an object society. Like the human society, unique and universal object ID will play a fundamental role in the object society. Without such ID, it will be impossible to well organize and manage smart objects and to achieve the ubiquitous intelligence vision. Due to

the huge number and high diversity of the real objects, the associated methods, mechanisms, standards and technologies related to object ID including RFID are much more complex than the personal IDs.

Real objects are either living or no-living objects. It is interesting to electronically identify living objects including plants, insects, animals as well as their organs. Such universally identifications of living objects with further inclusions of their sensing and tracing abilities via attached/embedded perceptional and communicational micro chips/devices, we can not only monitor and manage them in novel ways but also investigate many unknown natural phenomena. Generally speaking, an object ID is only the partial information of smart objects, which are often in need of other contextual information related to 5Ws for their intelligent behaviors.

4) When do you think we will start living in a world where we are surrounded by smart objects?

To be honest, it is a difficult question to answer. The terms, “surrounded” and “smartness” are a bit subtle and vague. We may need a degree/level value attaching to their definitions. It is fact that some objects already have a certain level of smartness. Let’s take a look at some homes, in Japan for instance, we can find lamps with sensors, ovens capable of cooking automatically following instructions from the Internet, smart functions using embedded computers in a car, and so on. The word ‘smart’ originally has the wider meanings, the exact meaning in this context may be relatively hard to comprehend by the general audiences and it has not been yet widely adopted by ubicomp or percomp researchers. It is therefore, very normal to see that lots of ubicomp researches and applications have been named, besides smart and intelligent, with other terms, such as aware, context-aware, active, interactive, reactive, proactive, assistive, adaptive, automated, sentient, perceptual, cognitive, thinking, etc. It will be an evolutionary process in a long period, perhaps several tens of years, from the current world with very few smart objects to a truly smart world filled with ubiquitous smart objects. There is no doubt that we will be surrounded by increasingly smart or intelligent objects and environments from now on.

It is highly possible that there will be soon a booming period of developments and deployments of smart objects and environments since lots of big IT related companies have put their focuses on the ubicomp/percomp related technologies and products, and many developed countries have adjusted their national IT strategies from e-things to u-things covering the ubiquitous electronics, networks, services, etc. It should be pointed out that the ubiquitous intelligence is beyond of the ubiquitous networked services of any place/any time/any means, and is focused on the trustworthy services of right place/right time/right means, which are the core of object smartness or intelligence. The ubiquitous computational and communicational abilities are basic but not simply equal to the ubiquitous intelligence, which are much hard to reach. Therefore, how long the booming can last will greatly depend upon the associated research progress of feasible and trustworthy smartness integrated with real objects.

However in practice, it is hard to say a u-thing is absolutely smart or not. Probably, any smart u-thing possesses two co-existing facets: smart and stupid. A same u-thing may be smart in certain situations but stupid or annoying in other situations. Even if it is assumed

smart in a particular situation at specific time, but it may not be so in another time. Not only the situation and time, the smartness of a u-thing may be felt in various ways or probably with opposite feelings by different users. That is, an absolutely smart thing may not exist, just like no one in our world is completely perfect. Furthermore, it is also hard to say that smart is absolutely better than stupid in all cases. Even then, the u-things will surely be able to evolve towards smarter and smarter along with the progress in theories and technologies.

Although more often we use the relatively softer term of smart for trying to reduce unrealistic expectations to the ubiquitous intelligence because of current theoretical/technical limitations and to avoid unnecessary debates about complicated or abstruse philosophical, cultural, social, ethical, and other implications, we have to be coolheaded and clear in realizing the extreme difficulties and challenges in making real things truly smart. All of these difficulties mainly come from the real world diversity and complexity, which need to be well abstracted, precisely modeled, and semantically represented for any following computing. There are always gaps between the visions and realms at every current and future stage in the next decades or more for making smart things towards the smart world. What is worthwhile to point out regarding the underlying research and development of a smart thing is to be cautious about setting the timing for its achievement with due consideration to both vision and feasibility at the corresponding stage.

5) What is a "hyper-world" and how is it related to ubiquitous intelligence?

About 10 years ago, Prof. Tosiyasu L. Kunii, Prof. Runhe Huang and I realized the importance of integrating the multiple real and virtual environments, called the hyperworld, in which "we can, not only get passive multimedia information but also sense and control the real worlds directly and actively" *("Hyperworld Modeling", Keynote in the 1st International Conference on Visual Information Systems, Melbourne, February 1996)*. The foreseen hyperworld vision was a natural extension based on our previous research on active devices and media, tele-presence, multimedia networks, augmented reality and mathematical visualization modeling. We also proposed a one-to-many hyperworld system and its interaction reference model ("*Modeling Interface with a Multimedia Hyperworld*", *Proc. 12th Human Interface Symposium, Yokohama, October 1996, and "A Study on a Hyperworld System of One-to-Many Interaction"*, *Proc. of International Conference on Applied Informatics, Innsbruck, February 1997)*. In a word, a hyperworld is an integrated world environment of multiple interconnected real and virtual environments possibly mediated or synthesized with involving of many computers, which were somehow similar to what Weiser called one-to-many computing.

The basic characteristic of the hyperworld is the direct mapping between information worlds and real worlds via active devices including sensors, actuators, micro-machines, robots, etc. In 1996-1997, we made further study on the direct mapping ("*Towards Direct Mapping between Information Worlds and Real Worlds"*, *Springer-Verlag Lecture Notes, Vol. 1306, July, 1997)* and developed a prototype hyper system called CHEER *("CHEER: A Computer based Hyper-Environment for Educational Reformation"*, *Proc. of International Conference on Computational Intelligence and Multimedia Applications, Australia, February 1998)*.

Later, we realized that it would be too early to study the integration of the virtual and real worlds as the virtual world itself was unclear yet. Thus we shifted our research focus to the study on cyber worlds and developed various cyber applications related to virtual university,

e-commence, context-aware groupware, mobile multi-agent system, etc. We then, with others at CIS of Hosei University, created the 1st International Conference on Cyber Worlds (CW2002) to build a forum for multidiscipline joint research efforts among the world. Prof. T. L. Kunii, a great scientist, has continually working on the fundamental theoretical models and basic frameworks of the cyber world *("Algebraic Topological Modeling for Cyberworld Design", CW2003, Singapore, and "The Potentials of Cyberworlds –An Axiomatic Approach–", CW2004, Tokyo)*. It is my strong recommendation to read Prof. Kunii's papers to get real insights into the cyber worlds.

The cyber worlds emphasize more or less on digital virtual objects and environments. As the hyperworld is the integration of real and cyber worlds, it is still necessary to study real objects and environments with attached/embedded/blended computers in the real world. To be balanced, therefore, we proposed the smart worlds that are based on digital cyberspaces but with emphasis on real world applications. It is mainly characterized by ubiquitous intelligence or computational intelligence pervasion in the physical world with pervaded smart real things ranging from man-made artifacts to natural objects, from everyday appliances to sophisticated embedded systems, from small rooms to large buildings, from enclosed sites to open areas, and from stationary places to moveable vehicles. That is to say, the cyber worlds are targeted on the ubiquitous intelligence of the virtual digital e-things while the smart worlds are aimed at the ubiquitous intelligence of the real physical u-things. The further integration of the two kinds of ubiquitous intelligence is towards the future hyperworld.

The foreseen hyperworld is yet too far to achieve in near future. Currently we still need to put emphases on smart world related real smart things, i.e., smart objects, smart spaces/environments and smart systems. They are involved in many hard and challenging issues that require joint efforts across multiple disciplines and their fusions. To provide a common and open forum for researchers to exchange ideas and experiences in developing intelligent/smart u-things, Prof. Laurence T. Yang and I, as well as with great supports from many people, successfully held the 1st International Workshop on Ubiquitous Smart Worlds at Taipei in March this year, and its successor, the 2nd International Symposium of Ubiquitous Intelligence and Smart Worlds (UISW2005) will be held at Nagasaki, Japan, December 2005. We have founded an international Journal of Ubiquitous Computing and Intelligence (JUCI, by American Scientific Publishers) for addressing novel ubiquitous computing with the particular emphasis on the ubiquitous intelligence. Autonomic computing and trust computing have been recognized as the ultimate solutions to the increasing system complexity and distrust concern, respectively. In fact, such complexity and distrust are more serious and crucial issues to ubiquitous intelligent/smart applications. Therefore we are founding the Journal of Autonomic and Trusted Computing (JoATC) and organizing the 1st IFIP Workshop on Trusted and Autonomic Ubiquitous and Embedded Systems (TAUES'05).

6) What are you doing at Muse Lab in these areas?

The research of our laboratory is mainly focused on ubiquitous smart/intelligent environments, or more specifically, *smart hyperspace* that is a set of associated and integrated smart spaces, and *UbicKids*, a smart hyperspace environment of ubiquitous care for kids.

The words, 'space' and 'environment', are often used interchangeably, which are relatively abstract concepts of general sites or places. According to our research focuses and application scopes, these two general words can be replaced by more concrete things such as room,

office, laboratory, home, shop, road, car, park, land, etc. The research on smart space can be traced back to Boulder's Adaptive House since 1993 and Buxton's Reactive Environment in 1995. So far there are many researches on various smart spaces, and it is expected that more smart spaces are to appear in the next few years. It seems that each of the researches is only focused on a single specific space, and the different spaces developed are currently isolated and look like small islands in an ocean.

However, a person's daily activities often cover multiple spaces or environments. For example, the spaces involved in a professor's working day may include an office, a laboratory, a library, a few classrooms and other rooms. Suppose each of the rooms has been made smart, but it is still hard to expect all the rooms as a whole to be capable of providing optimal services to the professor if all of the smart rooms are isolated with each other, i.e., without information exchanges and having no context on the professor's transfer between the rooms. Except for working, the professor's other activities also exist at home, in shops, car, subway, and so on. Generally speaking, an individual's daily activities are often related to many spaces that somehow form some kind of associations.

These multiple associated spaces should be firstly interconnected and further integrated with considering the possible situational-spatial-temporal relationships of associated events and actions between the multi spaces. That is to say, for these related spaces, we should not only make each space smart but also let the spaces associated with each other as a whole become smarter. Such a set of associated and integrated smart spaces as a unity can be regarded as a higher level space, i.e., a smart hyperspace or hyper-environment. Actually the smart hyperspace can be seen as a subset of the hyperworld. Although it has been noticed that the smart hyperspace is very important and necessary, there is yet no systematic research on it. It is, of course, hard currently to initiate study and development of the smart hyperspace because the research on various individual smart spaces and their practical applications are still at their infant stage. However, we believe that now is high time to study the features, issues, models and technologies related to the hyperspace.

There are many challenging issues in creating smart/intelligent hyperspaces, such as hyperspace modeling and semantics, connections of heterogeneous smart spaces, context interrelations and sharing across spaces, smoothness of uneven spaces or space jitters, coordination of associated smart spaces, privacy and trust in multi-spaces, scalability and autonomic manageability of a hyperspace, interface and interaction of a hyperspace, hyperspace network infrastructure, hyperspace platform and middleware, hyperspace social/economic/ethical implications, etc.

To get down to concrete and deep study, we started the Project UbicKids, a smart hyperspace environment of ubiquitous care for kids, from early 2004. Its main objectives are three folds: (1) To develop a set of smart u-applications for helping parents to take care of their kids with more convenient, prompt, precise, reliable, secure and trustworthy services; (2) To build a representative smart hyperspace for probing and researching the novel issues, models and technologies related to general hyperspaces and ubiquitous intelligence towards the smart world; (3) To study both positive and negative impacts of ubiquitous kids care applications on families, especially the children's growth and development of their intellect, character, habit, psychology, etc., and find feasible solutions for making UbicKids systems and applications truly trustworthy and acceptable in terms of these non-technical factors.

Recently, there have been many ubiquitous applications developed or under development, such as the health monitoring systems for patients, home media appliance management for adults, learning support tools for students, location-aware mobile services for customers, etc. However, as to our knowledge, there are only very few ubiquitous researches for kids. MIT Media Lab's KidsRoom is for making an interactive and immersive story environment and UCLA's Smart Kindergarten project is targeted at a sensor-instrumented classroom for early childhood education. From our current survey, UbicKids seems to be the first project specially focused on kids care. With respect to general technological features and functional characteristics, UbicKids is comparable with PIHS (Personalized Instrumented Health System), a joint research effort by the UR, GT, MIT, and UF groups. But PIHS is targeted at caring the elderly, while we focus on caring the children.

We have been working on the general system architectures and spatial models with semantic representations. Several prototypes of outdoor safety care, ambient sound aware advisor, after-school monitor, toy finder, and umbrella reminder have being developed. Our Muse laboratory is closely collaborated with other laboratories of Prof. Laurence T. Yang in St. Francis Xavier University, Prof. Bernady O. Apduhan in Kyushu Sangyo University, Prof. Runhe Huang in Hosei University, Prof. Leonard Barolli in Fukuoka Institute of Technology and Prof. Makoto Takizawa in Tokyo Denki University. We have had many constructive discussions in meetings and seminars with other professors/researchers from a variety of disciplines including children psychology and economics. More details about our views on the smart hyperspace and our research on UbicKids, are described in our recent paper, *Towards a Smart World and Ubiquitous Intelligence: A Walkthrough from Smart Things to Smart Hyperspaces and UbicKids, in the Journal of Pervasive Computing and Communications, March Issue, 2005*.

Kids learn from their everyday interactions with their surrounding environments that play vital roles in forming their characteristics, behaviors, habits, personalities, etc., which may have great influence on the rest of their lives. Both positive and negative impacts of ubiquitous caring environments on kids need to be seriously and deeply investigated, and corresponding solutions to overcome the negative aspects must be discovered for relieving parents from worries of using such environments in practice. We expect more researchers to join us to create a variety of smart/intelligent hyperspaces towards the smart world. It is also expected that the children will greatly benefit from the products of ubiquitous or pervasive technologies, especially ubiquitous intelligence. After all, the children are our future! It is our belief that

Knowing more children, know more the world.

The betterment of children, the better world.