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# Smart u-Things – Challenging Real World Complexity

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## Abstract

The real physical things are called u-things if they are attached, embedded or blended with computers, networks, and/or some other devices such as sensors, actors, e-tags and so on. Smart u-things are ones that can sense, compute, communicate and take some responsive or automatic actions/reactions/proactions according to their goals, situated contexts, users' needs, etc. After clarifying the basic features and three categories of smart u-things, i.e., smart object, smart space and smart system, the article is devoted to possible challenges in smart u-things' research in terms of real world complexity. The challenges cover sufficiently and precisely detecting surrounding situations, anticipating users' needs, finding the dynamic relations between things, building common knowledge to u-things, letting u-things self-aware, and making looped decisions for error corrections. These real world complexity oriented issues are more crucial and more challenging as compared with many other well realized technology challenges.

*Conjectures are of great importance since they suggest useful lines of research. - By A.M. Turing*

## 1. Introduction

Cyber computing can be basically regarded as information technologies and applications in the digital cyber world or virtual world, in which there are a variety of digitized virtual things or *e-things* such as e-book, e-classroom, e-school, e-shop, e-clinic, e-money, e-community, and many others. The essential of cyber computing is converting physical things in the real world into some kinds of their virtual counterparts, i.e., e-things, in the cyber world so that a lot of conventional activities can be moved to the virtual world and done with e-ways, such as e-learning, e-shopping, e-health, e-commerce, e-science, etc.

Ubiquitous computing, opposite cyber computing, is not for making the pure virtual e-things, rather keeping physical things as they are in the real world and further improving their functions by means of adding digital abilities of information sense, communication and processing to the real things. The essential of ubiquitous computing, as emphasized by Mark Weiser, is "enhancing computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user" [1, 2].

The fact that the ordinary physical things are capable of sensing, computing and communicating is the natural result of two fundamental technology trends: (1) the continuing miniaturization of electronic chips and electro-mechanical devices, and (2) their available interconnections by networks especially using wireless communications. Therefore, many real things can be integrated with attached/embedded/blended computers, networks, and/or some other devices such as sensors, actors, e-tags and so on. Such the real things with the attachment/embedment/blending of computers and/or communications can be called *u-things*, against e-things, to differentiate the focuses between cyber computing and ubiquitous computing.

In 1950, a few years after the computer was born, Alan M. Turing raised the essential question, "*Can machines think?*", in his article "Computing Machinery and Intelligence" [3], which can be regarded as the seed of artificial intelligence (AI) and other intelligent computing. He believes machines think and also believes that "at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted". What he believed has been a reality far before the end of the 20th century.

Actually, since the end of the last century, the essential question has become "*Can things think?*" and "*When things start to think*" [4]. The consortium of Things That Think (TTT) has been formed since 1995 by MIT Media Lab with the goal of embedding computation into everyday things such as clothing, jewelry, and tables [5]. Thing thinking means the thing has some intelligence. When everyday u-things that think possibly become more, the next essential question is "*Can intelligent things be everywhere*?" We believe that the real world will be pervaded eventually with *ubiquitous intelligence* (UI) residing in u-things [6, 7], to extent similar as the EC's vision of ambient intelligence (AmI) [8].

Based on the two fundamental technology trends mentioned previously, it is quite sure that more and more u-things will appear in following years. Many of the u-things can sense, compute, communicate and take some adaptive actions/reactions/proactions according to their goals and situated contexts. Such kinds of active/reactive/proactive u-things are generally called *intelligent* or *smart u-things*. The ubiquitous intelligence means pervasions of the smart u-things in the real world, which would evolve towards what we have called the *smart world* filled with such smart u-things [7].

It is greatly challenging and also extremely hard to develop truly applicable smart u-things and associated systems. The difficulties are basically from two aspects: the technology complexity in developing such novel u-things and the real world complexity due to the great diversity and uncertainty as well as various non-technical factors in their practical uses. Recently there have been a lot of discussions about u-things related technological and social challenges [9-13].

However, challenges brought from the real world complexity are not enough addressed. Actually, the real world complexity oriented challenges are more crucial and harder to solve. This article is mainly attempted to examine these possible challenges in terms of the real world complexity so as to be aware of what basic harder problems we may face, and what greater efforts and correct altitudes we should take in researching smart u-things towards ubiquitous intelligence and smart world.

## 2. Smart u-Things

The concept of smart u-thing given so far is relatively abstract and too general. Before discussing the challenges, it is necessary to make the concept more concrete. Therefore, this section is devoted to some basic features and categories of smart u-things.

Smart u-thing can be with different levels of intelligence from low to high. However, the word 'smart' is a little bit subtle and vague, thus its exact meaning is relatively hard to comprehend by the general audience and it has yet to be widely adopted by all of researchers. It is therefore, very normal to see that lots of ubicomp/percomp 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*, *autonomic*, *sentient*, *perceptual*, *cognitive*, *thinking*, etc. Among these, 'smart' is probably the most often used in literatures in recent years. It looks, at the current stage, that the term smart is a more general one possibly covering the meanings of the above different terms in the context of ubicomp. It is also commonly seen that the two terms, smart and intelligent, are interchangeably used in some cases with almost equivalent meanings.

Smart u-things may cover innumerable kinds of physical things in the real world. They can be roughly classified into three categories, i.e., smart object, smart space and smart system, according to their appearances and functions.

### Smart Objects

This category is about smart/intelligent ubiquitous objects or u-objects. They may be very sophisticated equipments such as smart TVs, cameras, PDAs, cell phones and so on, but many of them are usual things like keys, watches, pens, bags, clothes, books, tables, windows, doors, etc., that is, almost all objects ranging from man-mad artifacts to natural ones, such as plants, insects, animals, and human bodies, in the real world.

Although the smart/intelligent object, as a common term, is relatively acceptable for this category, other terms are also used in literatures as subsets of smart objects, such as smart devices, cards, labels, e-tags, sensors, motes, artifacts, appliances, instruments, goods, furniture, textiles, materials, etc., for more specifically covering different sets of smart objects [14-16]. The term of "smartifact" is sometimes used for cataloging a large collection of smart objects, i.e., artifacts. This term was first coined by researcher Harry Vertelney at Apple Computer in the 1980s to refer to new forms of software-based agents, and used by Paul Saffo in 1997 to connote something different: physical objects possessing rudimentary "intelligence" sufficient to be aware and affect the environment around them [17].

The robots can be also seen as some special kinds of smart objects, but many of them are aimed at partially human-like or animal-like behaviors with relatively high intelligence and more complex as compared with these smart everyday objects. In addition to intelligence, robots are usually able to move by themselves. However, the self-moveable function is not a generally necessary feature for usual smart objects. Robot as an exciting field has been gotten a great deal of attention. Lots of robots have been already applied to various situations such as game, entertainment, housework, rescue, military and manufacture. It is said that only industrial robots are about one million in the world, nearly half of them in Japan, by the end of 2004, that is, intelligent robots will be everywhere and ubiquitous [18, 19].

### Smart Spaces

This category is about smart/intelligent spaces or u-spaces, which are electronic-enhanced real spatial environments, or u-environments, including not only a number of various smart u-objects but also other relatively powerful computers/gateways to manage and serve these smart objects. 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, the two abstract words can be replaced by more concrete ones such as room, office, laboratory, home, shop, road, bridge, car, park, pool, land, etc. [10, 20].

The core and essential features of the smart space are that (1) it is a physical environment equipped with electronic devices and embedded systems, which may be in different shapes, sizes, forms, functions, etc.; (2) it must have some kinds or levels of abilities of perception, cognition, analysis, reasoning and anticipation about users' existence and surroundings, on which it can accordingly take proper actions; and (3) it aims at truly adapting to humans rather than the reverse, providing convenient and comfortable services to users in their everyday environments without limiting to their desktops/laptops.

A set of associated smart spaces, once interconnected and integrated, can be regarded as a higher leveled super space, called *smart hyperspace* or hyper-environment [7, 21]. A smart hyperspace treats a set of related spaces as a whole while emphasizing the possible situational, spatial, and temporal relationships between the spaces for further understanding of users and thus providing better services to them.

**Smart Systems**

This category is about general smart systems or u-systems that are usually hard or sometimes impossible to describe by spatial attributes. They can be common service infrastructures including communication network systems, traffic management systems, some environment/activity monitoring systems, information delivery systems, etc. Or they are open software & hardware platforms, adaptive middleware and a kind of general service frameworks to support or serve smart u-objects and smart u-spaces as well as their u-services or u-applications. Although autonomic computing is targeted in making the self-manageable systems to cope with the problem of increasing complexities [22], such autonomic systems can be actually regarded as some kinds of smart systems.

The ubicomp/percomp can be regarded, in a sense, as the computing of all these smart/intelligent u-things, which are the basic elements and components of the smart world. The ultimate goal of smart u-things is to make them *clam* as suggested by Wiser and Brown [2], that is, they should behave trustworthily in both other-aware and self-aware manners to offer comfortable and convenient services in *right means right place right time*. Certainly, the intelligent physical things which fulfill the strict meaning of human-like intelligence would not or unnecessarily come in the near future. A reasonable expectation is to let the computable u-things to have certain level or limit but truly useful smartness or intelligence in a broad sense.

## 3. Real World Complexity Challenges

Any smartness or intelligence of u-things is based on their three fundamental types of functions below:

- Computation & storage for processing & memory
- Networking for interconnection & communication
- Sense and effect for perception & interaction

The u-things and their related ubiquitous/pervasive systems are more complex than the e-things. There are many technological challenges to attach/embed/blend the above three functions to the physical objects and let them functioning normally. These technology challenges include devices miniaturization, power management, ubiquitous/pervasive networks, ad hoc mobility, open service architecture, sensed information overload & database, context semantics & management, autonomic system administration, user interface, operating system, language, middleware, integration, cooperation, scalability, heterogeneity, dependability, availability, security, privacy, standards, etc.

These technology challenging issues are indeed very crucial, but we would not like to talk more about them since they have been relatively well realized and could be, although very hard, solved in the following years. As smart u-things exist in the physical environments in which many computers are invisible and serve our daily life, work, etc., it is felt that some issues brought from the real world complexity are more crucial, and much attention should be paid to them. Before discussing these real world complexity challenges, it is necessary to describe what essential behaving characters are expected for ideal smart u-things to have.

Research on smart u-things and related systems expends fast especially in the last three years. Although there are not yet many practical applications of smart u-things, we can find various prototypes and see lots of scenarios started from Weiser's Sal, to AmI's Maria, Dimitrios and Carmen, to Aura's Jane and Fred, to many others. From them as well as our research on UbicKids [7], it seems generally expected that an ideal smart u-thing should be able to act adaptively and automatically according to

- Surrounding Situations
- Users' Needs
- Things' Relations
- Common Knowledge
- Self Awareness
- Looped Decisions

Although a smart u-thing with all the above essential characters is perfect, a u-thing can be also regarded as smart even if only with part of the six. The questions here are how hard to make smart u-things capable of behaving like the above and what are challenge issues in terms of real world complexity? Let's examine the six characters one by one.

**Surrounding Situations**

To know the situations surrounding a smart thing, it is necessary to first get sensed information, i.e., necessary contexts. The context is any information that can be used to characterize the situation of an entity [23, 24]. The whole contexts are usually a collection of values and can be represented as

$$C(t) = \{C_i(B_i, L, t_h),\ i \in I(t),\ t_h \in [t-h, t]\}$$

Where $C_i$ is the contexts for some aspect/dimension $i$ which are described by an attribute vector $B_i$ and may be related to location $L$ and time interval $t_h$. The $I(t)$ is a number of all aspects/dimensions for representing the whole contexts at time $t$. It has been recently noted that context history is very important. Thus, $t_h$ means all available context information in the period $[t-h, t]$. In the above and the following formulas, a low-cased letter is a normal variable and an upper-cased letter is a set, a vector, or a matrix. Contexts can be divided into levels from low to high in order to differentiate levels of meanings and their abstraction. The lowest leveled contexts are raw date directly acquired from sensors.

The highest leveled contexts are often relatively compact but more semantic and therefore called situations, which are more understandable and may be directly used for decision making. The situations $S(t)$ related to a smart thing at time $t$ can be represented by

$$S(t) = \varphi[C(t)] = \{S_j(W_j, t), j \in J(t)\}$$

The $S(t)$ is determined by processing contexts $C(t)$ and then mapping the contexts into a set of situations, each of which is described by $W_j$. The $J(t)$ denotes the number of the situations for different aspects that are usually dynamically changed.

Context-aware computing is currently one of the most active and popular research areas in ubicomp. However, making a u-thing context-aware is one thing, and making its behavior context-aware trustworthily is another thing. Our assumptions about contexts $C(t)$ and the situations $S(t)$ can be seen as some approximations to states of the real environment surrounding a u-thing because the real world is constantly changing, intrinsically uncertain, and infinitely rich [25].

The challenging questions here are that (1) are the contexts $C(t)$ sufficient and precise enough to characterize a real environment? (2) how correct can the real situations $S(t)$ be determined based on the available contexts which may be incomplete and uncertain? and (3) what are impacts and consequences of fault situation judgments to a context-aware situated u-thing? For example, detecting human activities, as a kind of situations, has been researched in recently years. It is reported that the incorrect detection rate is from 10~50% in experimental environments [26, 27], which are relatively simple as compared with diverse and varied real environments. However, it is not yet unclear that what results of the fault detection even in a low rate means when applying the activity detection to the real systems and using them in practical. If incomplete and uncertain contexts and mis-judged situations are common and ubiquitous, we should keep these incompletion, uncertainty and misjudgment as intrinsic features in smart u-things' research.

**Users' Needs**

Many current computers and related technologies have been made based on the *interactive mechanism*, i.e., a process of request and response dialogs between human and computer. In this mechanism, a user gives commands via some input devices, and receives replies from some output devices. The user is often an activator of a sequence of computer and network actions, and the computers/devices play relatively passive roles.

Although the interactive mechanism works well in conventional computing paradigm, it may not for u-things' systems in ubiquitous computing paradigm due to the following three limits: (1) too small computers to be visible when their attached/embedded/blended in u-things; (2) too many computers to be interact-able with all of them spontaneously by a user; (3) too complex computer systems to be manageable interactively by users even for skilled system engineers. Thus, u-things are expected to be more active in a *proactive mechanism*, i.e., taking proper reactions by anticipating the users' needs with reference to the rich contexts [28], and more automatic in an *autonomic way* to work and manage by themselves under human supervisions/needs [22].

The users' needs are generally with multi aspects and subtly affected by many factors as shown in the following formula:

$$N(t) = \{N_{u,v}[P_{u,v}(t), S(t), S(t\text{-}\Delta)], u \in U(t), v \in V(t)\}$$

Where $N_{u,v}$ denotes the aspect $v$ of the needs for user $u$. It is depended on the individual personal factor $P_{u,v}(t)$, such as status, goal, preference, feeling, etc., and current situations $S(t)$ and past situations $S(t\text{-}\Delta)$ to a user. The $U(t)$ and $V(t)$ are numbers of users and needs' aspects, respectively, and both may be dynamically changed.

Human-to-human understanding is greatly expected but often very difficult in the complex real human world as said in an old Chinese saw – "know you and know your face, but don't know your mind". The question is how much can be expected to correctly and promptly know users' true needs? Detecting users' activities is one thing, while knowing users' needs is another much harder thing. It is extremely challenging to precisely anticipate users' needs/minds.

**Things' Relations**

When there are lots of smart u-things, some of them may form some kinds of relations that generally exist between u-things, between users, between users and u-things, between u-things and other things, etc. Such complex things' relations can be represented as

$$R(t) = \{R_q(T_q, U_q, t), U_q \in U(t), q \in Q(t)\}$$

Where $R_q$ denotes some kind of relations involved with things $T_q$ and users $U_q$, and $Q(t)$ is the total number of all possible relations. The question is how to define, describe and find the dynamic relations necessary for u-things' systems? The smart hyperspace is our effort to study the relations between associated smart spaces [7].

**Common Knowledge**

Usually analysis, reasoning, anticipation and judgment are based on some knowledge. Since smart u-things are in the physical environments and serve people's daily life and work, it is natural to desire smart u-things having some common knowledge about the physical world, human society, and so on. Suppose the knowledge represented as

$$K(t) = \{K_m(F_m, t_h), m \in M(t), t_h \in [t_0, t]\}$$

Where $K_m$ denotes one aspect $m$ of knowledge described by $F_m$, and $M(t)$ is all aspects of available knowledge. The $t_h$ shows that the knowledge may be given in the initial setting at $t_0$ and accumulated or learned during time period $(t_0, t]$. The questions are what knowledge is necessary for smart u-things, what knowledge should be initially set, what knowledge can be added or self-learned later, and how to use the knowledge? The main challenge is how to abstract, learn and use the complex knowledge about human and the world.

**Self Awareness**

Different from e-things, computers are attached, embedded or blended to physical u-things. No matter what novel functions they can provide, they must be always aware of they are parts or components of the physical things and have to follow the original functions and rules for these things. That is, smart u-things must be self-awareness, which can be expressed with

$$A(t) = \{A_z(G_z, t), z \in Z(t)\}$$

Where $A_z$ is one aspect $z$ of self-awareness described by $G_z$, and $Z(t)$ is all aspects of necessary self-awareness. Context-aware computing, although very important, is put more emphasis on other-awareness. As Tao Tzu said that, "Knowing others is wisdom, knowing yourself is enlightenment". This challenge is really hard since there is very rare research on self-awareness computing.

**Looped Decisions**

Smart u-things are expected to automatically and correctively respond to the real environments and users based on decisions as follows

$$D(t) = \psi[S(t), N(t), R(t), K(t), A(t), D(t\text{-}\Delta), E(t)]$$

It is impossible to assure that all decisions are always correct in 100%. Therefore, the challenge is to make looped decisions that can adaptively adjust or calibrate their decision precision based on the previous decisions $D(t\text{-}\Delta)$ and their dynamically detected errors $E(t)$. The looping mechanism is indispensable in smart u-things.

## 4. Concluding Remarks

It is my belief that smart u-things will be everywhere towards ubiquitous intelligence and smart world. After discussing this trend, the article gives basic features of smart u-things and three categories, i.e., smart object, space and system. In recent years lots of discussions have been devoted to technology & social challenges. However, we feel that some real world complexity oriented issues are more crucial and more challenging in smart u-things' research. These issues are big barriers even very negative to the smart u-things vision. The article's intentions are twofold: (1) to examine the possible hard issues to suggest some potential research lines; and (2) to let researchers in this field coolheaded and being aware of the hardness of these challenges in making real things truly smart.

## References


[1] Mark Weiser, "Ubiquitous Computing", IEEE Computer, October, 1993.

[2] M. Weiser and J. S. Brown, "The Coming Age of Calm Technology," P. J. Denning and R. M. Metcalfe, Eds., Beyond Calculation: The Next Fifty Years of Computing, 1996.

[3] Alan M. Turing, "Computing Machinery and Intelligence", Mind, 59, 433-460, 1950.

[4] Neil Gershenfeld, "When Things Start to Think", Henry Holt and Company, LLC, 1999.

[5] Things That Think, http://ttt.media.mit.edu/

[6] Jianhua Ma, Ubiquitous Intelligence - The Intelligence Revolution, ID People Magazine, April 2005.

[7] Jianhua Ma, et al, "Towards a Smart World and Ubiquitous Intelligence: A Walkthrough from Smart Things to Smart Hyperspaces and UbicKids", International Journal of Pervasive Comp. and Comm., 1(1), March 2005.

[8] The European Union Report, "Scenarios for Ambient Intelligence in 2010", ftp://ftp.cordis.lu/pub/ist/docs/, 2001.

[9] D. Saha and A. Mukherjee, "Pervasive Computing: A Paradigm for the 21st Century", IEEE Computer, March 2003.

[10] D.J. Cook and S.K. Das (Editors), "Smart Environments: Technologies, Protocols and Applications", Wiley-Interscience, ISBN 0-471-54448-5, 2005.

[11] D. Chalmers, et al, "Global Ubiquitous Computing: Design and Science", UC Grand Challenge: Manifesto, June 2005, http://www-dse.doc.ic.ac.uk/Projects/UbiNet/GC/

[12] The Beyond-The-Horizon Workshop on Pervasive Computing and Communications (PCC), Vienna, July 2005, http://www.cordis.lu/ist/fet/bthpcc.htm

[13] Jürgen Bohn, et al, "Social, Economic, and Ethical Implications of Ambient Intelligence and Ubiquitous Computing", *Ambient Intelligence*, Springer-Verlag, 2004.

[14] Smart Objects Conference (sOc2003), France, May 2003.

[15] Gilles Private, "Smart Devices: New Telecom Applications & Evolution of Human Interfaces", Keynote presentation at CASSIS Int'l Workshop, Nice, March, 2005.

[16] C. André Nørstebø, "Intelligent Textiles, Soft Products", http://www.ivt.ntnu.no/ipd/fag/PD9/2003/artikkel/, 2003.

[17] Paul Saffo, "Sensors: The Next Wave of Infotech Innovation", 1997, http://www.saffo.com/essays/sensors.php

[18] Jam Pinto, "Intelligent Robots Will Be Everywhere", in Automation.com, 2003, http://www.jimpinto.com/writings/robots.html.

[19] The 2nd International Conference on Ubiquitous Robots and Ambient Intelligence, Daejeon, Korea, Nov. 2-4, 2005. http://www.robotweek.or.kr/m1/m1s1.asp

[20] Roy Champbell, "Beyond Global Communications: The Active World", IEEE PerCom2005, Hawaii, March 2005.

[21] T. L. Kunii, Jianhua Ma and Runhe Huang, "Hyperworld Modeling", (Keynote) Proc. the 1st Int'l Conf. on Visual Information Systems, Australia, February 1996.

[22] A.G. Ganek, T.A.Corbi, "The Dawning of the Autonomic Computing Era", IBM Systems Journal, Vol.42, No.1, 2003.

[23] A.K. Dey, "Understanding and Using Context", Personal and Ubiquitous Computing, 5(1):4–7, Springer Verlag, 2001.

[24] G.D. Abowd, E.D. Mynatt and T. Rodden, "The Human Experience", IEEE Pervasive Computing, No.1, 2002.

[25] C. Lueg, "On the Gap between Vision and Feasibility", Pervasive'2002, LNCS 2414, Springer-Verlag, 2002.

[26] E. Munguia, et al, "Activity Recognition in the Home using Simple and Ubiquitous Sensors", PERVASIVE 2004.

[27] M. Muhlenbrock, et al, "Learning to Detect User Activity and Availability from A Variety of Sensor Data", IEEE PerCom2004, Florida, March 2004.

[28] R. Want, et al, "Comparing Autonomic and Proactive Computing", IBM System Journal, Vol. 42, No.1, 2003.