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Everything is Alive: Towards the Future Wisdom Web of Things

Akihiro Eguchi, Hung Nguyen, Craig W. Thompson

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Abstract The *Everything is Alive* (EiA) project at University of Arkansas is focused on pervasive computing. We consider that every physical object can be a living smart object and any services can be a living phenomenon. The goal of EiA is to *make everything alive to make our lives revive* with the objective to make use of all objects and services surrounding us to make our life better. Our project is goal-oriented, and the scope of this project is broad, encompassing Ubiquitous Intelligence, Cyber-Individual, Brain Informatics, and Web Intelligence. In this paper, we discuss how those technologies can be integrated together and fit into a seamless cycle like the one proposed in the Wisdom Web of Things (W2T). We also provide two case studies from our EiA project. The first case study is to demonstrate how a concept first tested in a virtual environment can be successfully implemented in the real world later when technological advances finally caught up. The data collection step and the ability to manually control smart objects of the W2T cycle are fulfilled in this step. The second case study is to show how the software simulator and hardware implementation are abstracted from the underlying algorithm, and thus, it serves as an example of how virtual worlds can be used as a test bed for W2T, especially with regards to the development of the remaining steps of the W2T cycle.

Keywords internet of things · RFID · virtual world · brain informatics · cyber individuals · ubiquitous computing · web intelligence · web of things · android · arduino · semantic world · second life · smart objects · mobile robot

A. Eguchi · H. Nguyen · C. W. Thompson
Department of Computer Science and Computer Engineering, University of Arkansas, Fayetteville, AR, USA
e-mail: aeguchi@acm.org

H. Nguyen
e-mail: hpnguyen@email.uark.edu

C. W. Thompson
e-mail: cwt@email.uark.edu

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1 Everything is Alive

Imagine if you could talk to any object in your house (e.g., TV, AC, a chair) as if they were alive. What would you like to ask? How would you like them to behave? Perhaps you ask the TV to auto-recommend to you the channels after studying your preferences, or the AC to auto-adjust to maximize everyone's comfort in the room, or a chair to auto-configure itself to fit your body. The *Everything is Alive* (EiA) project at the University of Arkansas is exploring pervasive computing in a future smart, semantic world where every object can have identity and can communicate with humans and other smart objects. In that sense, all objects are agents. The focus of the project is broad, including the fields of ontology, virtual worlds, smart objects, soft controllers, mobile computing, and mobile robots. In this paper, we discuss how those technologies are architected to combine together to build up the future world of EiA.

As Thompson described EiA in 2004 [34], in ancient days, peoples' lives were surrounded by many "living things" including rocks and trees, and many natural "living phenomena" such as wind and rain; people believed spirits resided in things and influenced their life in various ways. Therefore, people tried to understand those "living things" and "living phenomena" and asked how to live with those to maximize the happiness of their lives. With the introduction of science, people developed technology as a mean of conquering nature; as a result, we humans became self-centered believing that our intelligence distinguishes us from other things. It is true that peoples' lives became a lot more efficient and convenient. However, count how many physical objects you have in your room. If these were intelligent, imagine how many new services you could access. In EiA, we believe that any of those objects can be "living things", and any of those services are possibly "living phenomena", as we associate knowledge, action, and rules with those things or services in the world around us. The basic concept of EiA project might be stated as *make everything alive to make our lives revive*. We are exploring the architecture to convert a world of ordinary objects into the semantic world of smart objects where everything is alive, can sense, act, think, feel, communicate, and maybe even move and reproduce [34].

Our work contains various aspects that are related to or categorized into *Ubiquitous Intelligence*, *Cyber-Individual*, *Brain Informatics*, and *Web Intelligence* which combine together to add Intelligence to the *hyper world* where the social world, the physical world, and the virtual world are mixed together [42] as shown in Table 1. Within the *Ubiquitous Intelligence* field of study, one focus of the EiA project is the smart object research that explores and identifies the way to make object smart based on the protocols it obeys [11]. Similar to the concept of *Internet of Things*, we assign unique identity to each object and develop a communicative structure with networking capability. As a field of *Cyber-Individual*, EiA emphasizes the use of 3D *virtual worlds* to represent real environment and our individuals' lives [25]. We build a realistic

Table 1 Various aspects in EiA

Web Intelligence • Ontology service • Dynamic API distribution • Service distribution strategy	**Ubiquitous Intelligence** • RFID • Smart objects • Spatial searchbot
Brain Informatics • Psychological experiment • Biologically-inspired simulation • Interdisciplinary study	**Cyber Individual** • 3D reconfiguration • Virtual world • Prototyping

environment in a virtual world and use it as an environment to test architectures we developed for the future pervasive computing, which includes a spatial search bot [12], soft controllers [35], smart objects [11], and autonomous floor mapping robots [24]. This is significantly different from 3D modeling in that we can include social interaction of people. We believe this type of *Cyber-Individual* technology can help to develop the concepts and architecture of *Ubiquitous Intelligence*.

Besides, as a part of *Brain Informatics* field of study, we also emphasize the importance of learning from human behavior to build more efficient models. We proposed a new model of object recognition, which was inspired by a study of child language acquisition in developmental psychology [10]. Also, based on a biologically-inspired genetic model of economics, we analyzed effective decision making strategies, which would be important to build up *Web Intelligence* to distribute services effectively [9]. As the development of *Web Intelligence*, in terms of the architecture of distribution of services, one of the main foci of EiA is modularity via plugins and services. i.e., the way any agent can dynamically extend or remove their capability depending on need [27]. So, our development of Web *Intelligence* is based on goal-oriented service distribution. Depending on need for a certain goal, *Web Intelligence* provides appropriate support to our world. This work includes the idea of a soft controller, dynamic interface loading, and ontology services. The challenge for our project is how to efficiently combine those four domains of studies to develop an ultimate architecture for realizing the world of EiA where people, things, and services are synthesized to provide benefits in our lives.

1.1 Ubiquitous Intelligence

1.1.1 Key concepts

Ubiquitous Intelligence means that "intelligent things are everywhere" [42]. In other words, it also means "Everything is Alive." It happens when the world is transformed into a smart, semantic world with intelligent objects harmoniously coordinates with each other by utilizing omnipresent sensors. Key challenges include how things are aware of themselves, how to figure out user's need or context, and how to understand common knowledge [42].

Self-awareness is one important concept that makes objects behave more efficiently based on context understanding and on the way others perceive them. For replacement of human language communication, the objects may use query language that can retrieve and manipulate data. The work of GS [13] divided the smart object as agents into three different levels: owner object, active object, and passive object. They used a refrigerator as an active object, which can read RFID information of objects inside of the refrigerator as passive objects. Both owner object and active object have sets of query language, and, depending on query sent by the owner object, an active object can send a query to some passive object to meet the goal. This opens a new door to the way people interact with objects. We specify what rather than how things should be done to accomplish some goals, and the objects coordinate with each other to accomplish the stated goals. For example, people can be anywhere and tell objects in their house to take out meat from a freezer to defrost before they get home and start cooking. The freezer figures out what types of meat are available and takes out the appropriate one. The smart phone, freezer, and meat act as owner, active, and passive objects, respectively.

1.1.2. Ubiquitous Intelligence in EiA

In our EiA project, one important question is what it is about objects that makes them smart and how we can create a world for them. In order to answer the question, we identified protocols that can be added to an ordinary object to transform it into a smart(er) object. Example protocols are explicit identity, message-based communication, API, plug-in behaviors, security, associated 3D models and ontologies, and others.

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To demonstrate these ideas, Eguchi and Thompson [11] developed a demonstration in a virtual world, Second Life, on University of Arkansas island of a baby mannequin that nurses can use to learn how to help infants who need special care. Such babies stay in warming beds with several smart features. We visited our School of Nursing, modeled an infant bed, and created scripts to operate the bed (Fig.1). By itself, that was not our main contribution, it just set the stage to understand smart objects.

In order to understand how to create “smart objects,” we associated APIs with objects and then added the ability to discover the API of smart objects nearby. Then, when a *remote control* device is near those objects, it “discovers” the API and imports it to a display so that the object can be operated by remote control. This works with all objects that follow the API discovery protocol. We also identified several other protocols that make an object smart or rather smarter.

We describe how to do this in the real world using RFID and smart phones but demonstrate this using 3D virtual worlds where an avatar passing by smart objects can use a universal remote (which is a smart phone in the real world) to read an object’s API and control the object. We first used 3D virtual worlds to demonstrate and explore such protocols, and then translated these protocols to the real world. More details will be discussed in section 5.

Our next challenge is to give stronger context inference ability based on relationships between other objects. Eno and Thompson [12] built an avatarbot that autonomously roams around the virtual world to collect information of objects, similar to a searchbot in the web. Based on the spatial relationship and semantic relationship of meta-data retrieved, they successfully inferred names of unlabelled objects. We believe with the increasing number of smart phones, in the future, each person can be a "searchbot": by walking around the world with smart phones everyone contributes to gather the knowledge in Ubiquitous Intelligence.

In the EiA project, we first recognize that everything can be associated with intelligence by providing unique identity for each. People can use the identity of an object in interest to retrieve associated knowledge or possible commands to control the object. In addition, our searchbot collects such identities distributed in a space to make users easily grasp broader range of the distributed Ubiquitous Intelligence. However, one important focus of W2T is a circular flow of data. Even though this architecture may satisfy people’s intellectual curiosities by providing more knowledge about objects around in the world, the data flow eventually stops by achieving the goal. Therefore, in order to circulate the flow further, it is necessary to connect the Ubiquitous Intelligence to other aspects in W2T. For example, the Ubiquitous Intelligence collected by searchbot or by users with smart phone are flowed into next phase to build a centralized *Web Intelligence* which will enhance the inference ability of *Ubiquitous Intelligence*, resulting in a more comfortable and efficient life with many smart objects. Similarly, EiA sees *Cyber-Individual* is one of the research areas that flow of the knowledge into *Ubiquitous Intelligence*.

a **b**

Figure 1 (**a**) Baby mannequin in a bed that is actually used in a nursing school; (**b**) the model of the baby mannequin in Second Life

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1.2 Cyber-Individual

1.2.1 Key concepts

Cyber-Individual is a term that refers to a real individual's counterpart in a virtual space. The main idea of this research is to virtually place humans in the center of the world with *Ubiquitous Intelligence* [38]. Using a user's preference list, Lertlakkhanakul and Choi showed how to coordinate smart objects (e.g., AC, sofa, light, and TV) to make the environment most enjoyable for the user [18]. Although *Cyber-Individual* ideally contains a full description of an individual, it is not possible to reflect literally everything, so the important question here is what kind and how to represent description of individuals. Wen et al. [38] divided the set of descriptions of an individual into two: descriptions that require instant refresh such as psychological emotion and physical status, and descriptions that require gradual updates such as social relationships, experience, and personality. This kind of classification is important to build a realistic Cyber-individual.

Another area that is strongly related to Cyber-Individual is mirror world research. The concept of a *mirror world* is to synchronize any activity, environment, interactions between real and virtual world. Various types of sensing technology help to build models of the real world in a virtual world, and Ubiquitous Intelligence adds additional information of object, people, and places in the world. However, the other way around to reflect the change in the virtual world to the same change in a real world had been a big challenge. Fortunately, with recent technology of Augmented Reality, those two worlds are starting to be merged together [15].

Therefore, we can assume that a Cyber-Individual can represent an individual in a real world more accurately, both physically and socially. Based on the analysis over interactions in this virtual world, we may see similar results from what we expect in a real world. This field of study brought us a new means of freely simulating our life.

1.2.2 Cyber-Individual in EiA

EiA emphasizes the use of 3D virtual worlds as a mean of prototyping pervasive computing architectures, assuming the virtual world is a suitable surrogate representation of our physical and social world. Each person in the virtual world platform Second Life has an associated avatar. The avatar can interact with other objects: get information from and control other objects. One challenge in the past is how to link individuals in the real world with his/her counterpart in the virtual world. There are two problems to deal with: complexity and time consumption of life-like modeling of humans or things; and spatial, temporal, and social tracking of individuals.

a **b**

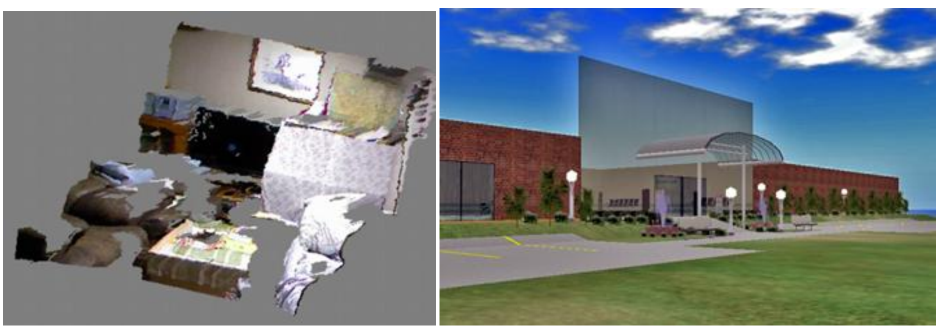

Figure 2 (a) 3D reconfiguration with Kinect; (b) hospital in Second Life island of University of Arkansas

Recent advances in research are promising keys to solving these two problems altogether. With the creation of Microsoft Kinect, we now have easy access to real-time and life-like 3D modeling of objects in the real world [16] (Fig. 2a). Given the complexity of modeling objects in 3D and the diversity of objects surrounding us, this new technology enables a normal person to not only model nearby things but also the individual. Then to link the 3D models with their counterparts in the real world, we can use RFID to tag and link objects between the two worlds. One disadvantage of this method is that we cannot track the objects in space or time. We can only identify the object. However, since most objects in the real world are static and sometimes immovable: TV's, refrigerators, lights, etc., identities of the object are enough for us to interact intelligently with them, as shown in the first case study in section 3. As for human individuals, identity is not enough, especially if we want to model interactions between human and objects, or even just between humans. Fortunately, with smart phones becoming more a commodity, we can track individuals not only in space and time, but also their social interactions [2].

These leaps in technology enable us to view the real world as a very high def, 3D virtual world that can be modeled by 3D virtual worlds that strongly resemble the real world both graphically and socially (Fig. 2b). Nevertheless, we cannot represent everything in the virtual world, but we do not think that would be a problem. The question is what kind and how much information we need to make everyday decisions like making coffee, playing chess with friends, etc. We do not need molecular level precise replicas of our world, and the growing information we can extract from the real world with current technology is already sufficient enough to make an increasing number of decisions in our daily life.

Currently in the real world, most objects are passive and not very smart. However, in 3D virtual worlds, objects can have associated behaviors (scripts). A virtual world such as Second Life or Unity can be used to represent the semantics of the real world since all objects are provided with unique ID, i.e., every object has a built-in identity. Additionally, in virtual worlds we can easily track xyz coordinates of every object, experience simple physics, and interact with other people as in a real world. Therefore, we see virtual world as a powerful environment to test new programs and architectures that will build *Ubiquitous Intelligence*. Thus, many of our results can be applied no matter whether we are connected to the real world or one of the virtual worlds. *Cyber-Individual* concept is not just as capable a representation of our everyday life but also as a great way to understand our own social interactions, both with other people and with objects surrounding us.

However, at the same time, Perkins [25] pointed out two areas for improvement in the current model of virtual worlds: the security issue of communication in the world and the need for better methods to communicate with external servers. Nguyen and Eguchi [24] also discussed several problems with using Second Life in the development of autonomous floor mapping robot. However, these problems are specific only to the virtual world Second Life and can be solved by extending its capabilities or switching to another more powerful environment.

1.3 Brain Informatics

1.3.1 Key concepts

Brain informatics is the interdisciplinary field of study that focuses on actual mechanisms used by humans. People in this field try to understand the core of human intelligence to offset the disadvantages of dependence upon logic-based inference by introducing many different perspectives such as biology, psychology, cognitive science, neuroscience, etc. [2] [40].

While object recognition is an actively investigated field of studies in computer science, physiological evidence show that the primate ventral visual pathway develops neurons that respond to particular objects or faces independently of their position, size or orientation, which seem to responsible for recognitions of

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transform-invariant visual objects and faces [26][6][33]. Over the past twenty years, the Oxford laboratory has investigated a range of problems in this field by developing a biologically plausible simulation model of the primate ventral visual pathway. This model has solved problems like invariant object recognition [31], segmentation of simultaneously presented objects [32], human body segmentation based on motion [14]. Additionally, this model is able to learn separate representations of different visual spaces such as identity and expression from the same input [37].

In addition to the detailed investigations of actual mechanisms of our brains, Brain Informatics also includes human's behaviors, which is controlled by the brains. One interesting example is Roy's [28] project to solve the puzzle of children's language acquisition. He set video cameras on ceilings of every room in his house and recorded two whole years of his son's growth, which can be reconstructed with 3D models to later analyze any moment of time with video image and sound. Based on the detailed analysis of the data, his group found a tendency of caregivers to adjust the way they speak to a child, which resulted in a significant impact on his child's words learning process. These data provided not only keys to solve the word acquisition problem but also insights to many other related areas such as action segmentation [20] and social interaction [5].

These works indicate that Brain Informatics can help solve current technical problems with insights to humans' behaviors, without which it might be prone to errors or impossible to solve.

1.3.2 Brain Informatics in EiA

One important characteristic of the EiA project is that the system includes not only smart objects but also humans or humans represented by their avatars in a virtual world. Therefore, in order to develop the communication between humans and objects, the field of *Brain Informatics* becomes important. One important fact that we cannot disregard is that the change in humans' psychological behavior in a computer mediated communication (CMC) setting. Experimental data collected by Eguchi and Bohannan [8] showed that Americans with their use of web-cam in CMC decreased both personal identity (self-perception of their uniqueness) and social identity (self-perception of their belongingness), which may be explained by a significantly increased feeling of anonymity. This study indicated that even if the Cyber-Individual accurately mirrors individuals, there will still remain strong psychological differences between communication in a real world and in a virtual world.

Brain Informatics can also enhance learning ability of computer program, specifically object recognition. Traditional object recognition model is usually focused on the shape of the objects, but it was challenging to distinguish two very different objects whose shapes are very similar to each other (deodorant spray can and insecticide spray can), or two differently shaped objects which perform essentially the same function (a normal chair and an oddly shaped chair). To solve this problem, Eguchi [10] focused on the mechanism that human children actually use to learn names of objects from the field of developmental psychology. Using Microsoft Kinect and machine learning techniques, he developed a new method to recognize an object based not only on its shape but also on its function in the same manner children actually do [17][23] and show how an insight to humans' mental capability helps improve current techniques which solely rely on machines (Fig.3).

Problems of the study in Brain Informatics, especially when focusing on functions of brain, is a need for the expensive facilities like fMRI and various issues to be addressed in order to use actual human subjects in the research. In the EiA project, we collaborate with researchers in field of Psychology so that we can pursue our main goal of EiA is to *make everything alive to make our lives revive.* Without deeper understanding of ourselves, we may be able to make everything alive, but cannot "revive" our lives. Our interdisciplinary study over humans provides a path to accomplish this.

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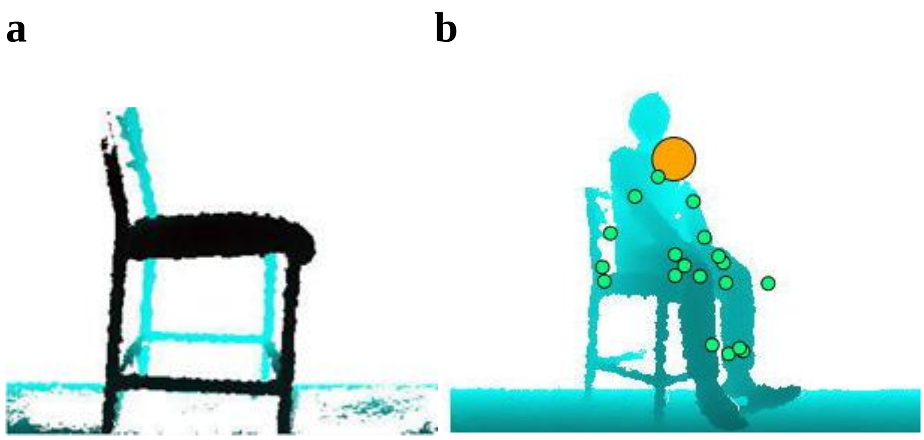

Figure. 3 Object recognition inspired by developmental psychology; (a) shape learning; (b) function learning

1.4 Web Intelligence

1.4.1 Key concepts

This paper so far has discussed the way to collect knowledge through Ubiquitous Intelligence, Cyber-Individual, and Brain informatics to form the data cycle in W2T. Web Intelligence is the essential concept that provides the way to efficiently make use of the knowledge. *Web Intelligence* is the concept that focuses on the Artificial Intelligence and Information Technology aspect at the development of Web information systems [39]. Web Intelligence possibly realizes self-organizing servers to automatically and efficiently match up individual needs and services. The server can be seen as an agent that can dynamically adjust the behavior. Additionally, based on various knowledge fed into the database, Web Intelligence is eventually able to provide people wisdom [41]. This research focuses on the new Web-based technology to process vast amount of information available in our world to provide people a better way of living, working, and learning. The challenges include design of goal-directed service, personalization feature, semantics, and feedback [42].

One example is the automated renewable home energy management system [3]. The system monitors daily energy consumption of a house and provides helpful recommendations to the owner via Internet. The provided information includes early warnings of low energy, task rescheduling suggestions, and tips for energy conservation that minimally affect our lives.

Based on data collected, *Web Intelligence* extracts knowledge and refines it to wisdom, and people will benefit from the services provided this new wisdom.

1.4.2 Web intelligence in EiA

One of our main foci in *Web intelligence* is the ontology problem. Humans can tell the difference between a door and a castle. However, real world objects are not labeled with explicit identities, types, locations, or ownership. 3D virtual worlds provide explicit identities, locations, and ownership, but names for objects are often not provided based on the analysis of collected data [12]. To build a smart, semantic world where every object is labeled and associated with knowledge, we need some way of associating object types, descriptions, APIs, and knowledge with things.

Like the semantic web, semantic worlds involve annotating things with metadata (types, super-types, API, attributes, costs, owners, locations, …). In EiA project, Eno and Thompson [12] developed two ontology services, one that takes Second Life labels, looks them up in the WordNet ontology, and then overlays them with metadata from WordNet. The other is an annotation service that depends on crowd sourcing so that any user can add metadata to any object. This service provides computer a way to infer the type of an object even if that object is not labeled explicitly with identity. This information would help the unknown object to be aware of its identity or role based on the environment it is in and would also help other objects to establish appropriate relationship with the unknown object. This ontology service could operate platform-agnostic, no matter whether it is connected to the real or any particular virtual world. Even though their implementation operates in Second Life environment, with RFID and smart phones, we can do this in the real world in the same manner. This ontology service is a step towards context-aware applications.

Suppose we can correctly identify each object by the use of some means like RFID, object recognition, and ontology service; then the next challenge is how to distribute goal-directed services. This is where the smart objects and soft controller architecture discussed in *Ubiquitous Intelligence* plays a role [11][35]. Whenever an active smart object like a controller detects identity of other smart object, it sends a query against a database to see if any related information is available. The information can be the history of the object, API to control the object, owner information, and so on. An actual implementation of this architecture in the real world will be presented in a later chapter. The model we developed can deal with the plural reference problem; i.e., differentiation between the command to turn off a single light and a command to turn off all the lights in this room. Future work will deal with business rules of smart objects like how an iPod and a speaker can be used together based on logic inference. More details are discussed in section 3.

Additionally, Eguchi and Nguyen [9] discovered a challenge in the development of a *Web Intelligence* service based on centralized cloud knowledge. If people are trying to maximize their profits among limited resources, there are always winners and losers, the consequence of the zero-sum game. In the extreme case, the seemingly best choice based on shared knowledge actually becomes the worst since it will be used the most. Suppose there is a web service to provide traffic information based on users' report. If many people use the web service and choose the same least crowded route at the same time, that route suddenly becomes overcrowded, and the route *Web Intelligence* provided becomes worthless. Using a biologically-inspired genetic algorithm in a context of minority game, we determined the pattern of cooperation over limited resources. The result indicated that people's accuracy of the report to build the centralized knowledge and the tendency of users to follow the centralized knowledge may play key roles in the context. Therefore, it is important to take those findings in account to build a future *Web Intelligence*.

2 Implementing the Wisdom Web of Things

The challenge of our EiA project is how the various architectures we developed will be integrated into one unified concept of EiA. Zhong, et al. [42] describe the data cycle for Wisdom Web of Things as composed of the following steps:

- Things to data
- Data to information
- Information to knowledge
- Knowledge to wisdom
- Wisdom to services
- Services to humans
- Humans to things

In this section, we show how to realize the data cycle with the current technology discussed in the previous section (Fig. 4).

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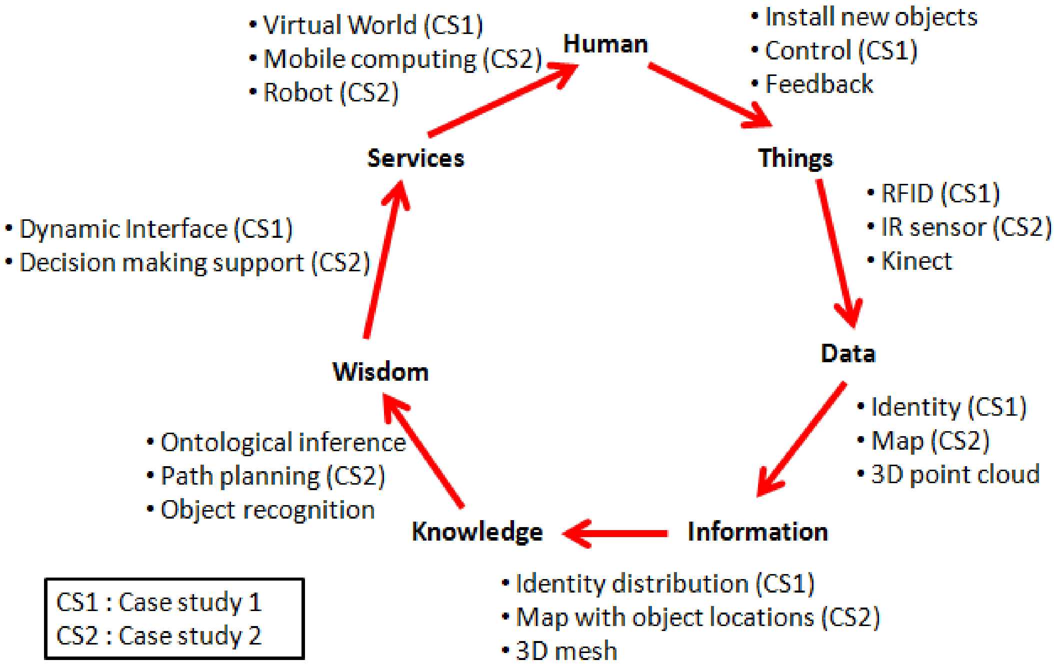

Figure 4 Data cycle in EiA and W2T

In the phase of things to data, various data are collected from the real world using sensors [42]. Not only are data collected from environmental sensors such as temperature or humidity, but also health information such as body temperature or heart rate. In addition, an object in the real world is represented by its unique ID in the virtual world. This ID can be given to the objects using RFID tags by their manufacturers. In addition, the shapes of objects and their locations can be updated using both the Kinect and RFID tags [11].

Then, data collected undergo “cleaning, integration, and storage” [42]. For temperature sensors, the data collected may be just a number describing the current temperature. For location and distance, the data can be a 3D vector describing the translation of object in 3D from some origin, either globally across different environments and domains or locally within a specific environment such as the coordinate system in Second Life. Data collected by sensors like mouse and IR sensor build a map of the environment [24]. For 3D modeling of objects, the data collected can be a mesh generated from cloud points emitted from the Kinect [10]. An RFID, like a social security number, can just be a unique number. This information will be stored on a central data server for further processing.

The step of information to knowledge is to fit data into some known models in order to gain further insights [42]. The weather forecast has been collecting environmental sensors to computationally predict the weather. Health sensors can be used to improve the data for a Bayesian network, which in turn more accurately correlates symptoms to diseases. Based on map and mouse tracking information, object can locate itself [24]. The 3D mesh and map of object locations give an accurate physical description of objects. Ontology service can provide knowledge of a name of object based on relational inference [12].

In the phase of knowledge to wisdom, Zhong, et al. [42] identify 10 problems of Wisdom Web and 7 characteristics of smart u-things “to develop the key intelligence technologies and strategies”. Collecting environmental temperature and other data helps forecasting the weather. Taking the similar approach into households, Banerjee, et al. [3] have developed a system that intelligently monitors household’s energy usage to identify waste resources. Similarly, a medical expert system with an ample pool of data will improve our understanding of diseases and perhaps can even find cure for them: analyzing data collected from individuals who have recovered may shed light to how the disease can be cured. Knowledge of name of object learned will differentiate similar looking object apart like humans [10]. A 3D modeling and map of objects not only helps identify the location of objects quickly but can also be used to help autonomous robots navigate and accomplish tasks which are normally carried out by humans [30].

The W2T can "provide active, transparent, safe, and reliable services by synthetically utilizing the data, information, and knowledge in the data center." [42] The wisdom synthesized from the previous phase can be converted or combined together into services readily available to whoever needs them. For example, house temperature sensors, AC/heaters, a person's temperature readings, his/her location, and perhaps his/her preference of temperature can be used to find the balance between a person's comfort and energy consumption. Wisdom of efficient decision making strategy learned from human behavior will be an important key for developing the service as well [9].

Services can be provided on-request or transparent to us humans [42]. We can ask the AC/heater to increase or decrease the temperature to our desire. A doctor can be notified of irregularities in a person's temperature and look for possible diseases that match the current set of sensory readings. Robots can be used to load or unload goods automatically using the 3D map, the RFID of the goods, and perhaps a protocol to realize where and how to load or unload between the robot and the smart vehicles.

Finally, the cycle restarts, and data collected during and after services are fed back into the W2T system [42]. A person receiving healthcare treatment can be monitored and documented to help doctors better understand the disease or improve current curing methods. Initially, we can teach the system to learn our personal preferences before it utilizes this knowledge to provide services to us.

In the following two sections, two case studies to show our attempt of the actual implementation of the data flow in W2T are discussed.

3 Case study 1: Android housekeeper robot

3.1 Overview

With smart phones becoming more of a commodity worldwide, the use of smart phones as a platform for ubiquitous computing is promising [4]. Due to Google's release of the Android Open Accessory Development Kit (ADK), a portal between the cyber world and the physical world made it possible to transform the ideas from EiA into the real world's working project. Having successfully implemented the soft controller in the virtual environment of Second Life [11], our first prototype was to demonstrate how an idea tested in a virtual world can be made to work in the real life. Thus, a robot that can roam around to detect new smart objects and enable the user to immediately control these new objects mirrors its counterpart in the virtual world. Surprisingly, we were not the only one trying to do so. The roles that the robot would be performing resemble a remotely controlled housekeeper. As we completed the project, we learned of that a similar idea is being developed by Google engineers [21]. One and a half year after we had first successfully implemented the virtual prototype, technological advances and the ubiquity of smart phones caught up to provide the means to realize this idea in the real world.

This case study also follows the W2T cycle in the following manner as described in the Fig. 4. We assume that in the near future, objects are associated with RFID tags, where each tag can uniquely identify the corresponding object. This is part of the data collected. Using only this and a centralized database, we can obtain manufacturer's information about object such as object's XBee MAC address, a unique address assigned to each XBee, which will be needed for user-control. Within the proximity of the RFID reader, we can detect many more objects automatically, and through their unique MAC address and perhaps with further authentication credentials, we can communicate with them wirelessly using only one controller, which in this case is the cell phone. The knowledge-to-wisdom step is not investigated, but through the group of objects recognized by the RFID reader, we can infer about the user's environment, e.g. home, office, or schools, etc., and perhaps even the user's location with the phone's built-in GPS in order to provide better services or enable/disable certain capabilities of the objects for security purposes. However, for our application of automatically controlling a newly discovered, unknown object, the identity is all the *wisdom* that we need since, in addition to the XBee MAC address to establish the communication, the user can also retrieve the associated API's to control the objects of interest using their smart controller. This service is delivered to the user to satisfy his/her needs in response to the request originated from the real world or the virtual world in which this concept was first tested. As a result, the user has now achieved the goal of controlling the unknown objects of interests using a consistent flow. Virtual world is used for prototyping this flow first, and based on analogous technologies in the real world, we have shown how this flow can be realized in the real world. Since we first started investigating this in 2010 when smart cell phones were still in early to mild adoption phase, virtual world provided us an appropriate environment to investigate this latent concept, and it can also be used now as a test bed for the W2T.

3.2 Usage

Similar to W2T idea, the robot's main functionality is to provide some service to humans. It enabled a person not only to view his/her house via the Internet from a far distance but also to control other objects in the house. This is useful in case that one wants to check to see if s/he has turned off the oven, AC/heater, or lights before leaving for work and turns those devices off remotely. The scenario is especially useful if one has to rapidly evacuate due to natural disasters and wants to check his/her house from a safe location to monitor the state of the house or perhaps make past-last-minute arrangements such as moving forgotten valuables to a safe place using a robotic housekeeper.

3.3 Set up

The robot is located at the authors' apartment and is controlled from our campus. Our assumption was that the robot was just introduced into the house, so it has to discover other smart objects around it and present the user with a graphical interface to control the newly detected objects. The robot can also be viewed as a smart object, even though in our case, it is somewhat smarter than the other devices, and the protocol to control it is different from other smart objects.

3.4 Architecture

The basic architecture for dynamic API retrieval had been developed and tested in a virtual world previously [11]. With combination of technology that recently became available, we are now able to convert the virtual world prototype into a real world product (Table 2).

1. **Hardware**
    a. The robot's hardware and communication with other smart objects are handled by an Arduino board, a popular open-source electronic development board.
    b. The Arduino board is controlled by an Android smart phone using Google's ADK.
    c. The user is equipped with another Android smart phone which he uses far from home as a robot and smart objects' controller.
    d. Each object is associated with an RFID tag. The robot is equipped with an RFID reader.
    e. Objects communicate with robot wirelessly using XBee's modules, an IEEE standard which has an indoor range of 100 ft. (30 m) [7], which is more than enough to cover an entire house.
    f. Two servers accessible to the internet.
2. **Software**
    a. A server named Turing serves as a gateway between the robot and its controller. This server authenticates the robot and its owner so that only the owner can have access to it.

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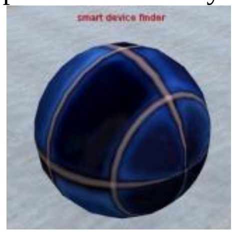
Table 2 Virtual prototypes and real world implementations

	Virtual World (second life)	**Real World**
active object (detector)	prim controlled by avatar 	robot with Arduino board 
owner object (controller)	Virtual controller in SL or on a web 	Application on Android phone (simulator) 
passive object (controlled)	AC, bed, X-ray machine 	TV, LED 
identity	UUID of prim attached to object	RFID attached to object
control	Linden Scripting Language	Google's ADK
communication	open channel (not secured)	XBee
API downloaded	text base	Android program's plugin

b. The other server runs as a MySQL database which maps an object's RFID to the appropriate smart phone plugin which can be used to control that object. Our design requires that ownership is also authenticated by this database such that only the rightful owner of the object can control it. However, our final implementation skipped this authentication to simplify the protocol and to speed up the development. The plugin, RFID, and ownership are handled by the manufacturers and distributors.

3.5 Protocol

1. **Initialization**
   a. The robot's Android logs into Turing using its pre-determined username and password to create a portal (Fig. 5a).

World Wide Web
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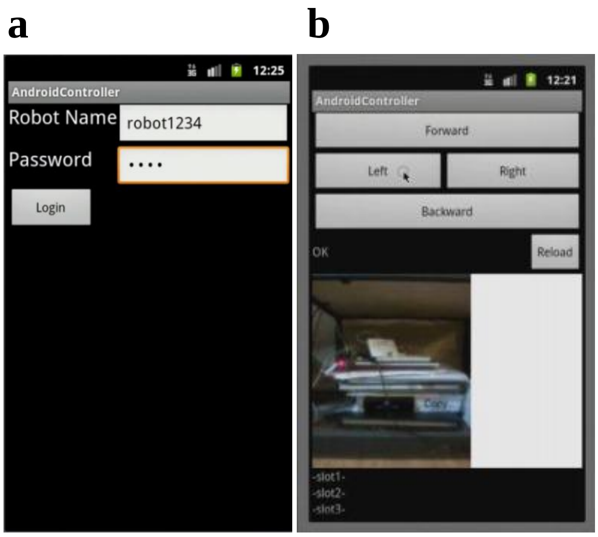

Figure 5 Controller Graphical Interface; (**a**) Login Screen; (**b**) Robot Control Panel

b. A user uses his/her Android phone to log into Turing using the same username and password as the robot to establish a connection to it. User will not be allowed to proceed if authentication fails. Otherwise, user is presented with the robot's menu. User can now control the robot's movement (Fig. 5b).

2. Smart Object Detection

a. The robot, controlled remotely by the user, reads an RFID and passes this information to the controller phone.

b. The controller queries its own internal database to determine if the RFID belongs to a new object or not. If the RFID is not found in the database, it proceeds to the next step of downloading and installing the plugin. Otherwise, it does nothing because all known plugins have been loaded.

3. Download and Install Plugin

a. After the controller determines that the object is new, it connects to the MySQL database and uses the RFID as the key to retrieve a row from the MySQL database. Current implementation does not provide authentication of ownership at this step to simplify the protocol, but changing the database and protocol so that user has to provide both RFID and his/her credentials in order retrieve information is totally possible.

b. The controller phone is provided with the necessary information to control the new object. For the current implementation, this includes:
  - The URL to the plugin.
  - A 64-bit MAC address of the XBee by which the robot will communicate with the device.
  - A product ID to group multiple objects belonging to the same model and category together, e.g. different chairs of same model have different RFID's but same product ID.

c. After installing the plugin from the URL, the controller presents the user with a new graphical interface to control the new object (Fig. 6) .

d. The user can now control the new object by pressing the buttons on the graphical interface. The messages exchanged between the devices, their media in parentheses, and the data types are (footnote here):

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- Android phone controller → Robot phone controller (Java socket): strings
  msg xbee;<XBee MAC address>**;**<RFID>**;**<command>

- Robot phone controller → Arduino board (USB): bytes
  <xbee_forward><XBee MAC address>**;**<RFID>**;**<command>

- Arduino board → smart objects (XBee): bytes
  <RFID>**;**<command>

4. **Notes**
   a. Handshaking is used to confirm the action performed by the robot and other smart objects. For example, the controller will block input until it receives confirmation from the smart object that the command has been executed successfully.
   b. XBee can communicate directly with a computer via USB interface, as demonstrated in the autonomous floor mapping robot [24]. Thus, a computer can substitute for an Arduino board to control with the smart objects.

Figure 6 New Plugins Installation; (a) LED installation prompt; (b) New LED plugin; (c) TV Remote installation prompt; (d) TV Remote and LED plugins

3.6 Results

We successfully implemented the idea of a smart controller, initially developed in a virtual world, in the real world using smart phones, XBee, and RFID technology. Furthermore, since we cannot modify existing hardware such as a TV to incorporate XBee control, we have also shown how to convert simple “dumb” objects into smart objects in the real world. Even though a 5-V LED is used in place of a light bulb, we can easily extend the implementation to control normal 110-V incandescent lights.

3.7 Summary

With real world objects become smart, the boundary between virtual world and real world becomes blurred: we can use either virtual or real controller to control both virtual and real world objects. We can now have a 3D model of the real world which can be used to monitor and control objects surrounding us. This implies that a change in the virtual world will be reflected in the real world, and vice versa. Therefore, it resembles the data cycle of the W2T discussed in section 2.

Extending the idea further, we can replace the manual controller with a *smarter* controller: one that can control other smart objects to accomplish some goals under some constraints. Thus, the *smarter* version of our controller is the Web Intelligence component of the W2T. As Shirakyan [29] envisions, it is this “magic wand” that plays the key role in widespread acceptance of household robots since they can collectively share information with other smart objects using the Wisdom Web of Things as the central center and be not only smarter but also more socially friendly, the type of robot that he classifies as “White Collar Robots”.

Since smart phones are now widespread, they can be used as both the Ubiquitous Intelligence, such as the phone controlling the robot in this case, and as the link between Cyber-Individuals and real people since sales of smart phones currently surpass those of PC’s [1]. Since the concept of smart controllers was first investigated in the virtual world and then ported to the real world, this confirms we can use virtual world as a testing and modeling environment for Brain Informatics, provided that we accumulate enough data to construct relatively accurate Cyber-Individuals.

3.8 Lessons Learned and Future Work

Since the idea of mirroring the two worlds is both exciting and intimidating, we took great care in developing the protocol to protect individuals’ privacy. Current implementation does not encrypt the Internet and XBee wireless communication; both Java socket and XBee wireless allow standard ciphers to be added to protect the underlying data. Together with authentication methods, this make it safe to mirror the two worlds since only the authenticated and authorized persons are allowed to control both virtual and real objects.

The adoption and inter-operability of smart objects will call for a more universal standard than our current approach to object communication, especially if we want to build *smarter* controller, aka Web Intelligence. One of the standards being developed is the universal Electronic Product Code (EPC). Similar to barcode, EPC enables product identification and naming among different vendors. Unlike barcode, EPC uses RFID tags to identify and track objects [36][22]. Nevertheless, EPC alone does not present an object’s properties or its services or how to use them. However, if we combine EPC with OWL-S, which is “a standard ontology, consisting of a set of basic classes and properties, for declaring and describing services” which “enable[s] users and software agents to automatically discover, invoke, compose, and monitor Web resources offering services, under specified constraints” [19], we can have both a universal and easy way to identify smart objects, and the semantics necessary to describe them in such a way that an even *smarter* controller can automatically utilize.

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4 Case study 2: Autonomous floor mapping robot

4.1 Overview

The objective of the autonomous floor mapping robot project at the University of Arkansas was to develop a platform which is highly customizable and cheap to experiment with a floor mapping algorithm [24]. The 2D map generated by an autonomous robot can be used by other robots to efficiently and correctly navigate to their desired destinations. The project utilized two virtual environments, Simbad and Second Life, and a real robot to develop a new algorithm for floor mapping. This abstraction of software and hardware sped up the development. The abstraction of software simulator and hardware implementation can be regarded as the abstraction of the virtual and real worlds. Thus, the technique can also be applied to the development process of W2T.

This case study shows how the data cycle in W2T can also be fit into the development of new technology. Iterating through many rounds in the data cycle, we gradually developed the autonomous floor mapping robot by first building the primitive model in a virtual environment and later doing so in a real world environment, a similar development flow to the previous case study. The basic idea of the data flow in this case study is described in Fig. 4. First, the distance data between the robot and any obstacle in the environment are collected by an IR sensor. Those data are then integrated into a map stored in memory, which is expanded as the robot acquires more data. Based on the knowledge from the partial map, the robot knows where it has already explored and determines where to map next. The map can be re-used by other autonomous agents to plan the most efficient path to reach a specific location in the map. Since the mapping robot can roam in an unknown environment, we can perhaps add an RFID reader on top of it to discover objects' locations and label them in the map. This case study touches only on some parts of the W2T cycle, yet this is an important demonstration since it shows how we applied the algorithm to both the virtual and real world environment through the use of an abstraction layer from which the algorithm could not distinguish between the virtual and real world. In other words, it appears the two worlds had been merged into one when presented to the algorithm. A similar approach can be applied to W2T in which the core algorithms can cross the virtual-real boundary easily in order to be seamlessly deployed in the real world after being tested and developed in a controlled virtual environment. Since at the other end of control is a machine and not a human, there were many issues with implementing this abstraction layer that needed to be resolved [24].

4.2 Abstraction of Software and Hardware

A common interface for both software and hardware implementations serves as a connection hub between the underlying algorithm and its environment. The connection between the implementation and algorithm could be as short as one line of code in Java [24]:

```
Interface robotInterface = new SoftwareInterface();
Interface robotInterface = new HardwareInterface();
```

Even though polymorphism is neither new nor available only to Java, the different languages used to develop software and hardware will call for a universal way to describe the polymorphic relations between classes and interfaces. XML is a promising structured and platform independent way to describe this relation. Once we can describe the common interface between different platform and separate the implementation from the specifications, moving from one platform to another such as software simulation to real world hardware is as trivial as changing one line of code [24], or changing a platform configuration file in a more complicated project.

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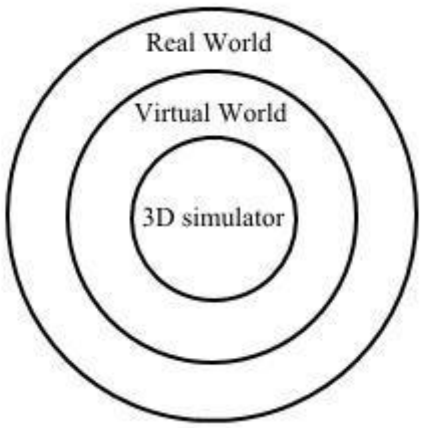
The benefit of separating software from hardware was initially done to isolate real world noise and prevent it from interfering with the algorithm. Second Life was not a perfect world free of noise due to its design -- we had to cleanse our environment further through the use of the Simbad simulator. This process can be viewed as going to a more noise-free environment in which we have total control.

The algorithm was then tested in the isolated and noiseless environment of Simbad. As we move closer to the real world, noise models can be added, and the core algorithm can be modified to be more resilient to noise. The process can be viewed as moving from the inner rings that enable us more control and have less interferences to the outer rings which can increasingly be noisy and unpredictable, with the outermost ring being the real world (Fig. 7).

Even though we tested our algorithm on the real robot after success in Simbad, the Second Life environment could have been used to make our algorithm more immune to noise in Second Life had we not been able to resolve the hardware issues that make the real world so hostile to machine intelligence. Fortunately, we resolved most of the problems using hardware innovations [24], and, despite many shortcomings, the real world resembled the noise-free world of the Simbad simulator when presented to our algorithm. Thus, we did not have to modify our algorithm to account for undesirable interference in the physical world.



a

	Real World	Second Life	Simbad 3D simulator
implementation	moderate	difficult	easy
controllability	high	low [25]	high
cost	high	low	low
noise	high	moderately high	none
social interaction	yes	yes (Cyber-I)	no
design (quality / easiness)	moderately high	high	low

b

Fig. 7 Comparison of virtual and real worlds; (a) rings of increasing complexity; (b) features comparison of different worlds

4.3 Abstraction of Virtual and Real Worlds

The separation of platforms enabled us to make some assumptions not currently possible or still under development in the real world first; and then either we resolved them or tried to modify the logic to account for noise later. A similar pattern is demonstrated in the first case study: we first explored the concept in a virtual world and then implemented it in the real world. In the end, both the virtual and real worlds appear the same to a controller which can also be virtual or real.

This demonstrates how technology will eventually catch up to concepts previously thought unreachable. We believe that now is the time for the Wisdom Web of Things and for Everything is Alive to flourish with the ubiquity of smart phones, advances in RFID research, and the recent release of Microsoft Kinect. Smart phones enable grand-scale data collection and analysis, and RFID identifies a physical object and serves as a link between the physical and virtual entities while the Microsoft Kinect resolves multiple issues in 3D modeling and provides a cheap but reliable platform on which to further develop ideas applicable to both worlds.

5 Conclusions

The world is getting smarter due to various rapidly developing technologies, so far being developed in semi-isolation. In such a world, surrounded by many artificial objects and services, it is important to figure out how those concepts are related together and how to make our life much more efficient. The *Everything is Alive* project focuses on the problem. Our goal is to *make everything alive to make our lives revive*. Our work includes various aspects of pervasive computing such as smart world, smart objects, soft controllers, mobile computing, ontology, psychology, virtual worlds, object recognition, and mobile robot. In this paper, we discussed four different perspectives of our project in terms of Ubiquitous Intelligence, Cyber-Individual, Brain Informatics, and Web Intelligence, and how those ideas interact. We also discussed how the EiA project fit into the endless cycle of Wisdom Web of Things by introducing future work as well.

In addition, we provided two case studies of EiA to represent different concepts of the theme. The smart household robot project shows how a concept well-developed in a virtual world previously will eventually have corresponding real-world technology catch up to it and thus become real. The autonomous floor mapping robot project represents the development of a new technology within virtual world emphasizing the importance of abstraction of software and hardware, which can be extended to the development of W2T services to mean: abstract the worlds from the models we are building, construct a fully controlled and noiseless environment first, and then add unpredictability and noise to the model and make it less susceptible to those unwanted effects. Together, the two case studies provide a roadmap for future development of W2T: the virtual environment. In this virtual world, current technical difficulties can be temporarily suspended waiting for solutions in the future. An abstraction layer can be erected between the algorithms and the worlds so that the virtual world can be used as a test bed for real world implementations.

With new technologies, we are increasingly provided tools and resources to share knowledge with others. Just as the invention of cars and airplanes provided us with greater mobility in our lives, and just as the invention of computers enabled us to share our experience with others more easily, the invention of smart phones has helped make it easier for us to share those information anywhere and anytime we want to. In other words, the world is becoming a much easier place for us humans to reach out to each other both physically and socially. With the knowledge pool getting larger by sharing, we are forming a centralized web of wisdom, which can be utilized to provide much greater services, those that can be provided by using smart devices and objects. In the world that everything is alive, we give clues as to how to make things around us coordinate in a harmonious way to achieve that goal.

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