HCIS: THE HOUSING CONTEXT INFERENCE SYSTEM MODEL FOR SMART SPACE

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Abstract. This research is about the basic methods in making computers understand human behavior in an architectural space in regards to reaction to interaction between the machine and human. Its ultimate objective is to analyze the related technology making this series of works possible synthetically on the basis of information system within architectural territoriality. In the end it is expected to offer a theoretical basis to embody smart space, up-to-date and intelligent architectural space. There are two issues that motivate this research: what are the Housing Context and its Inference System, and how smart space can infer the Housing Context and react with proper response. The Husing Context consists of 1) state of user, 2) state of physical environment, 3) state of computational environment, 4) history of user-environment interaction and 5) architectural territoriality. Especially, spatial information of architectural territoriality is a significant key of HCIS. Spatial divisions and boundaries made of architectural elements or facilities determinate their own micro-territorialities. Ontologies are used to describe the Housing Context predicate. In this paper, we can say that the Housing Context and the Housing Log(history of user-environment interaction, a set of the Housing Context) written by ontologies can be a beneficial model of HCIS. Furthermore, we can develop the Housing Log Databases and its variable applications that have enabled to make simulating and analyzing tool of design, the Augmented Web Presence and the other helpful applications.

1. Introduction

The evolution of the computing environment can be explained, in short, with the development of three trends; compact size, excellent performance, interface with ease. These trends have changed the concept of computers from the mainframe to the minicomputer to the desktop computer.

Furthermore, research on the new form of computers has been actively underway by putting computer parts on the human body and making it possible to access them at all times. These can change the usage concept of conventional computers by combining concepts of pervasive computing and ubiquitous computing, which signifies the invisible computers or devices everywhere, with advanced user-interface technologies, such as motion, gesture, image and voice recognition. Also, the rapid evolutions of hardware technologies, for example, display, battery, CPU, and memory, can satisfy the new concepts. These computers with new expended ability increased accessibility, improved ergonomics, and should supplant the desktop as the preferred computing interface.

The feature and concept of these new computing systems can turn up in the embodiment of the ubiquitous computing environment. The peculiarity of this environment is the com puting environment in which space acts as an intermediary. Our life has been formed in the physical circumstance, architectural space. In other words, the ubiquitous computing environment can be embodied in the architectural environment offering the utmost satisfaction to inhabitants in the context of interaction of computers transplanted on the base of physical architectural space, the smart space.

This research is about the methods in making computers understand human behavior in an architectural space in regards to reaction to interaction between the machine and human. The purpose of research is to analyze the related technology making this series of works possible synthetically on the basis of information systems having architectural territoriality.

In the end it is expected to offer a theoretical basis to the embodiment of smart space, up-to-date and intelligent architectural space. And more, there are some additional objectives as following;

1) Define the Smart Space on the basis of the structured data model of architectural space and human being’s basic behavior.

2) Infer how the comprehensive interacting network can react with the Housing Context.

3) Present a Housing Context Inference System model which makes computers recognize and react with human behavior on the basis of territoriality of the architectural space.

4) Introduce Housing Log and its applications.

2. The Smart Space and the Housing Context

2.1. PHYSICAL SPACE VS. CYBER SPACE

As the information society develops, geographical limitation will disappear. This means that when the technologies exceed the limit of development physical space no longer maintains its position, but the value of electronic space or cyber space increases.

Fundamentally, however, cyberspace has not only the possibility of an unlimited extension but also fabrications and drawbacks. Electronic space is originally the realm of fiction. Electronic space is unstable because of this inside weakness of fiction. It is easy to imitate the electronic space because it is unsubstantial. Rather, meaninglessly mass-produced information cause information smog. Although information has been copied and forwarded in the velocity of light, eventually they can make the efficiency of real space come to nothing through the paradox that there is nothing which is created, produced or consumed. For this reason, cyber space is sometimes underestimated as Bubble Space. Most of all, the question is that evil influences or problems of cyber space exert in the velocity of light without any obstacle or friction. Cyber space is a domino-effect dominant space.

Even though electronic space has many problems, we are not able to go back to physical space. We have already realized that electronic space could overcome a variety of restrictions of physical space. When one volt of energy is needed in electronic space to get information, tens of thousands of volts of energy is needed to get the same amount of it in cyber space. Physical space in itself is a cost.

2.2. THE THIRD SPACE: SMART SPACE

A Smart Space consists of users, embedded devices and traditional computing devices; a communication mechanism, typically wireless, between all of the devices is also necessary. “Smart Spaces are everyday environments, which are populated with raditional computing hardware as well as embedded computers, information appliances, and multi-modal sensors allowing people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers”. The Smart Space vision is closely related to that of Ambient Intelligence, which is essentially a combination of the Ubiquitous Computing, Ubiquitous Communication and Intelligent User Interface areas. “Ubiquitous Computing is the integration of microprocessors into everyday objects like furniture, clothing, white goods, toys and even paint.” “Ubiquitous Communication enables these objects to communicate with each other and the user by means of ad-hoc and wireless networking.” An Intelligent User Interface enables the inhabitants of the Ambient Intelligence environment to control and interact with the environment in a natural and personalized way.

Martin Herman describes Smart Space as having the following characteristics (NIST -National Institute of Standards and Technology- Smart Space Laboratory, http://www.nist.gov/smartspace/):

1) It may perceive and identify users and their actions and goals.

2) It may use speech, natural language, computer vision, and other perceptual user interfaces.

3) It provides interaction with information- rich sources.

4) It enables devices carried or worn into the space to be easily integrated with the devices present in the space.

5) It provides extensive information presentation capabilities.

6) It understands and anticipates user needs during task performance.

7) It provides for distributed and local collaboration, including collaboration with field personnel and mobile workers.

8) It provides improved memory and summaries of activities and deliberations for later use.

The goal of smart spaces is to place people at the centre of the environment while the computing infrastructure should be almost invisible and people should also be able to interact with the environment in a natural way. The ability to adapt the computing infrastructure to the environment and individuals as opposed to adapting the individuals and the environment to the computing infrastructure is key. Advances in the areas of Human Computer Interfaces and wireless communication have been important to enabling this. Further improvements are expected in the next number of years especially with the cost of embedding intelligence into devices that will enable items such as the smart toothbrush etc.

2.3. HOUSING CONTEXT

Housing Context is one of an interface between human and physical space. The physical space is a mediated space and based on the ubiquitous computing environment. We humans are just living in our environment. Figure 1 shows the human-physical environment (computer) interaction with a housing context.

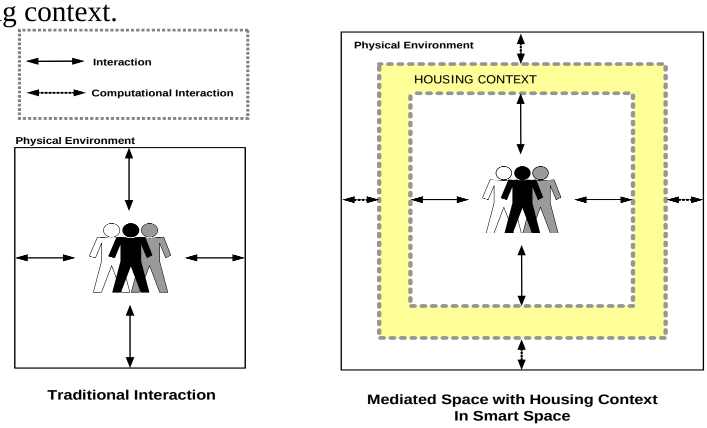


Figure 1. Human-Physical Environment (Computer) Interaction with Housing Context

In architectural domain, following context definition can be a modified version of context as the following housing context.

HC = { (S_u , S_{pe} , S_{ce} , H), T }

HC is Housing Context
S_u is State of the user
S_{pe} is State of the physical environment
S_{ce} is State of the computational environment
T is Territoriality of the Architectural Space
H Is History of the user-environment interaction

Figure 2. Definition of Housing Context

2.3.1. Housing Context Model

In order to allow environments to be context-aware, we first need a model for context. We have developed a context model that is based on predicates. We use ontologies to describe the properties and structure of different context predicates. This context model provides the basis for Housing Context Inference System.

2.3.2. Housing Context Predicate

We represent a context as a predicate. We follow a convention where the name of the predicate is the type of context that is being. This convention allows us to have a simple, uniform representation for different kinds of contexts. Besides, it also allows us to easily describe the different contexts in ontology, as we shall see later. It is also possible to have relational operators like "=" and "<" as arguments of a predicate.

Example context predicates are:

· Su (Lee , entering , living room)
· Spe (Living room , "=" , 98 F)
· Sce (Air conditioner , "=" , On)
· T (Living room(Near the Sofa, Side lamp, "=", On))
· H (Lee, Turn on air conditioner , 2003-05-01 13:00, Scheduled 1 hour)

2.3.3. Ontologies to describe Housing Context Predicates

The structures of different context predicates are specified in ontology. Each context type corresponds to a class in the ontology. This ontology defines various context types as well as the arguments that the predicates must have. The ontology is written in DAML+OIL, which is fast becoming the de-facto language of the semantic web.

For example, many context predicates are defined to have arguments in an SVO (Subject Verb Object) format. Thus, the structure of these predicates is ContextType(<Subject>,<Verb>,<Object>). For instance, the ontology declares that the Location predicate must have a subject which belongs to the set of persons or things, a verb or preposition like “inside” or “entering” and a location, which may be a room or a building.

The ontology is used to check the validity of context predicates. It also makes it easier to write different context predicates since we know what the structure of the predicate is and what kinds of values different arguments can take. It also allows different ubiquitous computing environments to inter-operate since it is possible to define translations between the terms used in the ontologies of these environments.

This logical model for context is quite powerful. It allows us to describe the context of a system in a generic way, which is independent of programming language, operating system or middleware. Since the structure and the semantics of context predicates are specified in ontology, it allows different components in the system to have a common understanding of the semantics of different contexts.

3. Housing Context Inference System Model

3.1. ENABLING CONTEXT AWARENESS ELEMENTS

There are different kinds of agents that are involved in the Housing Context Inference System (HCIS) Infrastructure.

1) Context Providers: Context Providers are sensors or other data sources of context information. They allow other agents (or Context Consumers) to query them for context information. Some Context Providers also have an event channel where they keep sending context events. Thus, other agents can either query a Provider or listen on the event channel to get context information.

2) Context Synthesizers: Context Synthesizers get sensed contexts from various Context Providers, deduce higher-level or abstract contexts from these simple sensed contexts and then provide these deduced contexts to other agents. For example, we have a Context Synthesizer which infers the activity going in a room based on the number of people in the room and the applications that are running.

3) Context Consumers: Context Consumers (or Context-Aware Applications) are agents that get different types of contexts from Context Providers or Context Synthesizers. They then reason about the current context and adapt the way they behave according to the current context.

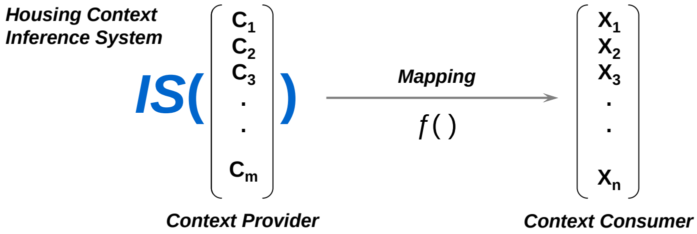


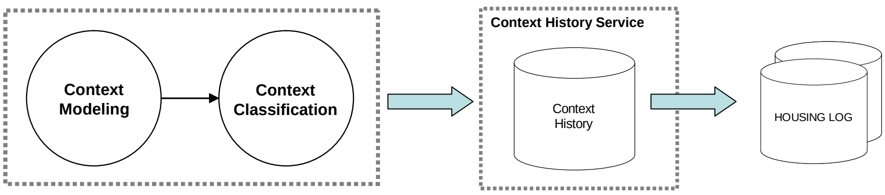
Figure 3. Housing Context Providers to Context Consumers (Responses)

4) Context Provider Lookup Service: Context Providers advertise the context they provide with the Context Provider Lookup Service. This service allows agents to find appropriate Context Providers. There is one such service in a single ubiquitous computing environment.

5) Context History Service: Past contexts are logged in a database. The Context History Service allows other agents to query for past contexts. There is one such service in a single ubiquitous computing environment.

6) Ontology Server: The Ontology Server maintains ontologies that describe different types of contextual information. There is one Ontology Server per ubiquitous computing environment.

7) Housing Logging: The Housing Log Server records log file that describe different types of contextual information.



Feature 4. Housing Log From Context History Service

8) Architectural Territoriality: Our Physical spaces have its own macro and micro territorialities. This is an important fluent to decide ranking of human behaviors and to characterize the physical environments.

These components are based on the middleware for context-aware computing, such as GAIA (Active Spaces for Ubiquitous Computing, University of Illinois at Urbana-Champaign, 2003) and COBRA(Context Broker Architecture, University of Maryland Baltimore County, 2003), etc. Figure 5 shows the concept of the middleware making contribution to build architectural territoriality basement, and enabling housing context awareness.

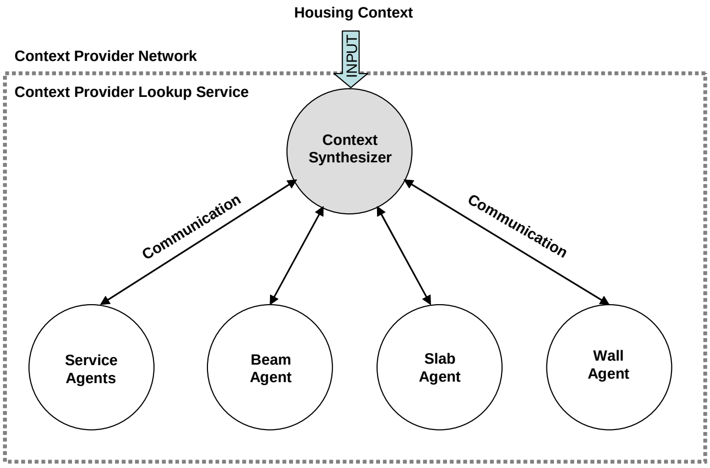


Figure 5. Context Provider Network Example

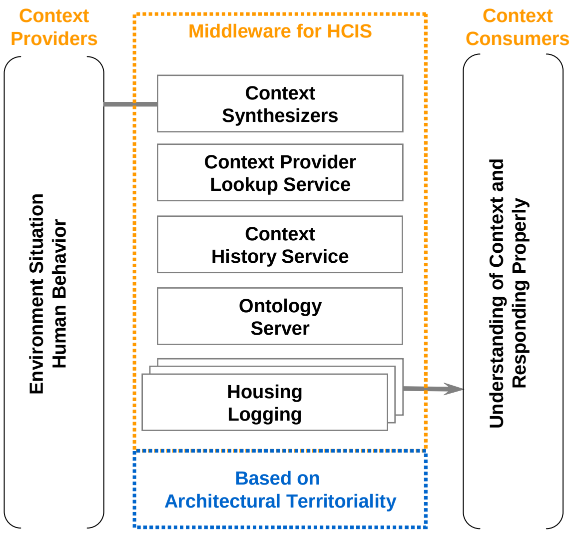


Figure 6. HCIS Infrastructure Overview

3.2. HOUSING CONTEXT INFERENCE SYSTEM MODEL

3.2.1. Spatial Network for Context Providers

The elements of HCIS operate on the basis of spatial territoriality. Spatial network defines how architectural elements of space are connected, and make systems understand and judge physical organization of space. Context Provider in space coincides with physical elements of space.

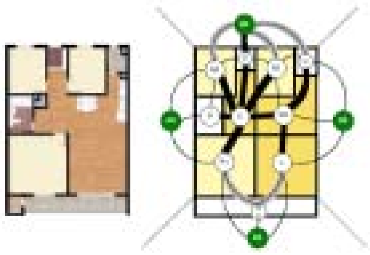


Figure 7. Example of a Spatial Network for a Floor Plan Relationship (Hwang, J-E. 2002, SpaceScope: Developing a Spatial Information Retrieval System -Focused on Apartment Unit Floor Plans)

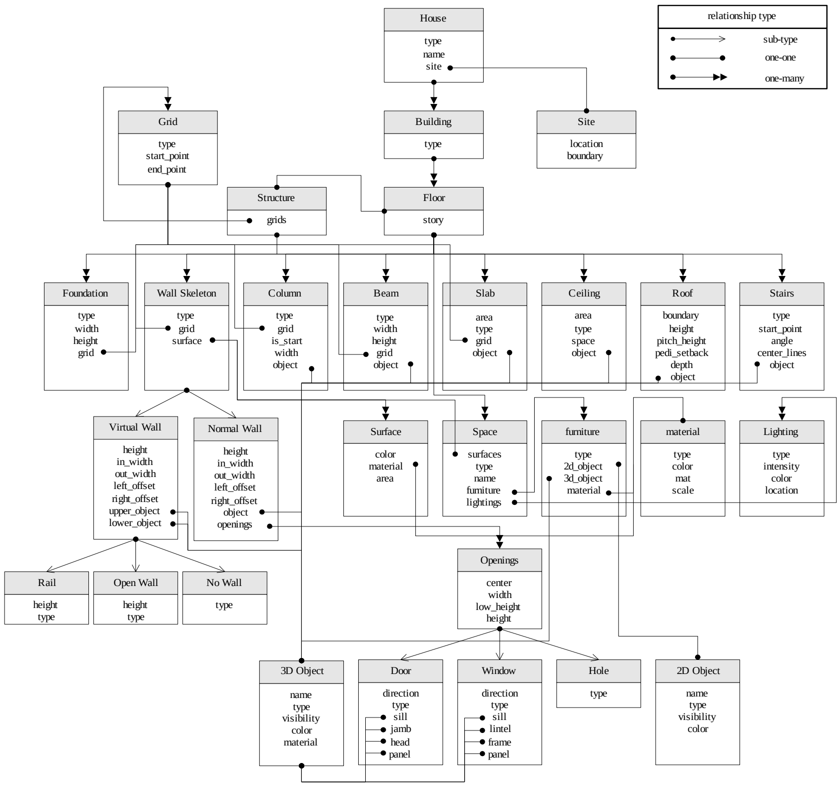


Figure 8. A Building data model (Choi, 1997, Quote from Hwang, J-E. 2002, SpaceScope: Developing a Spatial Information Retrieval System -Focused on Apartment Unit Floor Plans)

For example, if a sensor and a computer are pervasive in the elements such as beams, slaves, walls, and etc. which are constituents of structure, and so the environment which is operated with mutual wireless communication is formed, the system of spatial network is coincided with the context provider network. The example of spatial network is shown in figure 7. Figure 8 shows a building data model for architectural structure. This illustrates general features of the building data model that would satisfy various applications. In this research, it is for the use of representation spatial network for context providers.

3.2.2. A Model of Housing Context Inference System

Housing Context Inference System operates as the inference engine linked organically with each element of infrastructure, that is, Context Provider, Context Synthesizer, Context Consumer, Context Provider Lookup Service, Context History Service, Ontology Server, and Housing Log appeared in the synthetic result. Figure 9 expresses a classical Black Box and the way of occurrence is the reaction as prescheduled. Meanwhile, HCIS has the flow of information connected in order with every element from the Context Provider, the beginning, to the Context Consumer, the end.

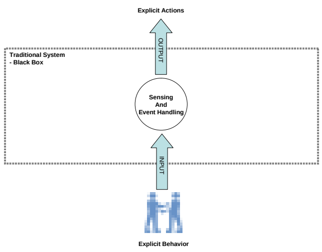


Figure 9. Traditional System; Black Box

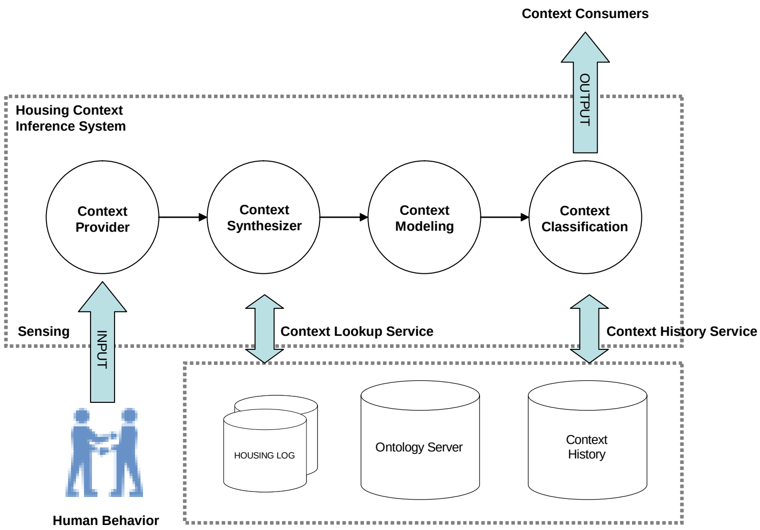


Figure 10. HCIS Flow

Figure 10 describes the Housing Context Inference System's information flow. Housing context will be provided by human behavior and its sensory data, and it was handled by context providers and context synthesizers. Context consumers can show proper responses in the course of context lookup services and context history services. Figure 11 shows that some behaviors could be forecasted by context history services and housing log in accordance with changing territorialities.

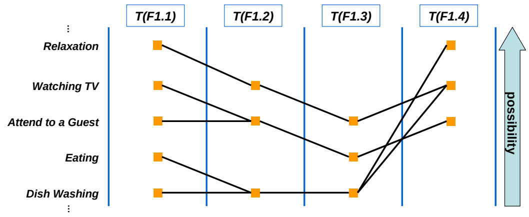


Figure 11. HCIS forecast Some Behavior Occurrence by the Territoriality

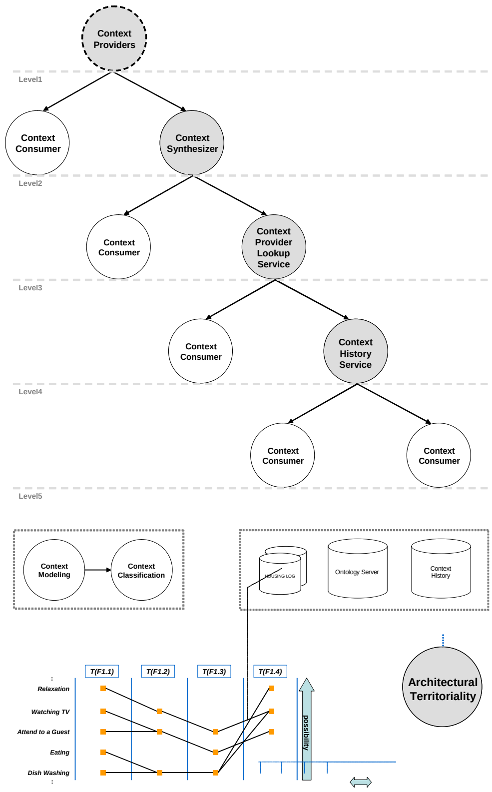


Figure 12. Running HCIS Model

Figure 12 describes running HCIS model. In level 1, multiple housing context providers make an effect context synthesizers and context consumer directly. That runs with not a hierarchical flow but an agent-based flow. Context consumers, proper responses, will run any level of the running model. Architectural territorialities bring effect all of the process with communications between history service and housing log.

3.2.3. An Example of the Housing Context

This chapter deals with the example of Implementation of HCIS, and infers one result. In order to do that, the following processes are:

1) Decide on an example with one interior architectural space and construct a situation with basic virtual information

2) Extract such situation in the form of housing context before-mentioned in the former chapter

3) Analyze the extracted housing context and how it is related as it goes through the inference process in the Inference System as previously stated in the former chapter.

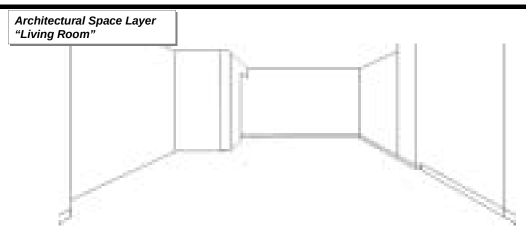
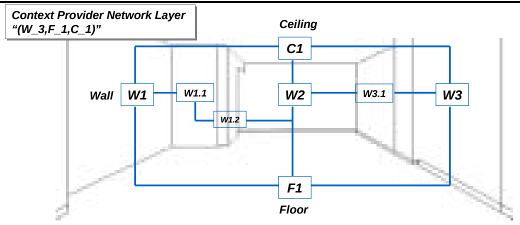
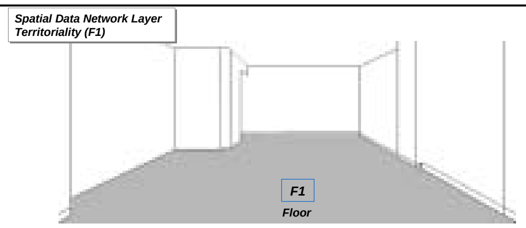
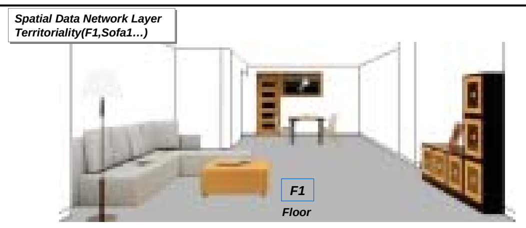
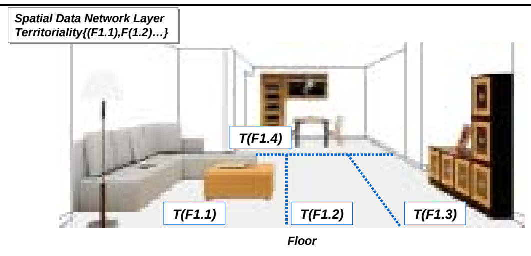
4) Record the housing context log and study practical use.

Figure 13 shows an example of the Housing Context for HCIS implementation.

Figure 13. An Example of the Housing Context

Figure 13 can describe the spatial layer by territoriality and statement as Table 1

Table 1. Spatial Layer by Territoriality

Layer	Feature	Statement
Physical Architectural Layer		"Room"
Context Provider Network Layer		Spatial Network of living room
Territoriality (F1) Layer		F1 has Territoriality "Floor"
Territoriality (F1, Sofa1…) Layer		Territorialities Organized by Facilities
Territoriality {F(1.1),F(1.2)…} Layer		"T(F1.1),F(1.2)…}"

3.2.4 Modeling of the Housing Context Example

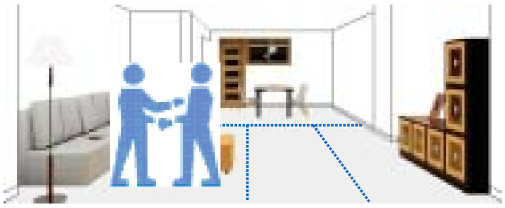


Figure 14. An Example of Housing Context Territoriality "T(F1.1)"

We will use Web Ontology Language to model various ontology and policy in Housing Context and Housing Log. Web Ontology Language is semantic mark-up language for defining Web ontology. In Web Ontology Language, an ontology is a set of definitions of classes and properties. Ontology constraints can be employed on those classes and properties.

The statement of the figure 14 is; "Michael and John are near the sofa.", "Michael is the host of the house.", "John is a guest.", "Air conditioner is running.", "Music box is ready.", "Screen TV is off." …...

Housing Context of the figure 14 can describe as following;

T = T { F (1.1).In } …

Su = Su { (A.Michael.host), (B.John.guest) } …

Spe = Spe { LivingRoom.F(1.1), W1, Sofa1, TeaTable1, Lamp1 } …

Sce = Sce { Sensor(F(1.1).In), W1.ready, Sofa1.ready, TeaTable1.ready, Lamp1.ready) } …

H = H { Record(HousingLog.HomeServer), Monitoring. Scheduling Service (W1.AirConditioner.on, W1.MusicBox.ready, W3.ScreenTV.off) } …

Table 2. Relationships Matrix between HCIS Elements and Housing Context

	Context Provider	Context Synthesizer	Context Consumer	Context Provider Lookup Service	Context History Service	Ontology Server	Housing Logging
T							
Su							
Spe							
Sce							
H							

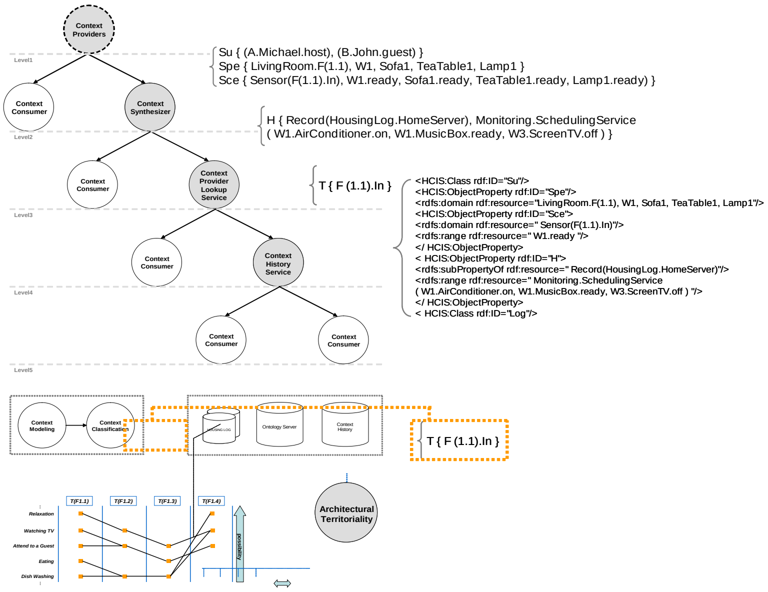


Figure 15. Running HCIS

Figure 15 describes running HCIS model with predicated housing context and housing log. The flow of context providers to context consumers based on the relationships between housing context and HCIS elements as Table 2 That means as territorialities going change, as housing context and housing log would be changed.

3.3. HOUSING LOG

Housing Log is a collection of the Housing Context in a computerized record of events. This is similar to weblog recording the whole visiting record.

Housing log example is as following:

[{ Su { (A.Michael.host), (B.John.guest) }, Spe { LivingRoom.F(1.1), W1, Sofa1, TeaTable1, Lamp1 }, Sce { Sensor(F(1.1).In), W1.ready, Sofa1.ready, TeaTable1.ready, Lamp1.ready) }, H { Record(HousingLog.HomeServer), Monitoring.SchedulingService (W1.AirConditioner.on, W1.MusicBox.ready, W3.ScreenTV.off) } },T { F (1.1).In }]

And show a partial Example of a Housing Context Ontology:

```
<HCIS:Class rdf:ID="Su"/>
   <rdfs:domain rdf:resource="LivingRoom.F(1.1), W1, Sofa1, TeaTable1, Lamp1"/>
<HCIS:ObjectProperty rdf:ID="Spe"/>
   <rdfs:domain rdf:resource="LivingRoom.F(1.1), W1, Sofa1, TeaTable1, Lamp1"/>
<HCIS:ObjectProperty rdf:ID="Sce">
   <rdfs:domain rdf:resource=" Sensor(F(1.1).In)"/>
```

```
   <rdfs:range rdf:resource=“ W1.ready “/>
</ HCIS:ObjectProperty>
< HCIS:ObjectProperty rdf:ID=“H”>
   <rdfs:subPropertyOf rdf:resource=“ Record(HousingLog.HomeServer)”/>
   <rdfs:range rdf:resource=“ Monitoring.SchedulingService ( W1.AirConditioner.on,
W1.MusicBox.ready, W3.ScreenTV.off ) “/>
</ HCIS:ObjectProperty>
< HCIS:Class rdf:ID=“Log”/>
```

Figure 16 shows an application example of housing context. Accumulated housing context by context history services would reuse in the course of analyzing housing log. It can provide resources of reconstruction and modeling housing context or human behavior in virtual space. In virtual space, housing log would be accumulated as a form of virtual housing log. That is one of the potentialities of the housing log applications.

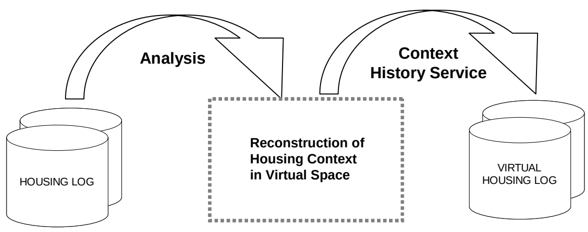


Figure 16. Virtual Housing Log Application

4. Conclusion and Discussion

The key challenges that exist when treating housing context for smart space environments have been examined in this research. These challenges include the creation of an information model with the representative capability for the realization of smart space.

In this research, we have researched and described a model of our middleware for developing context-aware applications enabling smart space. The Housing Context Inference System is based on a predicate model of housing context. This model enables agents – all of the architectural elements, facilities, etc - to be developed that either use rules or machine learning approaches to decide their behavior in different contexts. Most of all, in the space-centric viewpoint, territoriality of the physical space is the main point of the decision. The middleware uses ontologies to ensure that different agents in the environment have the same semantic understanding of different context information. This allows better semantic interoperability between different agents, as well as between different ubiquitous computing environments.

Since the smart space's importance and necessities are increasing, housing context-awareness technologies and theories are more consequential to us. Most of all, there must be human-centric agenda. There are propositions that the smart spaces are for the uplift of human life's qualities. We humans should not be overwhelmed by technologies but control computing technologies. In this research, we can use architectural territoriality that is mediated space and housing context with a space-centric viewpoint. Based on the housing context inference system model, the smart space corresponds with ubiquitous computing environments. This research makes a contribution to build a conceptual model of housing context and inference system for smart space with a space-centric viewpoint.

During the course of the research a number of areas that deserve further research work have been identified, these topics are outlined as follows:

1) It is necessary to construct a data model of human behaviors related to the Housing Context ontology and to classify the hierarchy of the computational model.

2) The application of architectural territoriality and its influence should be investigated in depth for the ubiquitous smart space adequate to the needs of the architecture field.

3) The more specific Housing Context usage is the more practical the inference system would be.

4) There are many potentialities in research about Housing Log and development application. For example, an established Housing Log can be analyzed and offer the tool of the human behavior analysis. And it can be used in related works such as building real house in cyber space in order to enable augmented web presence technology.

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