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SIMULATION 2004; 80; 367
DOI: 10.1177/0037549704046740

A Framework of Multi-Agent-Based Modeling, Simulation, and Computational Assistance in an Ubiquitous Environment

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The author exemplifies the framework of PSI (Pervasive System for Indoor-GIS) for exploring the spatial model of dynamic human behavior and developing various services in an ubiquitous computational environment. This does not mean merely constructing a software framework; rather, it means attempting to establish an inclusive service framework for ubiquitous computing. The most advantageous aspect of this component-oriented framework is that it contributes toward developing various service applications for ubiquitous computation as the occasion demands. That is, service applications are expected to do modeling, simulation, monitoring, Web services, and other applications. The author also discusses the relative issues on making a coordinating bridge between behavioral sciences and multiagent systems.

Keywords: Component-oriented framework, ubiquitous computation, modeling, simulation, multiagent system

1. Conceptualization

1.1 Background

The social behavior of people can be found anywhere and anytime. This includes the spatial pervasiveness of human behavior. Moreover, ubiquitous computation could eventually encourage people to behave more actively and pervasively. Ubiquitous computing that is embedded in our social surroundings will be expected to upgrade and enhance our daily activities, tracing, measuring, and inspecting these activities through implicit and tacit ways that we cannot recognize. So, what will ubiquitous computing provide for us? It can make computational modeling and quantifications of social behavior in an ubiquitous computing environment more critical and possible. To enhance our amenities, it should explore the nature of social behavior in various environments in terms of both behavioral science and other computer sciences.

Traditional social psychology and behavioral science cannot properly track and measure dynamic patterns of social behavior in the real world. Certainly, there have been technical problems in these studies since they have relied on static and reported data from numerous subjects. But ubiquitous computation, as well as its dependent modeling, can be expected to fundamentally use and enhance investigations on spatial states and dynamics of people's activities. With regard to computational and behavioral science, I would like to identify a model that enables one to coordinate with past studies in ordinary and extraordinary social contexts using those computations.

But some issues still remain as to how we can clarify and consider challenging problems, such as the modeling of social behavior and the computational foundations for decision making and other location-based services. Therefore, in this study, I explore how to quantify the social behavior of people in a social context, especially in upcoming and evolving ubiquitous environments. Actually, these sticky problems have led me to search for solutions about quantifications of dynamic social behavior, as well as some applications that would use spatiotemporal information and a geospatial information system (GIS). In due course, current topics on spatial information systems have inspired ubiquitous computation and have attempted to make sophisticated unifications between spatial and ubiquitous computation. Certainly, a part of pervasive and location-based services using mobile devices and cellular phones has already emerged—for example, in spatial maps with audio guidance and in navigation services using the Global Positioning System (GPS) in Japan and elsewhere.

As discussed later in this article, ubiquitous computation perhaps can enrich our social activities and daily lives with supportive services. Ubiquitous computing can provide context-aware services such as shopping, route

SIMULATION, Vol. 80, Issue 7–8, July–August 2004 367-380

DOI: 10.1177/0037549704046740

finding, and other geospatial-based behavior, and it can also coordinate with both physical and computational equipment [1, 2]. Our daily lives and activities underlie spatiotemporal constraints and restrictions; thereby, social context-aware supports can be considered by giving people on-demand geospatial maps and location-based guidance more intelligently [3, 4]. Furthermore, social behavior and its dynamics can be regarded as historical and structural patterns of a social network. We need to include social networks for analyzing various behavior patterns in social contexts [5, 6] because people who use mobile devices could create ad hoc relationships and coordinate with many unfamiliar others in social situations. In addition, people's behavior patterns may depict a historical graph structure in a spatial map.

It appears that we need to enable quantification and modeling on people's social behavior in spatial contexts, especially when embedding the ubiquitous environment. Moreover, we need to build service applications, such as decision making using spatial information and information services, based on these prior fundamentals.

1.2 Objectives of the Pervasive System for Indoor-GIS

Given the considerations presented so far, the following are several core features that should be tackled in ubiquitous computation and its applications:

1. Understanding social behavior more dynamically and continuously in social contexts:
    - The difference between behavior patterns between ordinary and extraordinary social situations
    - Managing spatial and location information in the specific area
2. Analyzing dynamic human behavior and cognitive aspects more quantitatively:
    - Understanding spatiotemporal patterns of human behavior and cognition in specific social contexts
    - Quantification for social models
    - Social networks
    - Modeling of human behavior and its simulation
3. Contributing applied services:
    - Decision support based on spatial data
    - Experiential education such as gaming simulation and collaborative learning

Using these core features, I have constructed and designed a framework that consists of a set of component-based services for ubiquitous computation. In this study, I explain my inclusive conceptualizations of the Pervasive System for Indoor-GIS (PSI) framework. This component-oriented framework enables one to develop various computational services using a multiagent system and ubiquitous computation. In particular, this framework models human behavior in assumed social situations and other computational services. Ubiquitous computing and its implementation consists of many applications—not only navigation supports but also decision making for people in a variety of social conditions. In addition, social simulation and spatiotemporal modeling using multiagent systems are significant methods for exploring dynamic human patterns as well [4]. With this in mind, my framework attempts to explore dynamic human behaviors and process spatiotemporal patterns in various social contexts and ubiquitous environments.

2. Fundamentals of the PSI Framework

2.1 Identifying the PSI

PSI has the ultimate goals of attaining quantifications and modeling social behavior, and it is a mainstay for decision making, combining with each software component. It is also assumed to be well established as a software foundation for the development of pervasiveness and its relatives. Thereby, it has attempted to integrate with four parts: ubiquitous computing, a human model of social behavior, spatial informatics, and a multiagent system. I have developed some service applications using the PSI framework. This framework attempts to equip architecture so that it can coordinate with physically spatial information and computational services using a multiagent system. Fundamentally, it aims at exploring more properly the dynamic behavior and its patterns on a mass of people in social surroundings.

The PSI has a set of finite available functions as building blocks of the software component. These functions can be classified mostly by three parts. The first part includes a spatial and geographical visualization and analysis. This implementation depends on spatial informatics and statistics, such as the quantification of human behavior and dynamic patterns in the virtual environment. I will analyze these implementations and necessities for spatial informatics later.

The second part includes the location-based service (LBS). LBS is related to modeling and analyzing spatiotemporal patterns. To begin with, it is necessary to prepare some devices to continuously get the human location. Otherwise, we need to develop an integrated system to coordinate with physical and computational aspects. The PSI enables one to support coordination with a location device, especially CoBIT [7], whereas a system such as AURA (from Carnegie Melon University) [8, 9] or QoSDREAM (from Cambridge University) [10, 11] assumes that other devices are used, such as ActiveBAT, ActiveBadge, and so on. These devices contain a feasible propensity and ability to track and monitor human behavior and activity patterns in specific areas. The navigation service that is used for people may be able to work with these devices.

The third and last part includes simulation of the dynamics of human behavior in assumed social situations, although there is no proof that the simulation of dynamic human behavior and specific modeling have an advantage when conducting prior and posterior analyses in virtual environments. Another requirement is a system design of multi-agent-based services to perform specific goals of both users and administrators. Spatial information and the multiagent system remain important facets that need to be coordinated with each other. Implementing services that require physical grounding in the real world and simulating dynamic patterns of people in the virtual world are possible with a multiagent system, which connects both sides.

In short, this framework can contribute toward the following applicable services. It assumes two types of users: those who need adequate support and those who want to verify and quantify data. Both types need to be compatible with each other in this system. Namely, this system aims at providing both implementation as user navigation and simulating spatial models. In the following, I narrow down some aspects in this framework on social behavior, spatial modeling, and appropriate decision supports in social surroundings, providing assistance for administrators, analyzers, and computational modelers.

- *Modeling*. The PSI provides a set of software component–based modeling, which is dependent on G-XML (Geospatial-eXtensible Markup Language version 2.0 or later; http://gisclh.dpc.or.jp/gxml/) and spatial informatics using an ubiquitous computational system. It also proposes agent-based modeling for exploring problems in various social contexts and situations.
- *Simulation*. The PSI enables one to simulate some agent-based models—that is, it may allow one to examine social behavior and relative aspects in specific social conditions.
- *Analyzing*. This tool can provide some functions, depending on spatial informatics and other statistical analysis on social networks.
- *Visualization*. This function can visualize continual and dynamic simulating conditions, such as behavior patterns of crowds and networks. This visualization is based on spatial modeling and data structure (G-XML).
- *Monitoring*. This tool enables one to monitor various social behavioral patterns as well as modeling and simulation.
- *Network-oriented coordination by agent services*. The PSI helps to build some applications and services such as agent service platforms and other network-oriented ones.

Some functions are for users of this system who are clients, providing informational assistance such as the following:

- *Informational assist for decision making*. This tool allows one to manage general information set on location and topological position. Namely, it can assist with the decision-making supports of people in unfamiliar social situations. Such information can be promoted both automatically, by multi-agent-based computation, and also manually, if the administrator wants to do so. This tool is not a neccessity; rather, it recommends some informational resources for decision making.
- *Educational and academic services using mobile devices in an ubiquitous environment*. This framework provides students with educational services. The purpose of the PSI is to enlighten collaborative and experiential activities in ubiquitous computational environments. For example, one good premise would be constructing an online learning community as a collaborative and experiential learning space for children. Children would be able to walk around in a natural science museum and other educational institutions, learning about different things along with the mobile device more actively.

On the other hand, there are several reasons why I have prepared a component-based framework for application services in ubiquitous computations. First, this equipment has a common foundation for software development and the management of information systems. Because of the heterogeneous and various platforms, devices and networks still exist in the computational environment. Another aspect is, needless to say, encouraging rapid development (Fig. 1)—that is, it is hard to design and develop something using a component-based model.

This framework of the PSI has been written mostly in Java language and contains two types of class libraries as packages: core and extend packages. The software components are made up of Java Beans, which are reusable, manageable, and extendable materials. That is, assumed services are provided as the building blocks of software components for coordination and building user interfaces, network/Web services, monitoring, and other services. Component-based services can be regarded as a methodology based on object-oriented design, which can easily be managed and reused [12] because the computational design should take care of both the requirements and the management of the architecture. But I aim to be well founded as practical and manageable serves frameworks rather than imply only design patterns on software engineering. Component-based development and other computational activities (e.g., modeling and verification) can be expected to devote their merits sufficiently to ubiquitous computing. Each package includes a variety of subpackages, such as the following:

1. Core packages (including common features)
   - *GUI:* psi.gxml.swing, psi.gxml.ui
   - *I/O & Network:* psi.gxml.io, psi.gxml.net
   - *G-XML:* psi.gxml.elements
   - *Fundamental kernel domain:* psi.gml.core
   - *Mover and spatial agent:* psi.gxml.mover, psi.gxml.agent
   - *Spatial statistics:* psi.gxml.math
   - *Database management:* psi.gxml.sql
2. Extend packages (including platform-dependent services and wrapper classes of the Java Native Interface)

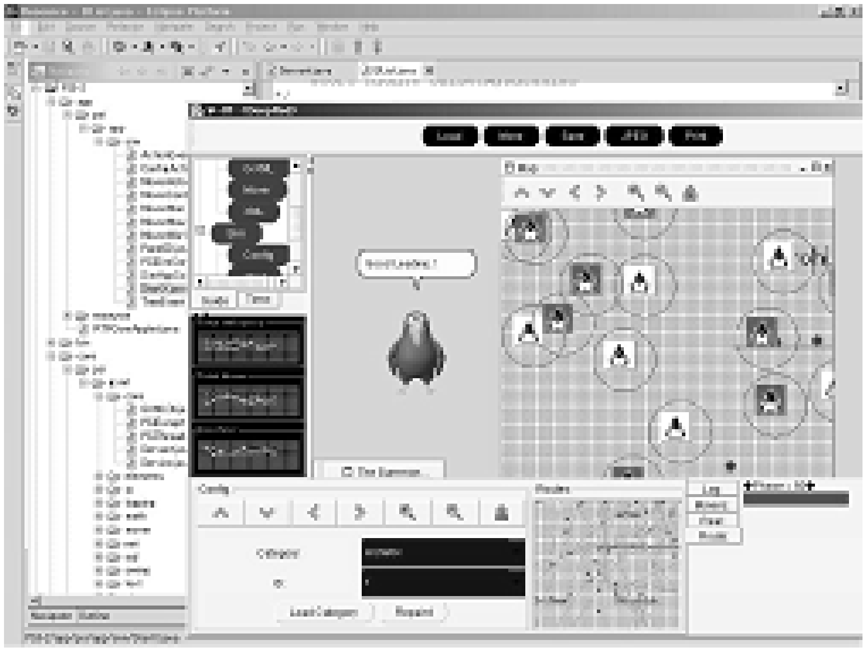

Figure 1. Developing an application based on the PSI framework using a RAD tool (e.g., Eclipse)

- *Location-based service with devices:* psix.CoBIT
- *Simulation support:* psix.sim.core
- *Communication with mobile devices:* psix.mobile
- *Semantics and ontology:* psix.semweb
- *Multimedia:* psix.CoBIT.jmf
- *Agent services (Java Agent Services) and grid computing (JXTA):* psix.jas.agent, psix.jxta
- *Platform-dependent user interface service (wrapper classes for Microsoft Agent, Java Speech API, etc.):* psix.jni.windows.msagent, psix.speech

Thus far, this whole library, as a set of software components and its packages, serves for fundamental development as Java software. I have already implemented several applications. Concretely, I have implemented the function of communicating with the server and mobile devices, as well as managing multimedia data and sound data for coordinating and transmitting with administrators and regular users.

2.2 Managing Spatial and Location Information

This section sheds further light on the management and practices of spatial and location information. It is becoming more important to include geographical and spatial perspectives for building some service applications of ubiquitous computing, spatial decision support using the semantic web [3], modeling on social navigation [13], and social simulation [14]. Spatial aspects may be able to enrich these informational services.

I recommend spatial data that use G-XML (http://gisclh.dpc.or.jp/gxml/; Fig. 2) or GML (Geography Markup Language; http://www.opengis.net/gml/01-029/GML2.html) in these settings. These formats extend XML, and its notations manage geographical data. These formats and specifications may foster the development of various implementations. The first is visualization, which also maps patterns of objects in the world. Two-dimensional visualization of human behavior and a specific location is very significant for user interfaces and indicates a variety of objects of spatial states. The second implementation, involving an interexchange of spatial and geographical data through the Internet and networks, is called an Internet-GIS or Web-GIS. These trends of information technology may suggest the significance of using spatial data. Hence, by using this format, we can manage and exchange many geographical and spatial data in a more unified and elaborated style. I have already implemented a framework using G-XML and its specifications to visualize and manage continuous movements of crowd and geographical information.

An object model of G-XML[1] (version 2.0) is defined in its specification as follows. Of course, each feature has many detailed specifications and properties. Anyway, we can express and articulate geographical and spatial patterns as a combination and description of these elements:

1. The current version of G-XML is version 3.0, available since the beginning of 2004. Enormous specifications such as syntax and notations on this version of G-XML have been elaborated and improved.

```
<Mover id="1" category="HUMAN">
<History historyorder="1"><Record historyorder="1">
  <Mover>
    <SpatialLocator> <Coordinates>7251, 1443</Coordinates></SpatialLocator>
    <TemporalLocator><At time="2002-11-18T12:00:00+09:00" /></TemporalLocator>
    <Status><Direction>
        <Angle><HorizontalAngle angletype="bearings">NE</HorizontalAngle></Angle>
        <Scalar name="Speed" unit.speed="km/h">2</Scalar>
     </Direction></Status></Mover>
   </Record></History>
</Mover>
```

Figure 2. The mover as part of G-XML elements

- Metric geospace
- Topological geospace
- POI (point of interest)
- Mover
- Route
- Picture
- Rendering rule and style

According to specifications of G-XML, room and specified location information can correspond with the geometric feature in the metric or topological geospace. Humans and each agent can represent an instance of the mover, and a mass of the mover means a crowd of people in the environment. In addition, spatiotemporal patterns and patterns of humans and agents represent the route, and historical information can describe part of the history. For example, it shows notations and definitions of G-XML. Figure 2 explicitly denotes a definition of the mover as one of the G-XML elements.

In this PSI framework, Java class objects represent each G-XML element. Figure 3, as a class diagram of the Unified Modeling Language (UML), depicts a part of Java class hierarchies and relationships in this framework. Mainly, it shows the mover class and other relatives. The mover of the G-XML element corresponds with the mover as a Java class. Also, each class object contains properties, which are implemented to conform with a specification of G-XML. For example, many elements of G-XML retain a property of coordinate data as spatial location information and a unique ID.

There are mainly three types of G-XML in use in the PSI framework. First, there are the spatial data repository and the database management. Spatial and environmental data require proper management, and it is necessary to critically hold temporal data [15]. The database service agent in the PSI undertakes the spatial and dynamic location data of humans, such as users' unique ID and mail addresses for communicating with each other, spatiotemporal positions, and other unique properties. If the user or the system requires some information of the target person, the database service agent can reconstruct spatial data and resend data in a G-XML format. Egenhofer [16] used a specification of the GML and RDF (resource definition framework). The PSI also has a function to manage RDF and other semantics services with G-XML.

The second type involves data transaction and coordination with other agents and the required system services. The framework undertakes network services and communicates with implemented agents. It is also necessary for it to support interoperability of the agent communication language (FIPA-ACL) and the various data exchange protocols. Certainly, the interexchange of spatial data within agents may involve applying ACL for coordinating with various service agents. Noran, Simon, and Sood [17] have already attempted to implement an agent system using ACL and geospatial information. The PSI also has been developing this function so that eventually, it can coordinate with other systems.

The third way is to retain an interface for other data formats, metadata, and ontological knowledge bases. This implementation is under experiential examination, but I have been exploring semantic and ontological services using extended G-XML, integrating both services. I recognize that decision support and navigation for people using mobile devices depend on spatial and geographical information, which could be progressed along with semantic Web techniques [3].

2.3 Spatial Informatics and Multiagent Systems

2.3.1 Outlooks on Spatial Informatics and Multiagent Systems

It appears that both spatial information and multiagent systems have mutual merits. Generally, this involves an agent-oriented service along with computations of physi-

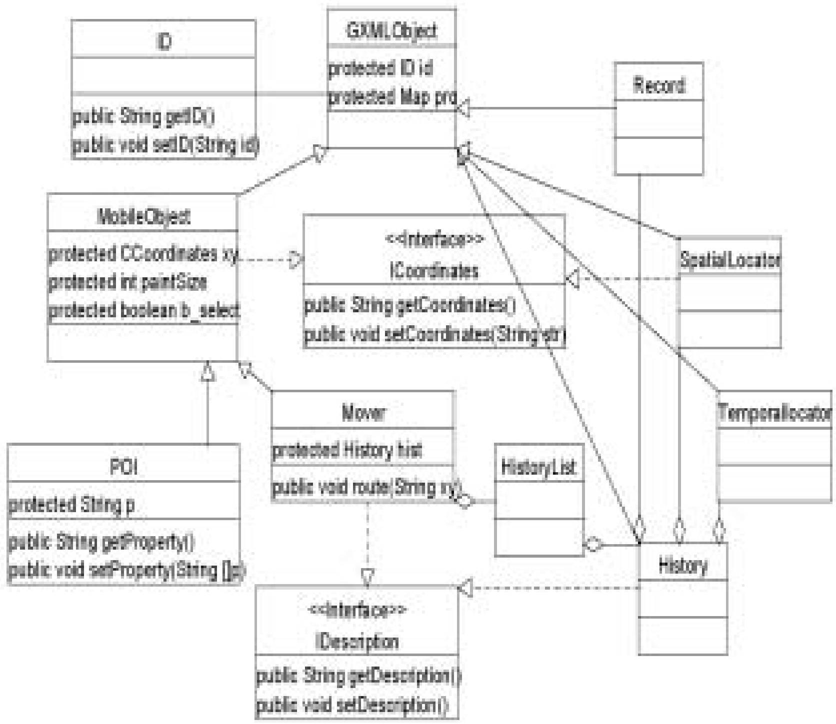

Figure 3. UML diagram of the mover as a Java class of objects in the PSI

cal grounding for people in the real world [18, 19]. Spatial statistics and informatics, however, could articulate a multi-agent-based model, such as artificial social simulation, in terms of visualizing and quantifying its spatiotemporal patterns [14, 20]. In fact, it is necessary to prepare physical grounding services by using ubiquitous computation in the real world. The social dynamics of behavior patterns in embedding ubiquitous services should be coordinated with real-world computational systems and modeling on desktop systems.

According to recent studies in robotics, this field seeks to actualize resemble issues, with inquiries about the effects of spatial cognition and behavior on the spatiotemporal navigation system in robotics and artificial intelligence [21]. Robotics and artificial intelligence studies have exemplified spatial activities and reasoning in an uncertain environment. However, the social behavior of people indeed should be emphasized by viewing mental and behavioral aspects.

2.3.2 Coordination

To begin with, the goal of ubiquitous computing service requires building a bridge between humans' cognitive and physical resources in the real world. Human cognitive processing and behavior are very restricted because they are too vulnerable to judge and behave differently in uncertain social contexts, whereas physical and spatial resources are various and not limited in the real world. Thus, those who conduct this research should have adequate information support, especially if this involves conjoining human interaction and spatiotemporal information.

As with other previous attempts on ubiquitous computing and indoor navigation systems, there seem to be several frameworks and architectures. As mentioned above, AURA has attempted to provide specific contributions toward navigation- and location-based services for physical grounding. Similarly, QoSDream provides an open architecture that includes multimedia and location services for an indoor navigation system using Active BAT and Active Badge. For example, Mitchell et al. [10] have applied each computational foundation to hospital information systems and nursing, which require a critical information infrastructure. Other studies and verifications have also used multiagent systems [22, 23]. In particular, Raubal [22] has specified spatiotemporal engineering by using agent systems. He has also attempted to investigate a navigation and support system in an airport and unfamiliar buildings. These mentioned service applications suggest the following: decision support seeks to be as appropriate as possible, and modeling social behavior is still needed in terms of verifying multiple social contexts.

2.3.3 Computational Modeling on Social Behavior

Some studies have made considerable progress in interweaving the spatial information system with the multiagent system. However, multi-agent-based simulation studies have an advantage in modeling human behavior patterns in artificial social conditions. Then I would rather conjoin with both standpoints to investigate more considerable points. Multiagent systems and GIS have many facets that coordinate with each other [14, 20]. In these simulations, not only the grid world of similar cellular automata but also more inclusive geographical standpoints, such as using GRASS software, may be able to represent spatial and geographical fields. Methodologies on environmental science and statistical inquiries using GIS have been established and elaborated on by those computations [24].

Several applicable ways of conducting research on multiagent systems and spatial information have been explored so far [19]. A multiagent system that models and simulates people in a given social context can focus on quantifying and verifying spatiotemporal patterns of human behavior in these simulations and contributions [25]. Certainly, other patterns and other systems [26] have explored inevitable facets of human nature. The objectives of these inquiries are to understand how a crowd of people emerges in social situations and how this can be supported dynamically by using navigation with spatial location information.

Past inquiries have examined social behavior in numerous assumed social surroundings. However, critics contend that in these past investigations, ordinary social scientific models and clarifications have lacked a geospatial and dynamic foundation. Mathematical sociology has clarified social models on interactions and emergent properties of the group and society [27]. Social psychological studies also have applied dynamic perspectives for cognitions and interactions [28] and artificial social simulations using the multiagent system. Certainly, human behavior and cognitive patterns should be investigated with more continuous viewpoints, even though traditional experiential design and analysis on dynamic and continuous human behavior have not achieved enough in various social contexts of the real world. These dynamic perspectives have emerged to import computational methodology to inquiries on human dynamics such as artificial social simulation and multiagent modeling from computer sciences and physical sciences. In other words, dynamic perspectives of social psychology would regard that the interaction between social members is important, generating some significant emergent properties from bottom-up processes.

2.4 Analyzing and Quantifying Spatial Human Behavior

There is a significant relationship between humans and their atmosphere and surroundings. Human behavior and cognitive patterns can be represented as activities in these social situations. The spatial perspective is a unique approach used to study human and physical phenomena. Exploring where specific spatial phenomena occur could help one understand why they occur and predict future tendencies, if possible. For example, I assume the dynamics of social behavior in social conditions as follows. As we know, these features have been acknowledged to occur in daily life or are expected in extraordinary conditions. Ubiquitous computing, embedded in the daily environment, may be able to track and grasp our behaviors and their patterns:

- Daily activities in specific outdoor and indoor spaces
- Evacuation behaviors in emergency situations
- Purchasing behaviors in shopping malls
- Continuous flow of people in passageways
- Collective dynamics of spatial networks [5], such as interactive relationships and group processes

The quantification of social behavior should essentially be on demand. Spatial analysis and its methodologies can help us to understand many spatial elements in specific social contexts and to develop visual conceptualizations of this human and environment linkage. Spatial statistics and informatics have helped to progress the knowledge and methods for spatial and geographical features. Therefore, human behavior patterns, in any given area, can be formalized and quantified [29].

- *Statistical distribution patterns*. I want to quantify distribution patterns of people and other spatial objects and analyze statistically significant meanings of specific areas (e.g., spatial autocorrelation, spatial statistical distribution, and other statistical examinations). Spatial autocorrelation means correlations of spatial distribution patterns of any object in the specific area or region. Namely, it indicates a degree of spatial relationship. If these adjacent areas are related statistically, we can estimate the linear correlation. For statistical examinations, there is the spatial autocorrelation as an indication of Moran's I and Geary's C. If these measurements are statistically significant in a spatial region, then we would be able to understand the meaningful patterns. Of course, this statistical analysis is just one of the effective methods to detect and verify spatial data. We should combine this method with various statistical methods to investigate this issue.
- *Spatial dynamics of behavior*. Spatial patterns and emergent dynamics of social behavior can be represented as interactive activities in specific spatiotemporal surroundings [4, 27]. If the dynamics of social activities are not rational enough in a high-uncertainty condition, then the social behavior could formalize itself based on the statistical model and be quantified in any given area. This would be very significant for investigating dynamic patterns in social contexts that include analyses with spatial statistics and informatics. Using these analyses, we can manage decision support and way-findings of peoples, for instance.

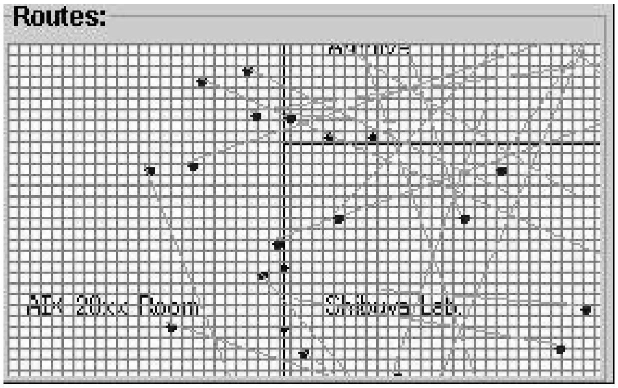

Figure 4. Analyzing an agent's historical movement as network patterns

- *Analysis on spatial and affiliation network patterns*. The framework contains a basic set of facilities to analyze networks. Spatial analysis of a network and its historical moving patterns of social behavior may indicate how the geometry in a specific area or region has been clarified or formalized. Network and topological graphs allow one to understand static and dynamic spatial relations. Spatial analysis of a network and its patterns indicates a clarification and formalization of geometry in a specific area or region. It can follow the tracks and routes of a specific agent in a simulation environment. This route denotes the historical movement of each agent. These route patterns could manage as the network and topological graph structure in the area (Fig. 4) [6]. By analyzing a spatial network and its structure, we can find tendencies of human behavior patterns and predict future patterns.

Furthermore, the affiliation network is the key foundation of human activities in an ubiquitous environment. The reason for this is quite understandable. Affiliation networks could represent and analyze distribution patterns and ad hoc networks of a mass of people by using mobile devices in an embedded ubiquitous world. Of course, because small-world phenomena have been examined by various fields (Fig. 5) [5], the spatiotemporal structure of mobile networks, which is based on spatial information, appears to be a very efficient concept for investigating human relationships and interconnections. These affiliation networks among people have been proposed as an efficient approach to classify relationships and clustering patterns in a specific social context [6]. Critics with a background in mathematical sociology have sustained the relational nexus and clustering structure of interconnected networks [30-32].

- *Location-based probabilistic estimation*. The biggest challenge is detecting where people are physically in the real world. For services that have a physical grounding in the real world, it is necessary to know where people are in the area at the moment. A system of the AURA [8] may provide us with images to detect people in specific areas. This framework can manage spatiotemporal information from a real-time location service and can be customized to visualize, restore, and communicate with other resources. In contrast, a stochastic model of the Bayesian network may be used to predict human needs and behavior [33]. These functions could also be used for practical services, especially when there are more physical constraints in indoor situations than in outdoor situations. Namely, indoor equipment and interior constraints, such as walls and doors, might restrict the flood and distribution of people's movements in a specific area. Hence, it would be very significant to investigate human behavior and its dynamic patterns in indoor contexts by analyzing spatial statistics and informatics. With these analyses, perhaps we would be able to inspect evacuation routes.

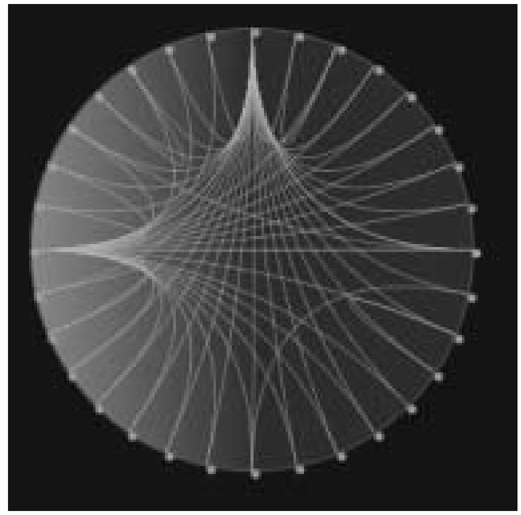

Figure 5. Analyzing network structure and interconnections

Lastly, it is a further motivation. The spatial database must underlie a system for managing human behavior and sequential time-series information. Then, data of spatial distribution and route historical information can be functionalized for spatial data mining. This implicates that these mining data can be used to conduct people in future situations.

3. Applying for Computational Services

3.1 Supports for Decision Making

According to many experimental studies on social psychology, human emotion and affect in adapting to emergency situations are too vulnerable for rational judgments to be made. In particular, it is difficult for social psychological studies to verify human behavior and cognitive processes in emergency situations [34]. Many iterated experiments have found that on such occasions, human cognition and related behaviors depend on emotions and heuristics [35, 36]. Of course, crowds of people are apt to lose their reasoned judgment and not behave appropriately, sometimes leading to panic [26] and riots [37]. It would be necessary to delve more broadly into human cognitive aspects and behavioral patterns on social psychological and group dynamic perspectives in these social environments [4].

In this respect, these defects of human cognition and behavior could be explored by using navigation in such situations. Social models also could simulate tragedies. People could therefore defer their emotional judgment and make an appropriate decision as to how to survive in such situations. I reconsider how possible it is for people to use this support with a multiagent system. I would assume that affect and emotional models are adaptable for the BDI (belief-desire-intention) architecture of an agent-based model. This means that social psychological knowledge can be translated to model agent and multiagent models. Human cognitive belief and affect have an influence on what people decide to do in various social conditions.

Ubiquitous computational navigation must be possible to conduct appropriate spatial information-based supports for people in specific social situations [38]. In emergency situations, most people's goal is to evacuate an area safely and quickly. However, emergency situations are restricted by geographical, physical, and spatial constraints. In most cases, people do not have the resources for cognitive processing and are restricted to looking around their environment and finding ways to evacuate. I also have been exploring and inquiring about a personal assist with a multiagent system that depends on spatial information and data.

A fundamental design for a location-based service system in the framework assumes that people often use and take one of the mobile devices in these conditions. Mobile devices that have a location service have emerged, presenting their value not only for communication but also for navigation [39, 40]. Navigation in an ubiquitous computational environment still can suggest concepts of the original investigation of spatial navigation [41]. There are various needs to visualize and navigate anyone who wants to use it [23, 42].

The system assumes two types of usage in describing the service platform of an agent architecture (Fig. 6). Users and people usually carry at least one mobile device, such as a cellular phone, PDA, handheld PC, and so on. If these devices are able to run Java code, then the Java program can communicate with the server in the PSI. In addition, this system is supposed to coordinate with the CoBIT system. The CoBIT system has the capacity to detect the spatial location of humans and other objects in the area and transmit spatial data to the PSI framework. Furthermore, it provides a kind of wearable device that detects the spatial position of humans and gives users correct information in the environment.

Service agents are classified into three layers. At the first layer, a service manages a fundamental domain of device dependence. A device wrapper manages the CoBIT system and coordinates with the location service agent in the upper layer. The CoBIT system can capture and track human dynamic behavior, and the device wrapper checks for updating data from CoBIT. Otherwise, for example, the location manages mobile devices directly with a wireless local-area network (LAN). Then, the location service agent broadly manages and supervises the location information of humans and physical objects in a specific area and coordinates with an interface agent in the upper layer. An interface agent visualizes spatiotemporal patterns of information and interacts with other people. These service agents in the service layer can use FIPA-ACL and communicate with other service agents in the framework, assuming that there are various queries and coordination between service agents. If there are any queries for spatial information, such as where a target person is, then the location service agent answers the questions.

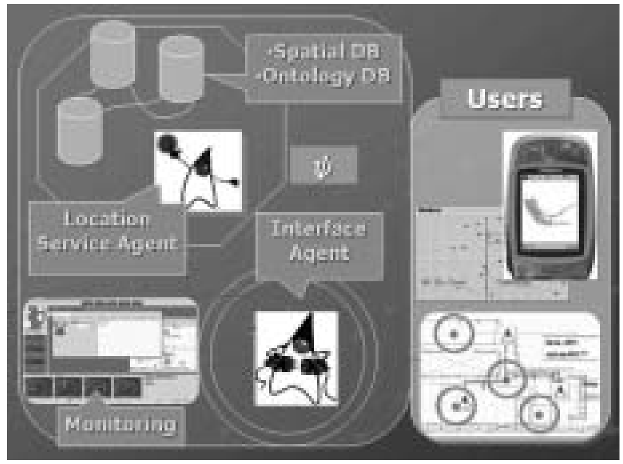

Figure 6. Online service overview of the PSI

3.2 Spatial Data and Ontology

Next, I explore more social navigation along with ontological aspects and spatiotemporal information that integrate with multi-agent-based services. Current studies on the semantic Web and ontology could improve various intelligent supports for people. The semantic Web aims to go beyond the World Wide Web by constructing knowledge in logically structured concepts. Recently, it also has become more favorable to include geographical and spatial perspectives for ubiquitous computing and decision support using semantic Web and related engineering [3, 16, 43].

This technological perspective could enrich informational services for user supports. Spatial and geographical data that use ontological services could also improve various intelligent user supports for navigation and other services in an ubiquitous computational environment. It may be possible to develop some functions for analyzing patterns of the way humans reason. Intelligent supports also help one to decide appropriate routes in the real world. Certainly, it is hard to construct a spatial ontology and specific knowledge in a social context, but this might enable researchers to develop some knowledge about restricted areas and domains such as offices and buildings.

Thus, fundamentally, it is necessary to engage in an ontological database of spatiotemporal information. Spatial and geographical data that use semantics could conjoin both advantages. First, it may be possible to develop some functions for prediction and reasoning. These intelligent supports help one to decide an appropriate route in the real world. For that reason, it is necessary to equip and prepare an ontological database and knowledge base in spatiotemporal information [44] for spatiotemporal analyzing and quantificational modeling. It is already known that multiagent systems and spatial information systems should be coordinated with each other. For example, there is an advanced way-finding service for people [22] using the multiagent system, and I am in the progress of improving on these points.

3.3 Modeling on Dynamical Human Behavior

As mentioned above, core software components for building service applications in the PSI include the agent-based model, spatial statistics, location-based services, and others. These building blocks promote the clarification of human behavior patterns in simulation and have been investigating modeling and simulation on social navigation [13, 22]. Alternatively, I focus on exploring social behavior patterns and the collective dynamics of an assumed crowd in an ubiquitous environment. This framework remains one of the goals in investigating some principles of a state of panic and catastrophe, as well as features of related social problems.

The agent is based on social psychological and sociological models of humans in this system [4, 27, 35]. This agent, as a representation of humans, cannot recognize information and manage resources of the environment properly. Moreover, it is known that humans have some restrictions in making decisions in an environment of social uncertainty. The cognitive heuristics of humans are vulnerable to adaptation in emergency situations. Hence, it is inevitable that chaotic crowds emerge and get out of hand in these conditions.

In this framework, when developing a simulation, the SpatialAgent class has inherited its superclass from the mover and implemented the autonomous interface. This interface can run its own thread and activate agents to implement their own activity rules. For example, the SpatialAgent could have a MentalMap object and some rule objects that implement the agent's own activity rule and attributes. It represents a cognitive map for the world and derives a specific activity rule (the rule object). According to experiential studies of social psychology on social cognition [36], human memory and cognition are implicity determined by cognitive representations of the real world. The MentalMap object also is different from the physical maps in the environment. This could imply that the mental map represents a limitation of agents' cognitive resources. If the mental map of an agent does not adaquately reflect the physical world, this agent cannot be adapted in the environment.

- *Emotional state:* The agent is always affected by its emotional states.
- *Eyesight:* Agent eyesight may be restricted in emergency environments.
- *Mental map:* The agent holds a cognitive mental map that does not always correctly reflect a physical map of actual surroundings.

Furthermore, this framework enables to define specific rules as social behavior patterns of an agent. A rule set of social behavior should be implemented through modeling and simulation. Agents autonomously behave according to an implemented activity rule in the virtual environment, and they seek to survive in dangerous conditions. For example, a leadership rule to guide other agents and a helping rule for others could be implemented. These rule objects are supposed to implement the rule interface, solidifying the methods and specific social behavior patterns of agents.

A rule set of specific behavior can be implemented with simulation. For example, it could assume implemented rule classes in emergency situations as follows. These rule objects would implement the rule interface and solidify the methods and specific behavior patterns of agents. This would show some of the implemented activity rules of agents as follows:

- *Lookup:* The agent looks around the world within the limit of its eyesight.
- *Way-finding:* The agent seeks to detect routes to evacuate if it can find ways.
- *Coordination:* The agent coordinates with other agents to survive if possible.
- *Communication:* The agent can communicate with other agents if possible.
- *Move:* The agent attempts to move, if possible, in dangerous conditions.
- *Stay:* The agent can stay and not do anything when it arrives at goal, or it can decide that staying is safer than moving.

I assume that these rules of social behavior patterns can be applied to GA (genetic algorithm), GP (genetic programming), and other adaptive algorithms for social simulations. For instance, the DNA bit patterns of an agent enable one to allocate some GP functions or determine an inclusive degree of adaptation in GA. Moreover, when developing some models of agent behavior rules, one may be able to compare other models to validate.

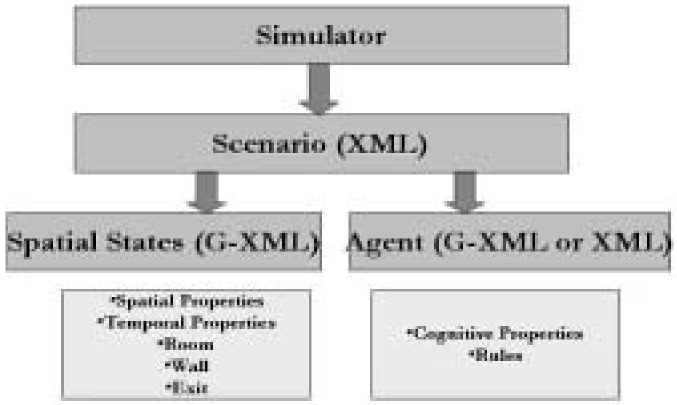

Figure 7. Overview of a managing simulation scenario

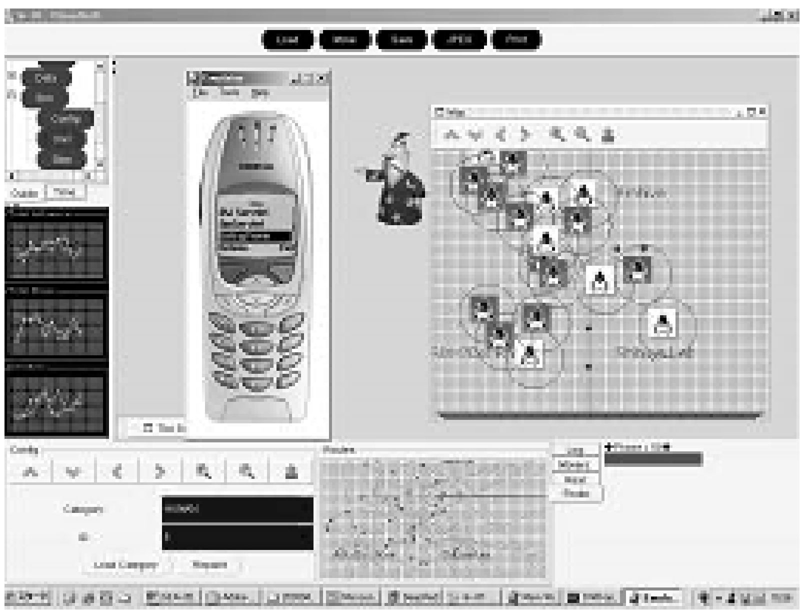

Figure 8. Social modeling and decision support based on spatial information

A simulator of the PSI framework defines a specification of a simulation scenario (Figs. 7, 8). This simulation scenario can determine the geospatial state and conditions as well as the agent state and properties using XML. The spatial state and properties can load and save data using G-XML, as mentioned above. For example, spatial states can denote the temperature, moisture, and amount of oxygen and toxic gas in the room. They also can define room and exit location information. Otherwise, an agent's properties and rules can load and store spatial data based on both the XML and G-XML formats because each agent can be represented as a Java object that can be serialized and loaded dynamically using the XML format (i.e., Java Beans serialization) and therefore can examine these configurations. To survive more appropriately and adaptively, agents should coordinate with each other. But the activity rule of human behavior is restricted by physical and spatial obstacles and constraints in many cases. Moreover, the floods of people and crowds are hard to survive. Then it is necessary to investigate various conditions and configurations in the virtual environments.

3.4 Experiential Educational Services

Location-based decision support for people can be well extended to educational services and can effectively apply

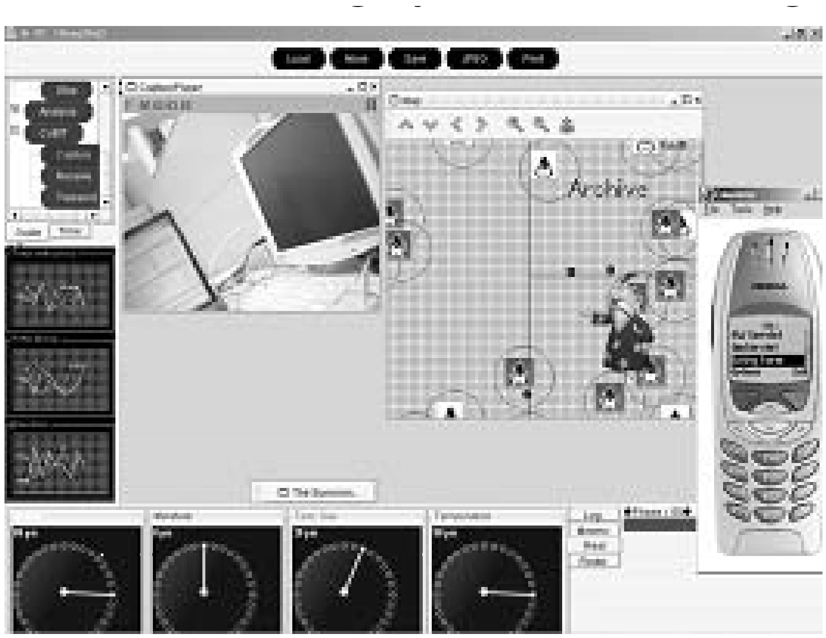

Figure 9. Collaborative learning workspace

computational services of the PSI framework for educational purposes. An experiential educational style could fit one of the service applications using the ubiquitous computational system because fieldwork and other educational activities in public educational and other institutions intensify the significance of experiential learning. Shibuya [45] pointed out the possibilities between ubiquitous computing and experiential education using a gaming simulation and collaborative learning in an ubiquitous system (Fig. 9). Educational services using ubiquitous computing have been conceptualized as follows:

- Education for knowledge discovery
  - Science museum
  - Natural history museum
  - Library
  - Education in indoor or outdoor fields
- Education by spatial information-based services
  - Developmental and educational psychological issues on the spatial cognition of children
  - Gaming simulations in emergency situations
  - Risk recognition and communication on hazards and tragedies
  - Experiential learning for decision making in specific social contexts
  - Environmental studies such as orienteering
- Education with computer-mediated communication
  - Computer-mediated communication with other people interactively
  - Online learning and computer-supported collaborative learning (CSCL)
  - Sharing social knowledge with other children

First, there is a motivation to apply education for knowledge discovery and experiential learning. Using the embedded services of ubiquitous computation, children and parents have opportunities to learn novel knowledge in public educational institutions such as natural history museums and so forth. Education for knowledge discovery, in terms of educational and developmental psychology and other relative studies, has already been investigated. Knowledge discovery and experiential learning have provided many benefits for people. In most cases, children seem to retain high motivation and learn to coordinate with other members more efficiently.

Moreover, I expect that actual experiences and coordination with others in the environment may be plausible for the cognitive and physical development of children. Certainly, past studies have researched spatial cognitive aspects in children and adults [46]. Varieties of cognitive development also have been acknowledged in children, as well as the vulnerability of spatial cognition and behavior. But this should point out the significance that experiences of navigation, simulation, and other educational viewpoints have in the real world. In addition, this may also be an alternative that underlies our perspectives of cognitive science as situated learning and ecological aspects, such as the concept of the affordance in social surroundings.

Second, there is much potential for gaming simulation using location-based services, which can be assigned in emergency situations and in learning traffic behaviors, for example. As mentioned earlier, the PSI is supposed to provide basic assistance in location-based navigation in an ubiquitous environment. More significantly, it can be used for learning latent risks in social surroundings and decision making, depending on the restriction of social space, because people cannot always recognize implicit risks and the significance of actually experiencing them in advance. In particular, it encourages students to be prepared for indoor emergency situations. Thus, location-based applications may underlie computational services that provide educational assignments such as route finding, mapping, and other informational supports in the ubiquitous environment.

Gaming simulation that relies on the architecture shows that users can communicate with other users and the system server of the gaming simulation with mobile devices. Thus, people can obtain some information on social context awareness in specific areas that provides educational suggestions and knowledge. The computational system tracks location information of people while providing continuous gaming services. The gaming simulation in this study provides some specific educational scenarios. For example, I assume that it prepares some scenarios such as escaping from dangerous buildings, emergency conditions, and other social conditions. It can also provide people with assignments to escape buildings more safely and find appropriate routes in actual rooms and buildings. Peoples are supposed to learn these educational assignments in specific social conditions while obtaining novel knowledge and coordinating with others.

Third, it is true that computer-mediated communication has many benefits for experiential learning. Computer-mediated communication with other people and computational agents in informational systems provides many opportunities to get useful information. Sharing information and knowledge with other people can also generate various educational objectives for children to discuss and learn. On the other hand, I have proposed the possibility of having network-oriented education for children more practically and collaboratively—that is, a kind of CSCL and workspace based on ubiquitous computing. This can be extended to online learning (e-learning) and constructive knowledge with various people and group members. It has already been applied to studies on cognitive and educational meaning [47, 48]. It is also beneficial to educate children with some appropriate mobile devices on online networks and more experiential conditions. Shibuya [49] has discussed the possibility of collaborative learning in ubiquitous environments, categorizing it as five aspects that consist of ubiquitous collaborative learning: spatiotemporal, distributed, interactive, experiential, and reciprocal aspects. Needless to say, collaborative leaning in an ubiquitous computational system literally underlies spatiotemporal dimensions and even can be established beyond those conditions creating distributed social networked relationships. It should be remembered, though, that collaborative learning and experiential activities facilitate mutual interactions among members. Finally, what is most important is encouraging students to share and educate each other reciprocally. With these points in mind, Shibuya has suggested possibilities of collaborating in small groups (i.e., ubiquitous jigsaw method) and with networked learning styles such as learning communities.

4. Concluding Remarks

In this study, I have presented my conceptualizations of a component-oriented framework for spatial modeling, quantification, and pervasive computation. Multiagent systems have the potential for improving social modeling and other computational services in a variety of social situations, such as managing spatiotemporal patterns and human behavior with more accuracy. Another idea is to improve some points of the PSI, such as the spatial database and the ontological foundations for navigating supports in future work.

5. Acknowledgment

The author thanks CARC members for discussing several points on earlier version of this article.

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