

学位論文

**Design and Evaluations of  
Personal Agent-oriented Virtual Society**

パーソナルエージェント指向仮想社会の設計と評価

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## Abstract

This thesis is concerned with the design, realization, and evaluation of a personal agent-oriented virtual society. A personal agent-oriented virtual society is a three dimensional audio-graphical computer-generated social environment which actively supports social collaboration between large numbers of distributed people.

In recent years, the combination of communication networks and computer technologies has made it possible to create a cyberspace on the Internet. Recently, several 3D shared virtual spaces and worlds have been developed in which users can share the same experience in real time. The next important step is to extend these environments into a “virtual society”. However, the majority of the previous studies have mainly focused on developing underlying systems for building multi-user distributed shared collaborative virtual environments. These studies have greatly contributed to the general work on the development of a virtual society. However a lot more needs to be done before we can come close to achieving this goal.

To realize a virtual society, it is important to obtain a large number of people in a virtual world and experimentally evaluate its various functions/interfaces based upon the populated world. Only the Internet makes it possible to implement the world and evaluate it with a large number of people. For this purpose, we constructed a personal agent-oriented virtual society called “PAW<sup>2</sup>” (Personal Agent World) by using our distributed system called “CommunityPlace”. PAW<sup>2</sup> is a 3D virtual society improved upon past virtual spaces based upon avatar and text communication by providing autonomous personal agents that support users plus a social/environmental infrastructure that allow social interactions in the environment.

This thesis consists of three parts. The first part describes and evaluates the CommunityPlace system, a virtual reality-based distributed system for realizing 3D multi-user distributed shared collaborative virtual environments over the Internet. The second part describes the design policy of a virtual society, system architecture, and implementation of PAW<sup>2</sup> system and its initial evaluation. The third part focuses on user-oriented evaluations of the PAW<sup>2</sup> system from the following viewpoints: user activities and social activities taking place in PAW<sup>2</sup>, and e-commerce system using PAW<sup>2</sup> as a market place. We evaluated the system populated by many people in the Internet. Finally, we introduce the notion of the next generation of a virtual society, i.e. a “self-sustaining” virtual society and discuss a possibility of realizing it.

We could observe that initially most users were accessing PAW<sup>2</sup> simply to enjoy the service provided by the system but they have gradually organized the unique social/cultural phenomena and creative activities in PAW<sup>2</sup>.

## 論文の内容の要旨

最近のコンピュータ技術とネットワーク技術の進歩により、サイバー空間を実現するための基盤が整ってきた。このような環境の中、三次元(3D)のマルチユーザ参加型共有仮想環境の実用化研究がなされ、参加したユーザが同じ仮想環境内で同じ体験を共有できるメディアとして様々な研究機関や企業で実現されてきた。このような共有仮想環境は、世界や街などの3Dのメタファを導入することにより、ユーザが滞在可能な新しい社会環境を作り出すことができる。しかしながら、これまで行われてきた共有仮想環境に関する研究の多くは、仮想環境のシステムアーキテクチャや、それを実現するプロトコル、ユーザインターフェース、アウェアネスの管理などに関するものが中心であった。これらの研究は、仮想社会を構築する上で不可欠なものであるが、それだけでは、大規模な仮想社会を作り出すことはできない。「社会」は、ユーザがその世界で社会活動をする上で必要な様々な社会的・環境的インフラストラクチャが十分に整って初めて実現できるものである。仮想社会の研究はまだ発展途上の分野であり、その様々な要素について実験、評価していく必要がある。仮想社会を研究する上で重要なのは、対象とする仮想環境を多くのユーザがアクセスし使い、社会システムとして機能している状態で評価することである。このような仮想環境が構築できる実験できる環境として、インターネットは非常に有効である。このため本研究では、次のようなアプローチをとる。インターネット上で多人数を収容できる共有仮想環境構築システムを開発する。このシステムを用い、多人数のアクセスを促す社会性を持つ共有仮想環境を構築する。本環境をインターネットに公開し、多くのユーザが使えるようにし、その環境をベースに実験を行い評価する。

最初に、インターネット上で3Dのマルチユーザ参加型共有仮想環境を実現するシステムのフレームワークを提案し、その実装であるCommunityPlaceシステムについて述べる。CommunityPlaceは、VRMLとJavaをベースとしたサーバクライアント型とpeer-to-peerシステムの特徴を持つ分散システムであり、WWWシステム上に3Dの共有仮想環境の構築を可能にする。CommunityPlaceは、(1)3Dの仮想環境を表示しナビゲーションする機能を提供するブラウザ、(2)共有仮想環境内のメッセージの配信・再配信を管理するサーバ、(3)共有仮想環境内のアプリケーションの実行環境であるアプリケーションオブジェクトの3つからなる。メッセージ配信を行うサーバシステムとアプリケーションの実行環境を分離することにより、環境内の変化をサーバ外のアプリケーションとブラウザ内のスクリプトの実行で実現可能にした。これに加えて、Auraモデルをベースにした少人数のメンバーのグループ内でだけ一貫性を保証することにより、システム全体のメッセージの配信量を減らし、システムにスケーラビリティを持たせている。また、アプリケーションの実行環境をサーバから分離することで、CPU負荷の高いアプ

リケーションをサーバと別のシステムで動かすことを可能とし、サーバが稼動するシステムの負荷を下げるができる。本システムを共有仮想環境内のユーザの振る舞いをシミュレートするプログラムを用いて性能を評価し、1000 人のユーザが同時にアクセスできることを示した。

次に、本研究の基盤となる社会性を持つ共有仮想環境を提案し、その設計方針と CommunityPlace 上の実装である PAW<sup>2</sup>(Personal Agent World)システム及びその評価について述べる。PAW<sup>2</sup> は、仮想社会を研究する基盤システムとして、数百人の同時アクセス、数千人の延べアクセスを目標として設計された。このため、(1)ユーザが PAW<sup>2</sup> に長い時間滞在するようにする、(2)ユーザが PAW<sup>2</sup> に再訪しやすくする、(3)社会的なアクティビティを行いやすくする、という観点から、次の 4 つの設計方針を立てた。(1)パーソナルエージェントの導入、(2)社会的・環境的インフラストラクチャの導入、(3)一人遊びの導入、(4) 平和な景観の導入である。パーソナルエージェントとは、仮想社会に参加するユーザを個別に支援する自律的なアプリケーションである。PAW<sup>2</sup> では、これまでの擬人化エージェントとは異なり、ユーザに過度な期待を持たせずにユーザが容易に接することができるように、エージェントを犬型の親しみ易い形状とし、あまり知的な機能を持たせないことにした。このため PAW<sup>2</sup> は、これまでのアバタとテキストベースの仮想環境とは異なり、各ユーザを個別に支援するパーソナルエージェントに加え、社会的・環境的インフラストラクチャを持つ共有仮想環境として実現された。本システムをインターネットで公開し、評価を行った結果、8 ヶ月で 32,000 人の登録ユーザ、523 人の同時アクセス、5~6,000 人の延べアクセスを達し、所期の目標を達したことを示した。また、同時に行った PAW<sup>2</sup> の機能に関するアンケートやデータベースの解析結果より、パーソナルエージェントの有用性、設計方針の妥当性を得ることができた。

次に、PAW<sup>2</sup> 内部でユーザが行っているアクティビティという観点からフィールドスタディを行った。これは、統計的な手法によるユーザアクティビティの分析と観察による社会的なアクティビティの分析の二つからなる。前者は、PAW<sup>2</sup> 内で行われているユーザアクティビティを統計的に調査・分析するものである。PAW<sup>2</sup> で行われるユーザのアクティビティは、コミュニケーション、パーソナルエージェント、イベント、アイテムに関連するアクティビティからなる。本研究では、そのカテゴリに属する 26 種類のアクティビティのログを 1 ヶ月間収集し、得られた 5,170 人のデータをもとに PAW<sup>2</sup> へのアクセスを目的変数、ユーザアクティビティを説明変数として回帰分析を行った。この結果、パーソナルエージェントが初期のユーザのアクセスに大きく寄与していることが分かった。後者の社会的なアクティビティの分析では、観察結果から、コミュニティの発生・増加、結婚式などのユーザイベントの開催、PAW<sup>2</sup> の情報誌の発行、独自のルールが発生など様々なアクティビティが行われ、一定の文化が形成されていることが分かった。本結果を他の社会性を持つ共有仮想環境アプリケーションと比較し、いくつ



かの類似性があることを示した。また、このようなアクティビティに加え、同時に反社会的行為も観察され、一種の社会問題が起きていることが分かった。PAW<sup>2</sup>では、システムの機能を社会的に受容可能なものにすることで解決を行った。

次に、仮想社会を E-Commerce という観点から拡張を行い、評価を行った。まず、仮想社会をベースにしたビジネスモデルを提案し、それをもとに PAW<sup>2</sup> システムに行った拡張と評価について述べる。本ビジネスモデルは、仮想社会をマーケットプレイスとして使用し、その仮想社会内に存在するオブジェクトを販売するというものであり、他の仮想社会にも柔軟に適応可能なものである。本ビジネスモデルに基づき、PAW<sup>2</sup> システムを拡張し、既存の課金システムと PAW<sup>2</sup> システムをリンクし Web ページ上で仮想オブジェクトの販売を可能にした。本システムをもとに、仮想オブジェクトに興味づけし販売する実験を2ヶ月間行った。この結果、期間中で1回以上アクセスしたユーザ 8,005 人のうちの約 10%、また、課金システムをすぐに使用できるユーザの 29.4%が仮想オブジェクトの購入を行ったことが分かった。この要因として、パーソナルエージェントが結果に寄与していることが分かった。本結果とネットワークでのデジタルコンテンツ(ニュース配信やソフトウェア)の購入とを比較し、本モデルの妥当性を得ることができた。また、本結果より、エージェントの機能をベースにしたビジネスの可能性も示すことができた。

最後に、次世代の仮想社会である「Self-sustaining virtual society (SSVS)」の提案を行い、これまでの PAW<sup>2</sup> の研究結果から、その可能性について議論する。SSVS は、ユーザ自身がその環境内でコンテンツや文化を構築することを可能にし、環境そのものを豊かにする creative positive feedback loop (CPFL) を提供する共有仮想環境である。SSVS は自身の環境をよりユーザ指向で自律した自然な方法で拡張・拡充することができ、現実世界に存在しない独自の文化形成などが期待できる。これまでの研究結果から、制限された機能であっても、CPFL が存在し文化やコンテンツが形成されていることが分かり、SSVS の可能性は十分にあることが分った。しかしながら、制限された機能であってもそれを用いた反社会的行為も発生しており、システムが提供する自由度が反社会的行為に使用される可能性が高いことも分かった。これらの結果から、SSVS を実現するためには、単に機能を提供するのではなく、社会的に許容可能な機能の提供が重要であり、それによって形成される文化やコンテンツを評価していくことが重要な研究のアプローチである。また、SSVS 以外の本研究の研究項目として、仮想社会構築ミドルウェア、パーソナルエージェントの拡張、仮想社会内の E-Commerce の支援、個人用仮想社会の支援、仮想社会との非同期インタラクションの支援、現実社会と仮想社会の融合、「非共有型」共有仮想環境について述べる。

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# 1. Introduction

The term “cyberspace” popularized by the media is being used today only in science fiction exemplified by such novels as “Newromancer” (Gibson, 1984) and “Snow Crash” (Stephenson, 1992). These are popular science fiction novels describing a cyberspace of the future. Newromancer envisions the computer network as an immersive virtual space, with people interact with each other. Snow Crash involves a computer-generated three-dimensional (3D) large-scale space and people performing business with their virtual embodiments. In these cyberspaces, many people share the same virtual environment with their embodiments, collaborate with one another in various ways, and create their own culture in the environment. On the other hand, the recent evolution of computer and network technologies has provided the technical means necessary to make the cyberspace a reality. By using these technologies, cyberspaces can be established in a multi-user distributed shared collaborative virtual environment generated by computer systems over a network. Such environments provide an electronic means for human interaction, communication, collaboration, and information exchange regardless of the physical distance between people or between people and various types of applications.

Several multi-user distributed shared collaborative virtual environments and worlds have been developed by different research groups and companies. These technologies can create 3D places and allow people separated by a great distance to visit these places and stay there. People can see and talk to one another, together visit different places, participate in various events, and organize various group activities in the virtual environment. They can also share the same experiences in the same environment. By introducing a 3D spatial metaphor (e.g. a notion of the world, or city) in the virtual environment, new types of social environment can be created in computer systems and shared among many people. We can realize, reproduce, and redefine everything that exists in the real world within the virtual environment. In such an environment, people may engage in various social activities including cultural or creative activities. In this way, different “real worlds” can be introduced into the virtual environments created by computer technologies. We call such worlds “virtual societies”. The next logical step is to extend the multi-user distributed shared collaborative virtual environments into a virtual society.

However, the majority of studies on this area have been confined to high-bandwidth communication networks supporting a small number of users to research its framework (Carlsson and Hagsand, 1993). Also, the previous studies have mainly focused on developing underlying systems for building multi-user distributed shared collaborative virtual environments including network protocol format (Thorpe, 1987), system architecture (Waters et al., 1997), user interfaces (Mohagege et al., 1997), world structuring (Greenhalgh et al., 2000) and awareness management systems (Benford et al., 1993). These studies have greatly contributed to the general work on the development of virtual society. However a lot more needs to be done before we can come close to achieving this goal.

To realize a virtual society, it is important to obtain a large number of people in a virtual world and experimentally evaluate what functions (especially social functions), software infrastructure, and user interfaces should be supported. We need to experiment with many people sharing the same virtual world, because the virtual world cannot function as a social system without many people. It is important to evaluate them in the system functioning as a social system. We consider that only the Internet makes it possible to realize the experiment environment.

For this purpose, we took the following approach. We develop a distributed software system called “CommunityPlace” for building large-scale 3D multi-user distributed shared collaborative virtual environments by using popular networks and computer environments. The system is a natural extension of the World Wide Web (WWW), which makes it possible to fit the virtual environments seamlessly into the Internet, and allows application developers to add/delete new functionalities in the environments dynamically. With the system, we implement a 3D multi-user “social” virtual world called “PAW<sup>2</sup>” to allows many people to organize social activities in the environment. We release PAW<sup>2</sup> into the Internet to allow all Internet users to access the environment freely. In this environment populated by many different people, we conduct experiments to evaluate it from various user-oriented points of view.

In this thesis, we describe the design and evaluations of the CommunityPlace system and the PAW<sup>2</sup> system.

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## **1.1. Multi-user Distributed Shared Collaborative Virtual Environments**

We can say that 3D multi-user distributed shared collaborative virtual environments (hereafter referred to as simply “MUSVEs”) are an extension of the traditional single-user virtual reality (VR) applications and computer supported

cooperative work (CSCW) systems. 3D MUSVEs are computer-based distributed systems which support geographically dispersed multiple users enabling them to interact with one another in a number of different ways including by using text or gestures. They support the notion of space, or world, and each user in the virtual environment is represented through an animated representation called “avatar”. The avatar is a visual representation of a user to other participants sharing the same virtual environment and a means of users’ interaction with the environment. These avatars are often represented in the form of humanoid-type creatures. Each user can autonomously move around in the virtual environment by operating his/her avatar via a user interface of the system. All elements in the virtual environment are defined as shared objects viewable by two or more users. If the environment supports a notion of the world, the world itself is also one of the shared objects. Such objects may have interactive characteristics and their behaviors are also shared among users. A robot automatically walking around in the virtual environment is a simple example of shared objects. Participants can freely interact with the robot. Its reactions, such as the swinging of its hand, are automatically distributed to everyone in the environment as updates. Thus, all participants can see the same objects and their behaviors under the same conditions.

The types of MUSVE being described in this thesis are 3D environments. We explain it with an example shown in Figure 1.1. It shows a screenshot of the CommunityPlace system, which displays a 3D MUSVE. The CommunityPlace system is our first MUSVE development system described in this thesis. In the figure, there are three users sharing the same virtual world. Each user is represented by avatar. In this example, animal-shaped representations are used. In the foreground, a dolphin-shaped avatar and a dog-shaped avatar are talking. In the background, there is a house and a cat-shaped avatar is looking at the foreground



Figure 1.1 An example of MUSVE

avatars. Each user can autonomously and independently move around in the virtual environment. Users also can interact with one another in various ways: text messages, gestures, and audio. In this example, each user’s chat message is shown in a chat balloon above their corresponding avatars.

## 1.2. Pervious Work

We describe the previous works on 3D MUSVEs from the viewpoints of CSCW systems and pioneer MUSVE systems.

### 1.2.1 Positioning of MUSVEs in CSCW systems

CSCW systems are categorized into the following four categories according to the timing and location of the collaborative activity (Ellis et al., 1991). This is shown in Table 1.1.

Table 1.1 The quadrant model of CSCW systems

	Same Time	Different Times
Same Place	<b>Face-to-face interaction</b> (e.g. electronic meeting rooms and interactive whiteboards)	<b>Asynchronous interaction</b> (e.g. AR-based* bulletin board systems)
Different Places	<b>Synchronous distributed interaction</b> (e.g. multi-user editors, video conference systems, and MUSVEs)	<b>Asynchronous distributed interaction</b> (e.g. e-mail systems, electronic bulletin board systems, and work-flow systems)

\*: Augmented Reality

The “Same Time” category shows the systems supporting works that all users do in real time. The “Different Times” category shows the systems supporting works that each user does independently. The “Same Place” category shows the systems supporting works that all users do in the same place. The “Different Places” shows the systems supporting works that geographically dispersed users do.

Electronic meeting room systems, such as Colab (Stefik et al., 1987) and Urp (Underkoffler and Ishii, 1999), and interactive whiteboard systems, such as Liveboard (Elrod et al., 1992), are within the “Same Time/Same Place” category. The systems in “Different Times/Same Place” enable users who work asynchronously to share information in the same place. Recently, AR (Augmented

Reality) technology, such as putting information on the real world (Rekimoto et al., 1998) would be within this category. Shared document creation and modification systems, such as GROVE (Ellis et al., 1988) and Quilt (Leland et al., 1988), and remote audio video conferencing systems, such as (Sarin and Grif, 1985) and MERMAID (Watanabe et al., 1990) are within the “Same Time/Different Places.”

MUSVEs are categorized into the “Same Time/Different Places” category which supports synchronous distributed collaboration. However, MUSVEs can be distinguished from the other CSCW systems in this category from the following two viewpoints: (1) the relationship between each user and the shared environment provided by the system and (2) the types of collaboration in the environment. As described in Section 1.1, in MUSVEs, each user is directly embodied by an avatar “within” the environment. Their interaction with the environment (or other users) is directly and independently represented by means of their embodiments. Unlike the other systems, these interactions are autonomously, unpredictable, and open to reinterpretation to others and also to the system. These natures allow users to equally transform the environment, add/create new meaning or value to the environment, and organize various types of user activities including social and cultural activities in the environment. In particular, 3D MUSVEs that this thesis focuses on can create a “space” in network environments where many users can stay for a long time. It allows users to immerse themselves in the created space containing various objects and other users accessing from remote computer systems. 3D MUSVEs also can introduce a notion of the world, or city to allow users to naturally organize various social activities occurred in the real world. So the 3D MUSVEs can create various different “real worlds” in computer systems using network.

## **1.2.2 Pioneer MUSVE systems**

Two different types of systems have pioneered the development of MUSVEs: military simulation networks known as SIMNET (see Section 2.1) and text-based multi-user applications known as MUDs (Multi-User Dimensions/Domain/Dungeons; see Section 2.2). Figure 1.2 shows the history of MUSVEs based upon (Smed, et al., 2002).

SIMNET was developed in 1983 by DARPA (the Defense Advanced Research Projects Agency). It is built for a military battle simulation environment based upon vehicle and flight simulators for training small units to fight as a team. SIMNET’s communication protocol DIS (Distributed Interactive Simulation) was established as IEEE-standard in 1993. The DIS protocol allows any type of player and any type of machine to participate in the battle simulation. Consequently, it is used in other systems, such as NPSNET (see Section 2.1). The military research focuses on realizing diverse large-scale system based upon the dedicated networks,



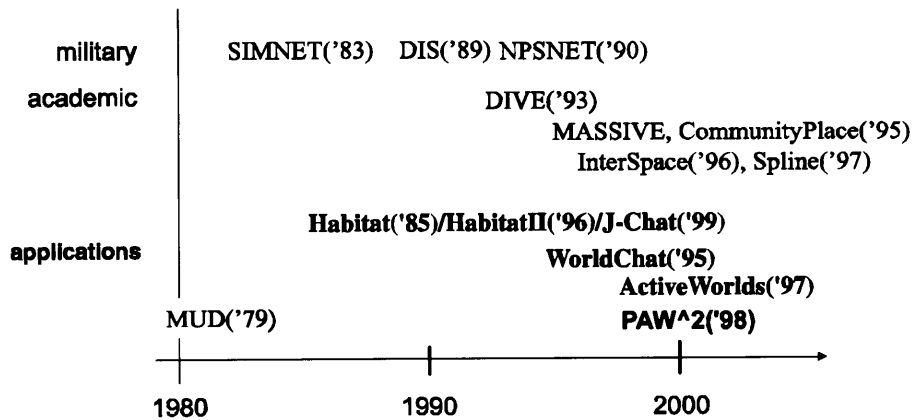


Figure 1.2 History of MUSVE systems and applications

such as MBone (Macedonia and Brutzman, 1994). Meanwhile, the academic MUSVE systems are mainly designed for local use and to support a small number of users. DIVE and MASSIVE (see Section 2.1) are the pioneer systems for multi-media conferencing in MUSVEs using IP multicasting. Our work differs in that our goal is large-scale collaborative systems capable of supporting many users interconnected through the Internet, i.e. low bandwidth, high latency communication links.

In term of MUSVE applications, obviously, MUDs are the pioneer system. The early MUD was written in 1979 by Roy Trubshaw and Richard Bartle on a DEC10 system at Essex University (Bartle, 1990). It was a combat/adventure game, except that it allowed multiple users to play at the same time and interact with each other. The user interface of MUDs is entirely textual and users in the systems communicate with each other in text and input text command for their actions. An improvement of these systems is Habitat (see Section 2.2), which is a MUD-like system where representations of virtual world and participant are 2D. Habitat is also the very first social MUSVE application which provides avatars, developed by Lucasfilm Games. The users could communicate in text and form a community in a shared 2D virtual world. In addition, Habitat provided social infrastructure, such as a barter system and economic system. It started out running on Commodore 64 computers in 1985. Meanwhile, the very first 3D MUSVE application is WorldChat (see Section 2.2) which became available in 1995. It provided avatar customization and text-based communication but no other social infrastructure. Our work differs in that our goal is a large-scale 3D collaboration system callable of supporting many users to organize various social activities.

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## 1.3. Contribution of this Work

The contribution of this work can be summarized as follows.

This study presents a framework for building large-scale 3D MUSVEs based upon the WWW architecture and the Virtual Reality Modeling Language (VRML). This proposed framework is targeted towards the Internet, or low-bandwidth and high-latency networks. The framework provides a flexible and powerful mechanism for dynamically introducing multiple shared applications in the same environment. We also developed an actual distributed platform system called “CyberPassage” and its successor, “CommunityPlace”. These systems enable developers to create 3D MUSVEs where one thousand users can communicate simultaneously by using a single server and a dial-up connection. Also, the CommunityPlace system has become commercially available and is widely used to develop commercial virtual worlds on the Internet. As the result of our effort to develop these systems, we contributed to the standardization of VRML2.0 and its ISO version, i.e. VRML97, especially with regard to its behavior mechanism, scripting, and Java binding section.

This study describes the design policy, system architecture, and methodology for building a virtual society and introduces a personal agent for the virtual environments. Based upon the developed design policy, we designed an actual virtual society called “PAW” and its successor, “PAW<sup>2</sup>” and developed them by using the CommunityPlace system. Unlike the previous MUSVEs with avatars and text communication, PAW<sup>2</sup> is a 3D personal agent-oriented virtual society with a social and environmental infrastructure where each user has his/her own personal agent. We made the system available on the Internet and evaluated its effectiveness with many users. The results showed that PAW<sup>2</sup> was accepted by a large number of users, successfully created a 3D space on the Internet, and our design policy was successfully supported.

We evaluated user activities taking place in the virtual society from the following two viewpoints. Based upon the statistical information on user activities, we clarified the characteristics of user activities in PAW<sup>2</sup>, the user structure, and the relationship between the users’ access behavior to PAW<sup>2</sup> and their activities within the system. The obtained results showed that the 3D nature of the environment affected the user activities and the personal agent played an important role in encouraging the users to visit PAW<sup>2</sup> repeatedly. In addition, we clarified what types of social activities are taking place in PAW<sup>2</sup> based upon observations. In these observations, we found a kind of cultural/creative activities formed based upon the PAW<sup>2</sup>’s functions, that we never anticipated. We compared our observations with other virtual worlds and found some commonality.

We developed a business model, system framework, and methodology for building an e-commerce system in a virtual society. The proposed business model uses the virtual society as a market place. We extended PAW<sup>2</sup> system to test the business model by e-commerce experiment with real money. Our hypothesis in the model was that by defining the meaning and value of a virtual object in a virtual society it becomes possible to sell such objects for real money, just like real goods. The results provided a weight of evidence in favor of our hypothesis and indicated the possibility of enhancing the e-commerce system using a virtual society. We also showed a business potential for agent technology-based B2C business and C2C business.

We developed the notion of a “self-sustaining” virtual society (SSVS). SSVS is the next generation of a virtual society which allows users to naturally enrich the environment by itself. We evaluated the possibility of realizing a SSVS based upon the results described in this thesis and showed that a virtual society on the Internet can potentially develop its own culture and become a SSVS.

## 1.4. Organization of the Thesis

The remainder of this thesis is organized as follows (Figure 1.3).

Chapter 2 describes the previous research related to this thesis.

Chapter 3 describes the design and development of a software framework for building 3D MUSVEs on the Internet. We present a distributed platform system called “CommunityPlace” based on the framework. In addition, we describe a

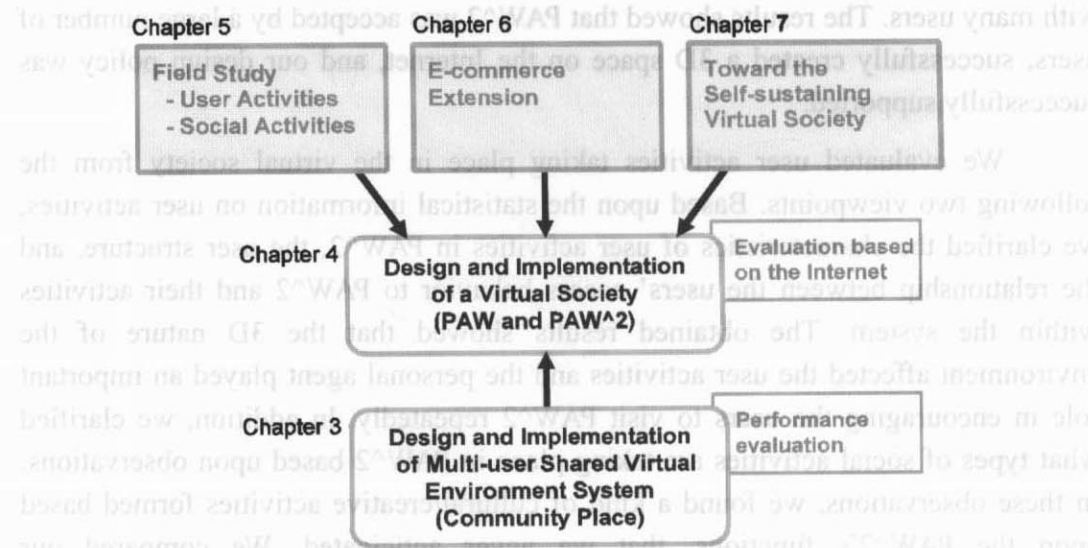


Figure 1.3 Organization of this thesis

multi-user application framework and communication protocols for realizing the 3D MUSVEs. We also discuss its scalability and evaluate its performance.

Chapter 4 describes the design and development of a framework for building a virtual society. We present our design policy for building a virtual society and its representation “PAW<sup>2</sup>,” which is developed using the CommunityPlace system. We also describe its functionalities and evaluate the effectiveness of PAW<sup>2</sup> on the Internet. Based upon the obtained results, we describe user profile, degree of satisfaction with the systems, and characteristic features of user activities.

Chapter 5 describes field study from the viewpoint of user activities taking place in a virtual society. This chapter consists of two parts: statistical analysis of user activities and observation-based analysis of social activities. In the first part, we obtain statistical information about user activities to analyze their statistical characteristics and user profile. In addition, we perform the multivariate analysis of the data to clarify which activities encouraged users to visit PAW<sup>2</sup> repeatedly. In the second part, we clarify what types of social activities based upon our observation in PAW<sup>2</sup>. We also describe the types of anti-social behavior and suggest approaches of dealing with such behavior by using computer technology.

Chapter 6 describes an e-commerce extension to a virtual society. We discuss possible business models based upon a virtual society and develop a new business model that utilizes the virtual society as a market place. We extend PAW<sup>2</sup> system based upon the model to evaluate it by conducting an e-commerce experiment with a virtual society. With the obtained information about the users’ purchasing behavior, we evaluate the possibility of conducting e-commerce business in a virtual society. Then we discuss the possibility of enhancing e-commerce through a virtual society.

Chapter 7 proposes the notion of a self-sustaining virtual society. Based upon the previous discussion described in this thesis, we discuss the possibility of realizing a self-sustaining virtual society and establishing a certain culture in the virtual world. We also describe some plans for the future work.

Finally, Chapter 8 presents our conclusion.

## 2. Related Work

In this chapter, we describe the previous research related to this thesis, especially from the viewpoints of MUSVE systems, MUSVE applications, personal agents, social analysis of user activities in virtual environments, and e-commerce systems via the Internet.

---

### 2.1. MUSVE Systems

MUSVE systems can be seen as the results of research on the VR, CSCW, and HCI systems. There are several types of MUSVE systems from client-server system to peer-to-peer system. This section summarizes some features of a set of popular MUSVE systems. Table 2.1 shows the comparison of the systems (Matijasevic, 1997).

These systems use a “rich” architecture based upon high-end graphics computers and use LAN or IP Multicasting as a basis for communication. So, these are hard to be used on the Internet by a large number of users who use low-cost consumer equipment. Similarly, some systems also lack flexibility and portability to construct a shared application in a 3D MUSVE.

SIMNET (Simulation Network; Thorpe, 1987) was the very first MUSVE system developed for military simulation networks in 1983 by the Defense Advanced Research Projects Agency (DARPA). It supported vehicle and flight simulators that generate real-time 3D images of a virtual world. A peer-to-peer network protocol and dead reckoning technology (Singhal and Cheriton, 1995) used by the system allows these many simulators to display other users’ vehicles and projectiles during virtual battle simulations. The SIMNET’s communication protocol DIS (Distributed Interactive Simulation) was established as IEEE-standard in 1993. Consequently, it is used in other systems, such as NPSNET.

NPSNET (Macedonia et al., 1994) was developed by the Naval Postgraduate School (NPS). It is also developed primary for large-scale battle simulations for thousands of users. NPSNET is compatible to the DIS protocol and the first system that can use IP multicast over MBone (Macedonia and Brutzman, 1994) to realize MUSVEs. To scale the system, NPSNET introduced AOI (area of interest) management based on regions. It can divide the virtual world statically into regions called “cell” and associates different multicast addresses to different regions. Changes performed by any client in the region are distributed to clients within the same region via its multicast address. Therefore, all information in the same cell is shared among participants in it in real time.

Table 2.1 Comparison of 3DCG-based MUSVE systems

	SIMNET	NPSNET	DIVE	MASSIVE-2	Spline	Community Place
Purpose	military training	military training	collaboration	collaboration	social interactions	social interactions
Number of users	850	> 1000	20	80	n/a	< 1000
Data model(*)	replicated	replicated	replicated	replicated	replicated	shared, distributed
Data replication	full	partial	partial	partial	partial	partial
Consistency	weak	weak	strict	weak	weak	multi-level
AOI (Area of Interest) management	none	region (cell)	artifact (aura)	region, artifact (aura) (MASSIVE-1)	region (locales)	artifact (aura)
Distribution	broadcast	multicast	multicast	multicast, unicast (MASSIVE-1)	multicast	unicast
Network protocol	UDP/IP	IP Multicast	IP Multicast	IP Multicast	IP Multicast	TCP/IP
Communication	no	text/audio	text/audio	text/audio/video	audio	text(audio)

n/a: the data is not available. \*: based upon the definition of (Macedonia and Zyda, 1997)

DIVE (Distributed Interactive Virtual Environment) is a 3D MUSVE system developed by Swedish Institute of Computer Science (SICS) (Carlsson and Hagsand, 1993; Frecon and Stenius, 1998). Users and the environment are represented as 3D representation. DIVE is based upon hybrid system (peer-to-peer multicast system with client-server system). Each node (computer) maintains a complete copy of world database for and allows adding/deleting shared object to/from the database dynamically. DIVE uses IP multicasting technology as a basis

for communication and assigns the multicast address to sub-areas in the virtual world. Application developers can use a scripting language (e.g. TCL/TK) to describe object behaviors and graphical user interface (GUI) for the virtual world. DIVE also supports VRML and its proprietary file format for 3D description.

SPLINE (Scalable Platform for Large Interactive Networked Environments) is a comprehensive toolkit for building 3D MUSVEs, which is developed by Mitsubishi Electric Research Laboratories (MERL) (Waters et al., 1997). It supports VRML to describe a virtual world and C/C++ or Java to describe object's behaviors in the environment. It also supports hybrid system (peer-to-peer multicast system with client-server system). Unlike the NPSNET, SPLINE allows developers to divide a virtual space into a set of logical areas called "locale" which has arbitrary size and shape and are associated with multicast addresses (Barrus et al., 1997). Each locale can be linked with each other to link the divided space. Each client can receive all information in the locale where the client (user) belongs and locales adjacent to it.

MASSIVE-1/2/3 (the Model Architecture and System for Spatial Interaction in Virtual Environments) is a 3D MUSVE system developed by Communications Research Group in the University of Nottingham (Greenhalgh and Benford, 1999). MASSIVE mainly focus on realizing a remote conference system with audio/video interface. MASSIVE-2/3 supports hybrid system, i.e. peer-to-peer multicast system with client-server system. However, MASSIVE-1 supports peer-to-peer unicast system with client-server system. The goal of these systems is to provide media-rich (text, voice, video, and graphics) communication environment, such as a conference system. It also supports AOI management based on area surrounding an avatar called "aura" (Benford et al., 1994), the third-party objects (Benford and Greenhalgh, 1997), and structuring/partitioning of virtual environment based upon the use of locale introduced by SPLINE system, with IP multicasting technology as a basis for communication. The third party object is mediators of awareness (aura) and relationship between objects in the environment.

InterSpace is a 3D MUSVE system developed by Nippon Telegraph and Telephone Corporation (NTT) (Sugawara et al., 1994). It is based upon client-server system. It allows users to put a video image captured by CCD camera on their face of avatar and communicate with other users using voice. These features enable them to introduce TV conference type communication into a 3D MUSVE. NTT is going to provide a new type of phone system based upon the environment. It supports proprietary scripting language to describe behaviors of objects in the world. FreeWalk (Nakanishi et al., 1996) also takes a similar approach with InterSpace and provides audio/video communication in 3D MUSVE.

## 2.2. MUSVE Applications

There are several types of MUSVE applications from text-based applications to 3DCG-based systems. This section summarizes some features of a set of popular MUSVE applications. Table 2.2 shows the comparison of them.

Table 2.2 Comparison of MUSVE applications

		Habitat(*1)	WorldChat	Machiko	ActiveWorlds	PAW^2
User Interface		2.5D	3D	3D	3D	3D
Communication	Conversation	Text	Text	Text	Text	Text
	Actions	Yes	No	No	Yes	Yes
Social Infrastructure (*6)	Name card	Yes(URL, J-Chat)	No	No (*2)	No	Yes
	Economic System	Yes	No	No	Yes(*3)	Yes
	Mail System	Yes	No	No	Yes	Yes
	BBS(*5)	Yes(Habitat)	No	Yes	No	Yes
	Pager	Yes	No	Yes	No	Yes
Environmental Infrastructure (*6)		No	No	Yes	Yes(*3)	Yes
Agent		No	No	Public Agent	No	Personal Agent
Event hosting		Yes	Yes	Yes	Yes	Yes
Function to kill users		Yes(*7), No(J-Chat)	No	No	No	No
Building capability		No	No	No	Yes	No
Avatar	Creation	No	Yes	No	No(*4)	No
	Customization	Yes	Yes	No	No(*4)	Yes
Accounting capability		Yes: Membership fee, selling avatar's body segments (J-chat)	No	Yes: Selling real goods	Yes: Membership fee	Yes: Selling virtual objects

\*1: including HabitatII and J-chat (the successors of Habitat).  
\*2: Machiko provides Web pages for self-introduction of authorized users.  
\*3: Some worlds provide this functionality. For example, AWgate world supports the day changes from day to night. Mutation world provides its own economic structure.  
\*4: unless a user hosts his/her own world.  
\*5: Bulletin Board System.  
\*6: See Section 4.4 about social and environmental infrastructure.  
\*7: When an avatar is killed, he/she is teleported back home, head in hands (literally), pockets empty, and any object in hand at the time dropped on the ground at the scene of the crime.

MUDs (Multi-User Dimensions/Domain/Dungeon) and MOOs (MUD, Object Oriented) are the systems whose user interface is entirely textual and also



knows as “text-based virtual world” (Evard, 1993; Randall, 1994). MOOs are extended upon MUD and provide object-oriented application programming interfaces to extend the system. These systems support client-server system using telnet command and the TELNET protocol to communicate with other computers. A user inputs text command to access the virtual world, chat with other users, and show the objects in the virtual world in text format. For example, “@who” is a command to show who are in the virtual world. Figure 2.1 shows a session to access MOO system (LambdaMOO) and chat with other user. Since MOO does not require sophisticated display device and is easy to extend the system, there are several variations of the system: LambdaMOO, ElseMOO, CombatMOO, and MOOSE Crossing. LambdaMOO and ElseMOO are social MOO (Cherry, 1995) and CombatMOO is game-oriented MOO (Muramatsu and Ackerman, 1998). MOOSE Crossing is a MOO-based learning environment for upper elementary and middle school students (Bruckman, 1997).

Habitat is the very first system supporting avatars, whose user interface is 2DCG (Morningstar and Farmer, 1991), originally developed based upon Compuserve service by Lucas Film Games, a division of Lucas Arts Entertainment Company. In Habitat system, a virtual world and users are displayed in 2D representation. The users can intuitively and autonomously navigate and interact

```
*****
* Welcome to LambdaMOO! *
*****

*** Connected ***
Would you like to start in a noisy or quiet environment? A noisy environment
will place you where you can get help from others and converse; while a quiet
environment will give you a quiet place to read help texts.
[Please respond 'noisy' or 'quiet' or '@quit'.]
noisy
The Coat Closet
The closet is a dark, cramped space. It appears to be very crowded in here;
you keep bumping into what feels like coats, boots, and other people
(apparently sleeping). One useful thing that you've discovered in your
bumbling about is a metal doorknob set at waist level into what might be a
door.
There is new news. Type 'news' to read all news or 'news new' to read just
new news.
Type '@tutorial' for an introduction to basic MOOing. If you have not already
done so, please type 'help manners' and read the text carefully. It outlines
the community standard of conduct, which each player is expected to follow
while in LambdaMOO.
Teal_Guest says, "hi"
"hello
You say, "hello"
Kouichi says, "hello""
"How are you doing?
You say, "How are you doing?"
Kouichi says, "fine!"
Tala floats in a shimmer of amber glow.
Tala (a star) waves.
```

Figure 2.1 A screenshot of MOO

with other users and the world. Figure 2.2 shows Habitat system. In Figure 2.2, users are represented as 2D avatar, such as humanoid type representation, and can chat with other users in text. The chat messages are displayed in the form of a speech balloon. Users can walk around in the virtual world in 2D way, make predefined gestures, possess objects, and exchange the objects between users through its user interface.

WorldChat (Damer, 1998) is the very first 3D chat world which became widely available on the Internet, developed by Worlds Inc, since 1995. The virtual world provided by WorldChat consists of a space station with dozens rooms and space-pods connected by hallways and escalators. In the WorldChat system, the virtual world itself is represented in 3D but user's avatar is represented in pseud-3DCG. Users firstly need to choose their avatars in the avatar room, then enter the virtual world (the space station), and they can interact with other users in the environment. Like the Habitat system, they can intuitively navigate and interact with other users and the world. Only text communication is available in the system.

Machiko (Koike, 1997) is the early 3D virtual marketplace where users can purchase real goods at virtual shops in the virtual environment, provided by NTT DATA in Japan. It is designed for the target audience of women between the ages of 25 to 35. The world is thus designed to look like a city in Europe, one of the most popular travel destinations among the target group. Unlike retail Web sites, it provides a choice of “window-shopping”, where users can walk around autonomously and “direct access”, where users go directly to the electric store of their choice. Users can use a shopping basket to place the goods they wish to purchase for real money in the basket.



Figure 2.2 A screenshot of Habitat system  
(Copyright 1986 LucasArts Entertainment Company)

ActiveWorlds<sup>1</sup> (Damer, 1998) is a set of commercial 3D virtual worlds provided by Activeworlds Corporation. It allows users to own their world and provides over 1,000 virtual worlds. Every virtual world is a part of one large world and has a latitude and longitude in the large one. Each world can support its own social infrastructure. Users are called citizens in ActiveWorlds. They can chat with other citizens, attend happenings in the world, and teleport to other worlds if they know their locations. Unlike other MUSVE applications, it allows citizens to build their own home in the world.

Digital City (Ishida and Isbister, 2000) is a research project to realize the next generation social infrastructure based upon a MUSVE system using a “real” city metaphor. By using Web browser, Digital city allows users to access information of the city via virtual world-based user interface, such as walking through the city and obtain the information of the building. Currently, four digital cities, those of American Online, Amsterdam, Helsinki, and Kyoto, are introduced. In digital city project in Japan, Sijo-gawara Street in Kyoto city was realized.

### 2.3. Personal Agents

Most research on autonomous agent and personal agent has been done outside of MUSVEs. Table 2.3 shows an overview of the systems described in this section with respect to the environments where the agent and personal agent work.

Table 2.3 Comparison of autonomous agent systems

SUVES		MUSVEs	
Using user’s context in SUVES	Using user’s context in the real world	Personal Agents	Public Agents
Steve (Rickel and Johnson, 1997)	C-MAP(Sumi et al., 1998)	Merlyn (Doyle and Hayes-Roth, 1997) (*1)	Julia (Mauldin, 1994) (*1)
Billinghurst and Savage (1996)	ALIVE (Maes et al., 1995)	DigitalCity(Isbister, 2000)(*2)	Nagao and Takeuchi (1994)
	Kadobayashi and Mase (1998)	PeopleSpace (Ochiai, 1997)	Helper Agent (Isbister et al., 2000)
		PAW^2	

\*1: in MUD, \*2: based upon Microsoft Agent (Microsoft Corporation, 1997)

<sup>1</sup> <http://www.activeworlds.com/>

These agents have functions to support or guide a user through a virtual environment based upon the user's context information in the environment (e.g. his/her location and interests). In single user virtual environments (SUVs), there are two types of approaches about usage of user's context information: the user's context in the virtual space and that in the real world. In MUSVs, there are two types of agent: personal agent and public agent.

Autonomous agent systems which work in SUVs are described below.

Rickel and Johnson (1997) developed VET (Virtual Environments for Training) by using a single-user 3DCG system. In this environment, pedagogical capabilities are incorporated into autonomous agents that can interact with users (trainees). Their pedagogical agent called Steve supports anthropomorphized 3D user interface. The agent can monitor user's context (trainees' progress) and interacts with the virtual environment itself (simulations of objects in the environment) and with users (trainees). The agent can utilize the user's context in the virtual environment and knowledge of the environment to support the user. They reported that, in case of pedagogical agents, interacting with agents in the virtual environment is more natural than using conventional text-based tutoring interfaces (Johnson et al., 1998). Several works about introducing similar types of the agent into 3D virtual environments have focused on tutorial application. For example, Billingham and Savage (1996) developed an agent that inhabits a 3D simulated nasal cavity and provides assistance in sinus surgery to medical students.

Kadobayashi and Mase (1998) and Sumi and others (1998) take different approach about user's context information in their systems. Kadobayashi and Mase examined the seamless guidance provided by a personal agent in virtual space based upon a user's interaction in the real world. They evaluated the personal agent in a virtual ancient village using the user's real-world context. They used two types of user interactions to decide what kind of guidance is suitable for the user: How long the user spent to see demonstrations and how often the user used on his/her portable computer to request the information related to the demonstrations. They reported that users would be willingly to accept guidance by a personal agent even if they do not need to. Sumi and others (1998) developed C-MAP (Context-aware Mobile Assistant Project) system to build a tour guidance system which provides information to visitors during exhibition tours based upon user's locations and individual interests. In the system, a personal guide agent with a life-like animated character on a mobile computer guides users. They reported that users had a feeling of intimacy with the character of their human-like guide agent but did not think it was helpful for improving the agent's reliability in C-MAP system.

The Artificial Life Interactive Video Environment (ALIVE) allows full-body interaction between people and a rich graphical world inhabited by autonomous agents (Maes, 1995; Maes et al., 1997). The user can move around in a space of

approximately 16 by 16 feet in front of a large screen. A video camera captures the image including the user and removes the background environment to retrieve the user's image and interaction. ALIVE system uses the information to project a synthesized picture to the screen, which consists of 3D virtual world inhabited by the autonomous agents and the captured image of the user. ALIVE is the very first virtual reality system where people can interact with the agent (virtual creatures) without being constrained by headsets. They reported that the design of interaction is more important than graphics in order to design an attractive and immersive environment.

Autonomous agent systems which work in MUSVEs are described below.

Doyle and Hayes-Roth (1997) developed Merlyn as an autonomous agent by using MUD, whose purpose is to be a guide and companion to children in their explorations of virtual worlds. In this system, the agent is intended to be a playmate, a teacher, and a friend to the exploring child. As MUD is text-based virtual world, their agent does not support visual user interface. The agent has ability to obtain basic information about objects, people, or locations in the virtual world to help child. In addition, Doyle and Hayes-Roth introduced "annotated environments" in the system. The environment itself can provide "annotation" (i.e. information about the virtual environment) to the agent. The agent can use the annotation to "endow" the child with environment-specific capabilities to guide his/her experimental learning. By keeping a record of places the child has already visited, the agent is capable of monitoring his/her interests and abilities, and tailoring the agent's personality and actions to him/her. However, no evaluation was done about Merlyn from user's point of view. Julia (Mauldin, 1994) is also an autonomous public agent in MUDs. Julia can connect to MUD and act like any other users. She can also answer questions about the layout of the MUD (and many other topics), pass notes, sing songs, and play games with the participants. Foner (1997) reported that Julia often elicited surprisingly intense emotional reactions in those who encounter her.

Isbister (2000) takes advantage of agent technology in research on digital city which is a project to realize real city such as Kyoto in a virtual environment. Digital city Kyoto (Ishida and Isbister, 2000) allows multiple users to visit Nijo Castle in Kyoto. They chat with each other with a guide of an agent (a kind of personal agent) in the virtual bus tour. This agent provides 2D user interface overlapped on the window displaying the Nijo Castle (3D virtual world). Therefore the agent is not shared among other users. It can provide context-sensitive information to the users in the tour. The agent is realized by using Microsoft Agent technology (Microsoft Corporation, 1997).

Research on agent technology supporting communication between people is reported by Nagao and Takeuchi (1994), and Isbister and others (2000). Nagao and Takeuchi developed a conversational agent with personification interface (i.e. face),

which has capability to hear the conversation done by people (who are in the real world) in front of the computer where the agent is executing. The agent can break into the conversation based upon what they talked with each other. They reported that the agent with personification interface is easy to get the attention of people talking in front of the agent and expand the bandwidth of the conversation. Isbister and others (2000) research seems to be the shared virtual space version of the research by Nagao and Takeuchi. Isbister and others (2000) introduced a public helper agent in 3D MUSVE (“FreeWalk”; Nakanishi et al., 1996) and conducted the evaluation experiment using 100 Japan and U.S. subjects about taking advantage of agent technology to support the cultural communication. Their agent can support communication between the subjects who have different cultural background. They reported that words of the agent affected not only the impression of the agent but also that of partner a subject spoken to. It also affected even the stereotype of national character for each country.

Also the network service using 3D world in MUSVE called “PeopleSpace” supported a personal pet (Ochiai, 1997). PeopleSpace is a VRML-based commercial chat service operated by People World Co., Ltd. They introduced a bird-shaped virtual pet in the service. However, their pet was provided as just an accessory and it did not function as a user interface like PAW^2’s personal agent. Also, no evaluation was done about the pet.

As described above, there are few research works about introducing a personal agent into social 3D MUSVEs to support users’ social activities. Although Doyle and Hayes-Roth’s approach is based upon text-based virtual world, our approach resembles their approach in terms of the following two viewpoints: taking advantage of the user’s context in the virtual environment to support user’s activities and providing an agent as a playmate, a teacher, and a friend to the exploring user.

Some features of PAW^2’s personal agent, such as feeding and growing up, are similar to the children’s computer game called “Tamagotchi”<sup>1</sup>. Tamagotchi is a portable egg-sized mobile device containing a virtual pet which requires feeding and attention from its owner. However, the most important difference between PAW^2’s personal agent and the Tamagotchi is that PAW^2’s personal agent can be shared and interacted by many users simultaneously in the PAW^2 world. Also users can interact with a personal agent even when the agent’s owner is not present in the world.

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<sup>1</sup> <http://tamagotch.channel.or.jp/> (in Japanese)

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## 2.4. Analysis of User Activities in a Virtual Environment

Many research on analysis of user activities in a virtual world were reported based upon text-based virtual world MUDs (or MOOs) and 2DCG-based Habitat (Section 2.2). Most of them have done based upon MUDs or MOOs, because they are easy to set up their server and clients and gather information on user activities in the virtual environments. Habitat's 2D user interface is also easy for researchers to investigate what are happening in the virtual world because they can see everything in the world in sight.

Research on analysis of user activities in MUDs or MOOs was reported by Schiano and White (1998), Cherny (1995), Muramatsu and Ackerman (1998), and Curtis (1996). Schiano and White (1998) analyzed user attributes and behaviors using questionnaires and access log data to MUD. According to the 558 questionnaires responses and statistical analysis using the log data, they reported that the main purpose for which users access MUD was social activities and 59% of total access time was spent for social interaction in MUD. Cherny (1995) investigated discourse structure and linguistic register<sup>1</sup> of conversations hold in two social MUDs (LambdaMOO and ElseMOO) from the viewpoint of linguistics. She reported about several characteristic discourse structures and the linguistics register in the MUD: unlike a face-to-face conversation in the real world, overlapping speech or interruptions is not observed in turn-taking of conversations in the MUD, its turn size is shorter than the average size for the face-to-face conversation, and one of the features of linguistics register is that conversations for behavior occurred in present tense. Muramatsu and Ackerman's (1998) analyzed the social structure and characteristic users in game-oriented MUD (combat MOO). They reported that tentative groups (or communities) whose members have a same goal (to kill monsters) were formed as a social structure within a single game session. In addition to the groups, "clans" (or communities) were formed independent of the sessions. So the MUD has a dual social structure over the virtual world. In terms of characteristic users, player killers were observed in the MUD. Curtis (1996) focused on the social phenomena in MUD. He reported that MUD users more attracted to more populated areas (he calls this phenomenon 'social gravity'), and one of the more impressive examples of MUD social activity is the virtual wedding.

Research on user activities in the Habitat system was reported by Morningstar and Farmer (1991) and Farmer (1994). Morningstar and Farmer (1991) is the initial report about the Habitat system describing lessons from their experience

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<sup>1</sup> A speech variety adapted to a special situation.

of operation of Habitat. They reported that the most important factors for forming a cyberspace itself are users' interaction taking place in a cyberspace and operation methods to allow users to establish their own goals. These were effective to form and enrich the cyberspace. Farmer (1994) analyzed social commitment for Habitat users to a virtual society and the characteristic social behaviors of users in Habitat. He reported that social commitment of Habitat users was gradually changed from passive users to active users. In terms of characteristic social behaviors, virtual wedding ceremony and social phenomena such as appending special characters describing user's attributes in the society to handle name are reported.

Meanwhile, research on user activities in 3D virtual world was reported by Bowers and others (1996), Inoue and others (2000), Craven and others (2000), Hirooka and Tsunematsu (1998), and Becker and Mark (1998). Bowers and others (1996) investigated about how avatar movement is used in a conversation in 3D virtual world. They reported that avatar movement was used to take a turn in the conversation. Inoue and others (2000) analyzed the organization process of communities and how communication media were used in a virtual world by analyzing the log data of the public trial using InterSpace system (Section 2.1). They showed that most users changed from non real-time communication media to real-time one depending on their familiarity. Craven and others (2000) described the operation methods of a virtual world to encourage users to visit the world and establish their communities. They analyzed the log data for user's access to a virtual world, user's movements, and the number of times about chatting occurred in the virtual world. From analysis of the access log, they reported that the hosted events appear to be important in encouraging users to return to the world. Hirooka and Tsunematsu (1998) analyzed the stability of users to a virtual world. They reported that a user who has more opportunities to chat with other users within two days after his/her first access to a virtual world has more tendencies to become a repeater (repeat visitor) to the service. Nakanishi and others (1998) investigated the effects which a 3D virtual space has on communication. They reported that 3D virtual environment equalizes the amount of utterance for each participant more than the other environments, i.e. face-to-face meeting and video conferencing systems. Becker and Mark (1998) conducted empirical research on social conventions in three virtual worlds, i.e. LambdaMOO, Onlive Travelers (DiPaola and Collins, 1999), and ActiveWorlds (Section 2.2). They found that a number of social conventions exist and that the nature of their expression was different depending on the media and functionality available in the environment.

Anti-social behaviors in a virtual world are reported by Dibbell (1994) and Becker and Mark (1998). Dibbell reported the first widely publicized rape in cyberspace occurred in LambdaMOO even if it is a text-based virtual world. Becker and Mark reported, in Onlive Travelers, that a female-type avatar was subjected to



harassing language by a male-type avatar, and the male avatar began to ram himself into the female avatar.

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## 2.5. E-commerce Systems

While research has been conducted in the area of e-commerce retail on the Internet, few published papers (Koike, 1997) discuss the role of e-commerce in MUSVEs inhabited by a large number of users. Therefore, in this section, we also describe related research on user interface design of retail Web sites, e-commerce agent and personal agent in a virtual space, and user purchase behavior about digital content.

In terms of e-commerce in 3D MUSVEs, a network service called “People Space” reported that they charged admission fees for the service but did not evaluate the result (Ochiai, 1997). As described in Section 2.2, Machiko is the early 3D virtual marketplace where users can purchase real goods (Koike, 1997) and J-chat (the successor of Habitat) is also provided as a commercial service. However, their evaluations from the viewpoint of e-commerce are not reported.

Mass and Herzberg (1999) proposed to use a 3D virtual space as a user interface for e-commerce. They developed a VR Commerce toolkit for designing, controlling, and navigating 3D VRML malls and stores. Some Web sites also use a 3D virtual world for supporting e-commerce retail. For example, Sony Music Entertainment Inc.<sup>1</sup> introduces a virtual 3D shop with a personal shopping agent for their on-line music retail business (Miyake et al., 2002). However, none of these Web sites deals with MUSVEs.

On the other hand, several researchers have examined the user interface design of retail Web sites based upon CBB (Customer Buying Behavior). Jarvenpaa and Todd (1997) surveyed user reactions to retail Web sites using a sample of 220 shoppers. They identified factors that affect the users’ behavior and suggested the methods to improve retail Web sites. They reported that physical effort in time saving, product preparedness for diverse needs of the users, and presentation of products and services are the most important factors in electronic shopping. Lohse and Spiller (1998) identified a number of retail Web site design features that influence online store traffic and sales. They used a regression model to predict store traffic and dollar sales as a function of interface design features such as number of links to stores, image size, number of products, and store navigation features. They also quantified the benefits of user interface features of retail Web sites. They suggested that improving the browsing and navigation capabilities of the stores and

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<sup>1</sup> <http://bit.sonymusic.co.jp/Special/SpaceStream/index.html>. (in Japanese)

especially the product lists will facilitate sales. In contract with that, they did not find an effort on improving the interface display.

To assess the behavior of repeat customers on retail Web sites, Lee and others (2000) evaluated e-commerce in terms of customer loyalty. They proposed a multi-phased model of the customer loyalty for Internet shopping. They reported that ‘trust’ and ‘transaction costs’ factors affect customer loyalty and suggested several ways of developing Internet stores to increase the customer loyalty. They concluded that if the customer feels a higher level of trust in the store, the customer would intend to revisit the site more repeatedly. Low transaction cost can increase the customer loyalty only for the low involvement products, but not for the high involvement products.

Several research projects have investigated the role of e-commerce agents that act as mediators and automate several of the most time-consuming tasks in the buying processes. Kasbah (Chavez and Maes, 1996) for example is one of the first online agent systems. It allows users to create agents to negotiate the buying and selling of goods according to specific parameters, such as desired or lowest possible price. They reported that the agent mediated negotiation has received attention in the field of e-commerce. Tete Tete is also a software agent that integrated product brokering, merchant brokering, and negotiation in e-commerce environment (Maes et al., 1999).

Purchase behaviors about purely digital content in the Internet is investigated in a report<sup>1</sup> based upon 655 questionnaire responses regarding the purchase of digital content (e.g. electric news flashes, news distribution, software, electronic mail distribution services or mail magazines). According to the report, 27.3% of the respondents had purchased digital content and spent an average of about 8,000 yen (about 80 US dollars) per year on such purchases. The report looks at some aspects of selling virtual goods discussed in this thesis. However, the target goods in the report differ from the ones in this thesis in that the former have meaning in the real world, while the latter are meaningful only in a virtual world.

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<sup>1</sup> <http://www.commerce.or.jp/minfo/enq/report11/dcon1.html> (in Japanese)