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The formation of virtual organizations by means of electronic institutions in a 3D e-Tourism environment

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ABSTRACT

In this article we showcase an agent-mediated B2C and B2B e-Marketplace. This e-Marketplace is part of the social and immersive 3D e-Tourism environment "Itchy Feet". We give an overview of the framework that forms the basis of the e-Marketplace and show how it is used to create B2C-, B2B- and Virtual Organizations that are visualized in a 3D Virtual World. This interface provides users with an intuitive and easy way to interact with humans and software agents by means of a 3D Virtual World. The business logic is realized by autonomous software agents offering services to customers. The e-Marketplace is regulated by Electronic Institutions to ensure that all participants adhere to the rules of the market. The article is concluded with a detailed discussion on bridging the gaps between Multi-Agent Systems and 3D Virtual Worlds and the preliminary results of a conducted usability study of "Itchy Feet".

1. Introduction

Electronic Marketplaces (EMs) are electronic platforms enabling buyers and sellers to conduct business. Various definitions of the term Electronic Marketplace exist of which two have been formulated by Grieger [13]. He defines an EM as an institutional medium that assigns different roles in a community, facilitates the exchange of information such as goods, services and payment and provides an infrastructure with protocols and processes to regulate the interaction in this community. The second definition describes an EM as a social community consisting of buyers and sellers which can be described by a certain condition that can be changed through market transactions according to the intentions of the participants. Possible conditions include the participants knowledge, intention, contracts or goods at a certain time. The most salient characteristic of an EM is that multiple buyers and sellers conduct business, whereas in other mediums only one seller and multiple buyers or one buyer and multiple sellers are present.

Wang et al. [32] did a comprehensive literature review of EM research and ascertained that most marketing and economic researchers studied decentralized electronic markets but paid less attention to central platforms. However, EMs are not only distinguished by their structure, but they can also be distinguished by the participating parties – whether both emerge from the consumer domain (C2C), the business domain (B2B) or different domains such as business to consumer (B2C) or government to business (G2B). Fisher and Craig [11] discovered that the lack of social interaction in online channels and the conflict between online and traditional channels are crucial issues that hinder the adoption of EMs. Furthermore, it is important to be aware of the fit between services that are provided by the EM and those actually needed by users [22]. Especially in the B2C domain it is important to bind customers to the platform by providing additional services.

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To address the lack of social interaction in online channels and to ensure trust and security within EMs our work concentrates on the development of an extensible framework supporting the creation of a regulated B2C and B2B e-Marketplace in a 3D Virtual World. The framework consists of a Multi-Agent System to define and regulate the marketplace, a 3D Virtual World as user interface and communication facilities to support community interaction. A simplified illustration of the e-Marketplace with two sample organizations is depicted in Fig. 1. The e-Marketplace comprises two different types of organizations (i) B2C organizations and (ii) B2B organizations. B2C organizations can be further classified into autonomous organizations that are independent of other organizations and those relying on the services of B2B organizations. A communication facility is provided by the framework which is used by organizations to exchange data and facilitates the formation of Virtual Organizations. The term "Virtual Organization" has been defined differently in the literature. Oliveira and Rocha [21] define a Virtual Organization as a cooperation of legally independent enterprises, institutions or individuals. This cooperation provides services on the basis of a common understanding of business and appears as a single corporation to externals. A comprehensive description of Virtual Organizations and their role in e-Commerce is given in Travica [30].

Within our e-Marketplace a Virtual Organization (VO) is a federation of autonomous organizations forming a single (virtual) organization that jointly conduct business and appear as single organization to all members of the marketplace as depicted in Fig. 1. A VO may contain an arbitrary number of B2C and B2B organizations and every organization can be a member of several VOs. All members of a Virtual Organization define the inputs they need and the outputs they generate, but only B2C organization may receive input data from customers of the e-Marketplace. Therefore, if a Virtual Organization wants to offer services or products to customers of the e-Marketplace, at least one B2C organization needs to be a member of that Virtual Organization. Otherwise, if a Virtual Organization only comprises B2B organizations, it can act as a supplier to other organizations of the e-Marketplace. We use the metaphor of a building to visualize an organization in the 3D Virtual World. Since customers only interact with B2C organizations, only these need to be visualized in the 3D Virtual World as depicted in Fig. 1. Consequently, if a Virtual Organization comprises B2B and B2C organizations, the B2C organizations are visualized in the 3D Virtual World and represent the Virtual Organization. In other words, the visualization of the B2C organizations resemble business office(s) of the Virtual Organization to provide their services and products to customers. Customers interact with software agents that implement the business processes of an organization.

On base of this framework we created "Itchy Feet", a 3D e-Tourism environment that supports the complex interaction patterns of providers and consumers in e-Tourism. Autonomous software agents are used to render the environment information rich and Electronic Institutions (EIs), a Multi-Agent System methodology, are used to regulate the actions of all participants, software agents as well as human users.

In this article the framework and the implementation of Itchy Feet are presented. The focus is laid on three major parts: (i) the framework and the e-Marketplace Itchy Feet, (ii) the interaction between users and software agents as part of the e-Marketplace, and (iii) the challenges of creating the framework that connects EIs with a 3D Virtual World. The remainder of this article is structured as follows. EIs and the framework are introduced in Section 2. The Itchy Feet environment and its key features are presented in Section 3. In Section 4 we discuss the restrictions and issues that arise when connecting EIs with a

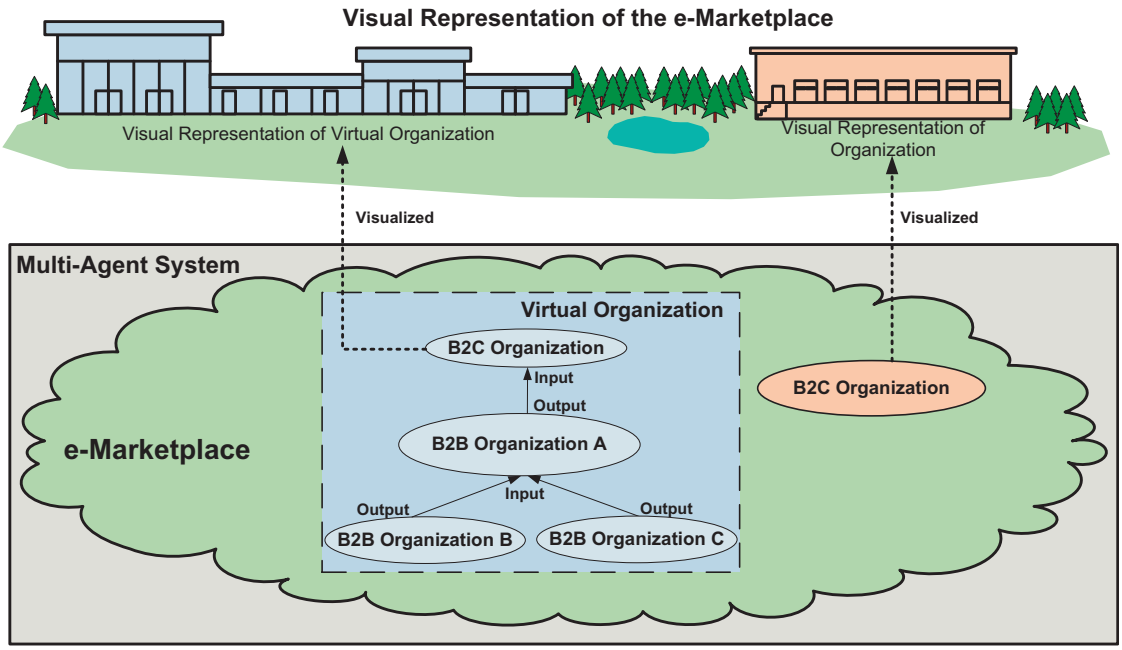

Fig. 1. Organizations in the e-Marketplace.

3D Virtual World and outline how they have been solved. In Section 5 we present the preliminary results of a conducted usability study of Itchy Feet. In Section 6 the related work is presented and in Section 7 the article is concluded.

2. Framework description

The framework, henceforth referred to as 3D Electronic Institution Framework, was developed to support the creation of an easy extensible e-Marketplace that can be extended with an arbitrary number of organizations. This framework offers the possibility to visualize any organization in the e-Marketplace. To realize the e-Marketplace and its organizations we use EIs, a Multi-Agent System methodology, and the Torque Game Engine[1] to visualize the organizations in a 3D Virtual World. Electronic Institutions resemble real-world institutions by using formal specifications to define interaction patterns between agents [9]. They establish regulated environments where all participating software agents have to act according to defined rules. Similar to Virtual Organizations, EIs require their members to obey the (business) rules and to use the (business) processes defined by the institution. We apply EIs to regulate the interactions between software agents implementing the business processes of an organization. The 3D Electronic Institution Framework enables the connection of EIs to a 3D Virtual World in order to allow human users to participate in the agent system and to facilitate the visualization of software agents in the 3D Virtual World [25]. In the following subsections we give an introduction to EIs, present our extension to support inter-Electronic Institution communication and describe our approach to connect EIs to the 3D Virtual World.

2.1. Electronic institutions

The building blocks of EIs are (i) the *Dialogical Framework*, (ii) the *Performative Structure*, and (iii) the *Norms* and behavioral rules. The *Dialogical Framework* defines the ontology and social structure within the EI. The ontology defines message and data structures that are used for communication within the institution. The social structure describes the possible roles that can be played by agents within the institution, the hierarchies and the relations among them. The *Performative Structure* comprises scenes and transitions. Every scene has a protocol that defines the possible interaction patterns among agents within that scene. Scenes are connected by transitions. Whenever an agent leaves a scene it needs to traverse a transition to get to the next scene. Transitions may impose restrictions on the movement of an agent by constraints. The Norms, i.e. the behavioral rules, establish role-based conventions that are used to verify if interacting agents behave according to the system's normative specification. They are expressed as pre- and post-conditions of the speech acts that are admissible in the *Performative Structure* of the EI. The EI methodology also defines a hierarchical structure for the organization of EIs. The top-level organizational construct is called Platform. Within the Platform construct multiple so-called Federations can be defined that aggregate multiple EIs to a conjoint construct with a local name space. Two EIs may share the same name if they belong to different Federations. Before an agent may enter an EI that is part of a Federation, it needs to enter the Federation. An agent is able to access any EI within a Federation. A detailed description of EIs is given in Esteva et al. [9].

2.1.1. Enabling the formation of virtual organizations

We leveraged the Federation construct of the Electronic Institution methodology to support the formation of Virtual Organizations in the e-Marketplace. Unfortunately, the Federation as well as the Platform construct do not offer a mechanism for inter-Electronic Institution communication. Inter-Electronic Institution communication in our work refers to the ability of software agents that reside in different EIs to exchange data with each other. In the original methodology it is not possible for two agents in different institutions to communicate with each other. However, the support of inter-Electronic Institution communication is crucial for the efficient realization of Virtual Organizations. In a Virtual Organization data needs to be exchanged continuously between the member organizations. Furthermore, it should be possible to define global functions that can be used by all members of the marketplace and regulate inter-Electronic Institution communication. Therefore, we enhanced the Federation construct by introducing the so-called `Ether`. The `Ether` is a dedicated EI offering inter-Electronic Institution communication functions as well as global functions such as a shopping cart, an inventory and a chat that are available to all user of the e-Marketplace. Since the `Ether` itself is an EI, it is possible to use all features specific to EIs for regulating inter-Electronic Institution communication. The `Ether` is not mapped to a building in the 3D Virtual World and its functions are accessible at every location in the 3D Virtual World.

2.2. Connecting electronic institutions with the 3D virtual world

In the framework two types of participants need to be considered: humans and agents. Agents are either autonomous or controlled by a human user. In the latter case, the couple human/agent is represented as an avatar in the 3D Virtual World. The user delegates tasks such as information gathering or product purchasing to the agent and learns from the agent which rules and restrictions apply in the environment. The user must act according to these rules. The movement and actions of the user in the 3D Virtual World are verified by the agent in the EI. Software agents must be visualized in the 3D Virtual World such that users are able to interact and learn from them.

[1] http://www.garagegames.com.

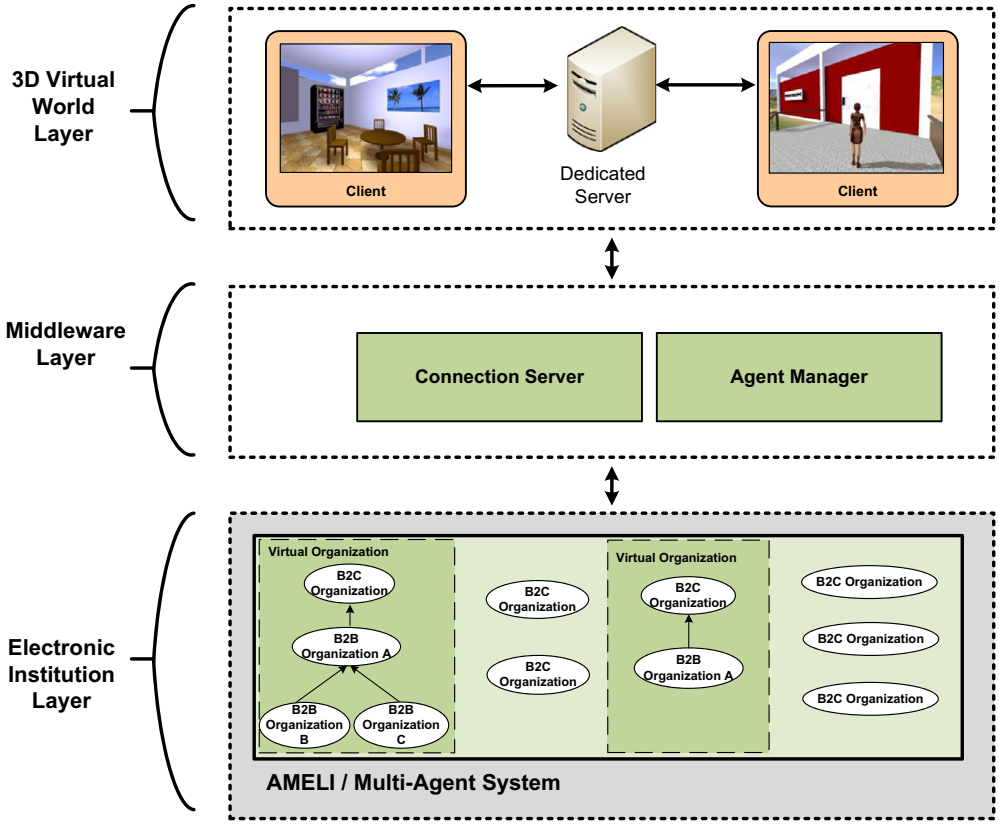

Fig. 2. The 3D Electronic Institution framework architecture.

The dependence between the two systems requires that the 3D Virtual World is causally connected to the EI. In our case this means that whenever the 3D Virtual World changes, the EI must change as well. Whenever the EI evolves, the 3D Virtual World has to be modified in order to maintain a consistent relationship. Conceptually speaking, the system is composed of three layers which are depicted in Fig. 2. The 3D Virtual World layer and the EI layer are causally connected by the middleware layer [4,25]. The EI layer contains Ameli, the EI runtime environment, which validates all actions forwarded by the middleware layer to check whether users act according to the rules of the corresponding EI. The middleware connects the 3D Virtual World with the Multi-Agent System. The users agents are managed by the Agent Manager component. Every user in the 3D Virtual World is the principal of an agent in the Agent Manager. Action requests from the user are sent to the middleware and forwarded to the user's agent. These agents act as external agents and communicate with the Ameli system. The Connection Server translates actions performed by users in the 3D Virtual World to actions understandable to the EI Layer and vice versa. Organizations are realized by EIs and the inter-Electronic Institution communication is facilitated via the `Ether` in the EI layer. Since users only interact with B2C organizations directly, only these are causally connected to the 3D Virtual World. Therefore, if a Virtual Organization needs to be visualized in the 3D Virtual World, at least one of its member organizations needs to be a B2C organization. The visual representation of this B2C organization then represents the entire Virtual Organization. For a detailed description of all layers we refer to Seidel and Berger [25].

3. Going three-dimensional in e-Business

EIs are useful for the creation of an agent-based e-Marketplace. They enable the participation of heterogeneous autonomous software agents and define a regulatory environment that governs their actions. However, the ability for human users to take part in EIs is rather limited. The Electronic Institution Development Environment (EIDE) contains a graphical tool which allows users to slip into the role of a software agent and participate in EIs. This tool requires a thorough understanding of EI concepts and is only valuable for developers, but not usable for end users. In order to overcome this limitation the 3D Virtual World is used as an alternative user interface for end users in our work. Furthermore, the 3D Virtual World is used to provide the functions of the e-Marketplace to the user. The fact that the user is participating in the Multi-Agent System is hidden by the framework and the user is only presented with those interface controls that are necessary to complete the user's goals. In the following subsections we will present the Itchy Feet marketplace which was created using the 3D Electronic Institution Framework described in Section 2.

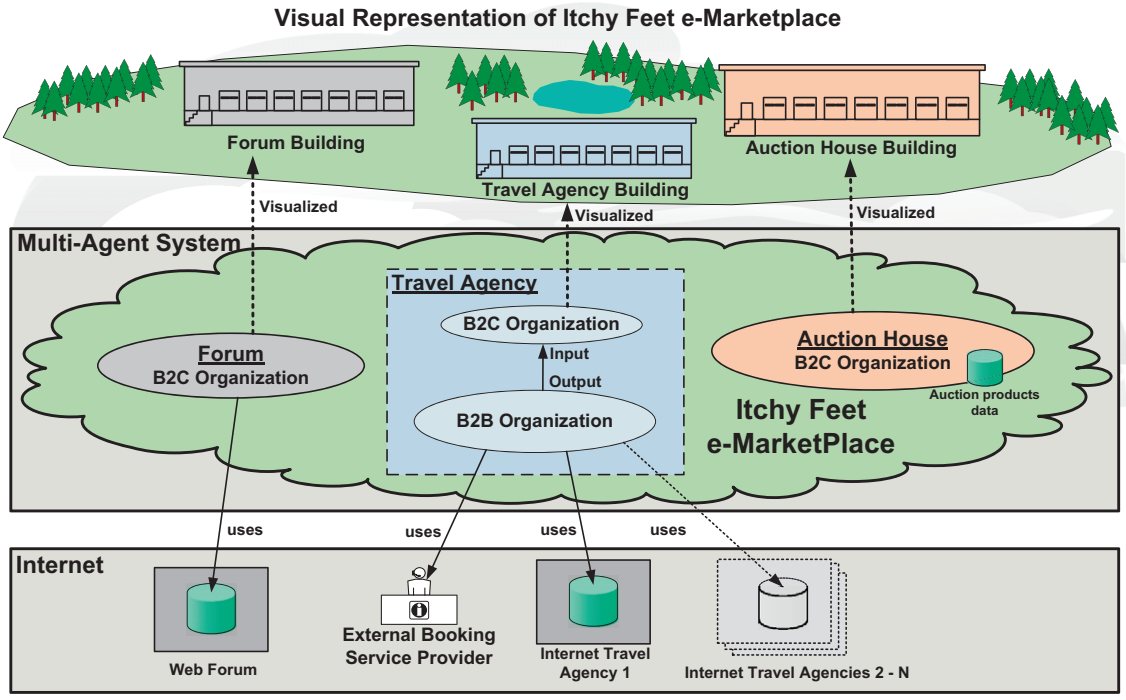

Fig. 3. Organizations of the Itchy Feet e-Marketplace.

3.1. The Itchy Feet marketplace

The Itchy Feet marketplace is dedicated to organizations in the e-Tourism domain. All organizations within the marketplace are realized as EIs and software agents implement their business processes. The marketplace comprises three organizations that differ in terms of services and products offered. In the Auction House users can participate in auctions to purchase flight or hotel products. In the Travel Agency fixed price products can be booked and users can get advice from professional travel agents. The Forum offers communication services and is the cornerstone for the creation of a lively community. It encourages users to stay in Itchy Feet and therefore indirectly attracts potential customers to the other two organizations in the marketplace. The Itchy Feet marketplace is depicted in Fig. 3. The Travel Agency is realized as Virtual Organization comprising a B2C organization that offers customer centric services and a B2B organization that provides product data and booking facilities to the B2C organization. The customer centric services offered by the Travel Agency are flight and hotel search facilities, the advice of professional travel agents and a payment functionality that automatically performs the settlement with the B2B organization that supplies the products. The member organizations of the Virtual Organization use the `Ether` to exchange data with each other. The B2B organization itself fetches, filters, aggregates and processes product data from various external sources such as Internet travel agencies and provides an interface to the B2C organization to perform searches on these sources. The B2B organization can be extended with additional external data sources via a well defined interface (depicted by the "uses" relations in Fig. 3). Furthermore, it is possible to connect additional B2B organizations with their own data fetching routines and workflows to the Travel Agency's Virtual Organization.

The Auction House is independent from any B2B organization and uses an internal data storage for auction products. The framework offers an administration tool to add new products to the internal data storage of an organization. The Auction House as well as the Forum have been realized via a single B2C organization. The Forum is connected to an Internet web forum and provides the knowledge of professional travel experts and tourists.

Users interact with software agents that are represented as avatars in the organizations buildings. The whole marketplace of Itchy Feet is modeled in the virtual environment, ranging from the product search to the product selection to the actual payment. This is an advantage over existing systems such as Second Life[2] where the user is required to switch to the web shop to buy a product. In our environment this system change is not necessary and the immersive experience is sustained. The virtual environment enables users to be aware of other users within the marketplace. This awareness brings a variety of advantages. Users are able to infer the attractiveness and pricing of a product by the amount of users that stroll through the supplier's organization. Similarly, the interest in an auction product can be assessed by the amount of users in the auction room. Furthermore,

[2] http://www.secondlife.com.

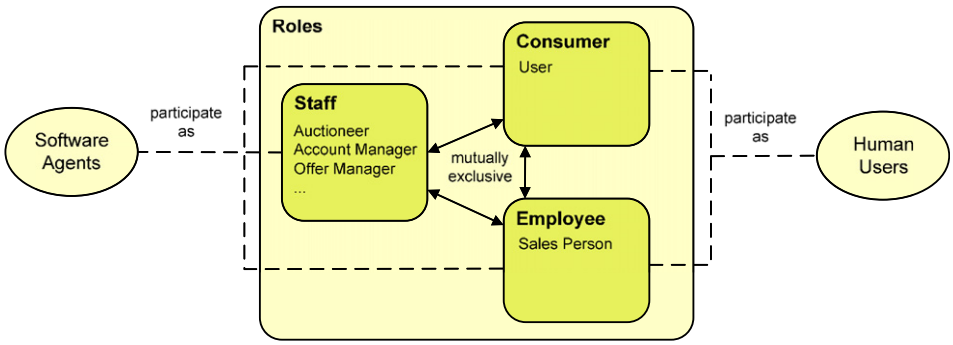

Fig. 4. Role policies in Itchy Feet.

users are able to directly interact with each other and can share information about bargains or interesting products in the marketplace.

The functionality, which is available in the buildings of the 3D Virtual World, is defined in the Multi-Agent System. Every building corresponds to exactly one B2C organization which is realized as EI in the Multi-Agent System. The Travel Agency building is the visualization of the `Travel Agency` EI, the Auction House building is the visualization of the `Auction House` EI and the Forum building is the visualization of the `Forum` EI. The scenes of an EI are visualized as rooms of a building and the transitions are visualized as doors. A user, impersonated as an avatar in the 3D Virtual World, may explore the world and has access to various functions depending on the avatar's current location in the 3D Virtual World. The user is the principal of an agent in the EI which maps the movement of the user to the entities in the EI. Whenever the user moves in the 3D Virtual World, the user's agent mimics the movement in the EI. For example, if a user moves from one room to another room in the Auction House, the user's agent will move to the corresponding scene in the `Auction House` EI.

3.1.1. Role policies in Itchy Feet

Access control in Itchy Feet is realized via roles. Every EI specifies a set of agent roles that define the access policy to this EI, to a certain scene or to a transition. For security reasons it needs to be ensured that agents playing in certain roles, such as the *User* role, may not have access to all scenes of an EI. The agent roles in Itchy Feet are divided into three groups: *Staff* roles, *Consumer* roles and *Employee* roles. These roles and their relationships are depicted in Fig. 4. *Staff* roles are solely played by autonomous agents whereas *Consumer* roles and *Employee* roles can be played by autonomous agents as well as user controlled agents. Agents playing in a *Staff* role provide services to *Consumer* agents.

The *Consumer* group contains one specific role at the moment, namely the *User* role. A user's controlled agent always plays in the *User* role. Note that the term *User* printed italic refers to the role in the EI that can be played by a software agent as well as a human user. In contrast the term "user" refers to an actual human user that is participating in Itchy Feet via the 3D Virtual World. The *Employee* group is extensible and every organization in the environment is able to define roles in this group. Agents and users who are playing in these roles act on behalf of the organization and provide services to *Consumers*. A detailed role description is available in Seidel et al. [26].

3.2. Auctions in the 3D virtual world

In this section the user interaction in the e-Marketplace is showcased by the example of the Auction House. The `Auction House` EI comprises five scenes: the offering scene, the information scene, the clearing scene and two auction scenes. The offering scene, led by the *Offer Manager*, is the control unit of the `Auction House`. The *Offer Manager* overlooks the commodity flows and ensures that every product is put on auction at the scheduled time. The *Auction Helper* is responsible for delivering products from the offering scene to the auction scene. *Users* inform themselves about available products in the information scene and pay for auctioned products in the clearing scene. Two types of agents, namely *User* and *Auctioneer*, participate in the auction scene. The interactions between these agents are defined by the scene protocol, which is implemented as a finite state machine. Those scenes that are accessible by *Users* are visualized as rooms in the Auction House building. Consequently, all but the offering scene, which is not accessible to *Users*, are visualized.

The auction scene is visualized as one room of the Auction House in the 3D Virtual World. As long as no auction is taking place users are able to enter and exit the auction room. During this time users may use the auction room to have a chat about the product in the upcoming auction and find out why other users are interested in it. When an auction is running no further users may enter the auction room and participants of the auction are not able to leave the room until the auction has ended. This behavior is enforced by the auction protocol where software agents are not allowed to enter or exit the scene in this state. When a user tries to enter or leave the auction room during an auction, an error message is displayed and the door does not open for the user. In case the user disconnects from the 3D Virtual World, the user's agent takes control over the auction process and remains in the auction scene until the end of the auction.

Fig. 5. The 3D Virtual World with the Auction House building and the auction room.

In the following we are observing the user Elaine who is participating in an auction via the 3D Virtual World. The auction room as well as the auction interface are shown on the right side of Fig. 5. The auction interface shows the item to be auctioned, the current status of the auction and contains an input box where the next bid is entered. The screenshot also shows three other actors which are participating in the auction. Two of them are autonomous software agents, while the third one is another human user who is logged in the 3D Virtual World as well. The autonomous software agents are visualized by the 3D Virtual World. The roles of these agents determine how and where they are visualized. The different locations and outfits of each agent role help the user to quickly identify the duties of each avatar and make it easier to differentiate the individual avatars.

When a user decides to participate in an auction, she enters the auction room before the start of the auction. As a consequence the user's agent enters the auction scene in the EI, enabling the user to engage in the auction protocol. The *Auctioneer* starts the auction at the given time following the auction protocol. The user may now bid using the auction interface. When a bid is submitted by the user, a request is sent to the user's agent, which sends out a bid message in the auction scene of the `Auction House` EI. The actions of each user and agent are visualized in the 3D Virtual World by gestures and other visual cues. The "going once", "going twice" and "sold" actions of the *Auctioneer* are visualized by a gesture where the *Auctioneer's* avatar is knocking on the podium with a small hammer. If a user is announced as the winner of the auction, the product is placed in the user's shopping cart. The product is then to be paid in the clearing room where the clearing scene is visualized.

4. Bridging the gap between EIs and virtual worlds

When causally connecting a Multi-Agent System with a 3D Virtual World a couple of restrictions, imposed either by the 3D Virtual World or the Multi-Agent System, need to be considered. In the following we propose our solutions and best practices to overcome the identified restrictions and discuss design considerations and decisions we made during the realization of Itchy Feet.

4.1. The structural design

EIs are a methodology to create and structure Multi-Agent Systems. Due to similarities between EIs and real-world institutions we map EIs to buildings in the 3D Virtual World. As a consequence, scenes of an EI are mapped onto rooms in order to ensure that any action performed by a user within a room can be validated by the EI. Therefore, as long as a user is in a building, his actions are validated by the EI. The problem is that the EI methodology does not provide mechanisms to regulate actions outside an EI. As a consequence the terrain outside a building in the 3D Virtual World cannot be regulated. Similarly no facility for inter-Electronic Institution communication is available. If an agent wants to communicate with an agent that resides in a different EI it needs to join that one as well. In case an agent needs to communicate with several agents spread across multiple EIs it has to join all of them. This results in multiple instances of the same agent which only act as communication endpoints. In order to support the construction of Virtual Organizations, inter-Electronic Institution communication is essential for the exchange of data between the member organizations of a Virtual Organization. In terms of the 3D Virtual

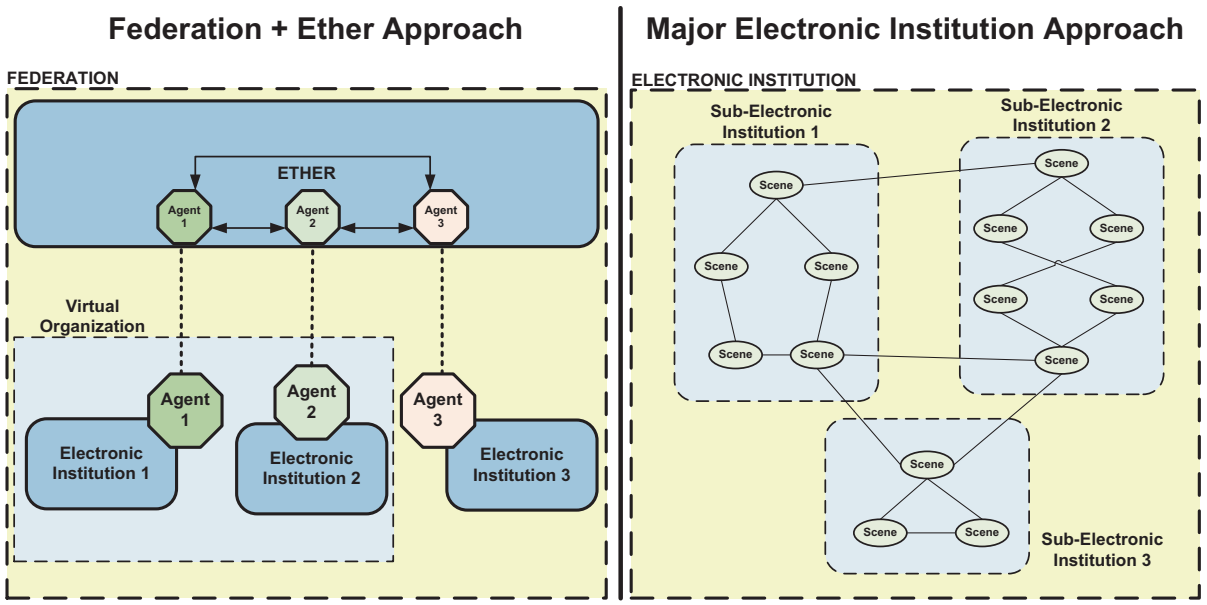

Fig. 6. Design approaches.

World the absence of global communication functions implies that users can only communicate with each other if they are in the same building. Furthermore, without the possibility to define global functions that are shared by all EIs, every EI has to implement functions that are vital for any successful e-Marketplace such as a shopping cart or an inventory separately.

To overcome the absence of a satisfactory inter-Electronic Institution communication facility, we considered two different approaches that are depicted in Fig. 6. First, the e-Marketplace could be realized via one major EI that is separated into logical units representing sub-EIs. This approach has the advantage that mechanisms specific to EIs such as controlled message exchange, role-based constraints and scene protocols can be used to model global functions. The major disadvantage of this approach is that the units (sub-EIs) are only logically separated and that no clear boundaries exist between them. Furthermore, since there is only one single specification of the entire e-Marketplace, it lacks extensibility.

The second approach is based on the Federation construct. A Federation is used to group EIs and defines a local name space for the creation of the e-Marketplace. This approach offers a high degree of extensibility as every EI and Federation has a separate specification. A new EI can be designed and developed independently from the Federation and existing EIs. The drawback of this solution is the impossibility to create global functions that can be shared by all members of the Federation such as a shopping cart, inventory or chat. Furthermore, the Federation does not provide any communication facilities to its members. To overcome these limitations we introduced an extension to the Federation concept named `Ether`. The `Ether` is an enhancement of the Federation construct and is an EI itself. It provides global functions that can be used by all EIs that are part of the Federation. Furthermore, we incorporated a communication functionality to facilitate inter-Electronic Institution communication which is vital for the support of Virtual Organizations in the e-Marketplace. All agents of any EI may communicate with all other agents in the e-Marketplace by using the `Ether`. We realized this by creating two instances of an agent: a global one that automatically joins the `Ether` and a local one which joins a specific EI. The global instance is shown as small octagon and the local instance as big octagon in Fig. 6. These two instances appear as one agent. The local instance is used to participate in the agent's native EI, the global instance resides in the `Ether` and is used to exchange data with agents of other EIs.

4.2. Multiple agent instances

In EIs, similar to other Multi-Agent System methodologies, agents may split into multiple instances and participate in multiple EIs simultaneously. This behavior must be reflected in the 3D Virtual World to maintain a consistent state. Imagine an autonomous software agent that participates in multiple EIs. In order to visualize this agent in the 3D Virtual World multiple avatars are needed since every instance of the agent has its own behavior. For example, the *Account Manger* in Itchy Feet participates in the Auction House and in the Travel Agency EI. Since users interact separately with both instances two avatars are needed in the 3D Virtual World for the visualization. Human controlled agents in Itchy Feet are realized as software agents as well. Technically these agents could also split into multiple instances, but this raises several issues. Whenever an user's agent would split into a new instance, a new avatar would need to be created. Since a human user is not able to control avatars in parallel, the user would have to decide which avatar he wants to control. This places an additional burden on the user and makes it more complicated to use the environment. Furthermore, the 3D Virtual World would soon be

crowded with inactive avatars and it remains unclear what happens if a user tries to interact with an inactive avatar of another user. Finally, the merging of multiple avatars into one avatar is another point of confusion for the user and further reduces the usability. Due to these drawbacks we decided to prohibit human controlled agents from splitting into multiple instances.

4.3. Advanced room mappings

The more complex an EI is, the more difficult it is to perform straight forward mappings from scenes to rooms and from transitions to doors. In some cases it makes sense to map multiple scenes to one room for usability reasons. This raises the problem that even though the agent's avatar moves into just one room, the actual agent in the EI has to move through multiple scenes. To overcome this problem we incorporated a functionality to divide a room of a 3D EI into distinct areas. If a user's avatar moves from one area to another, the agent moves into the scene that corresponds to that area. By using this functionality, it was possible to map the information scene and the clearing scene to the same room in the Travel Agency building. If an user's avatar approaches the ticket counter, representing a distinct area in the information room, the agent moves from the information scene to the clearing scene. Furthermore, we extended the functionality to map single actions performed in the 3D Virtual World to multiple actions in the EI.

4.4. Transition constraint validation

Another problem we faced was the fact that Ameli provides no information about the validity of transitions during runtime. Transitions are used to move from a scene to a subsequent scene in an EI and are mapped onto doors. The Performative Structure of an EI defines which transitions can be used to move from one scene to another and which constraints must be satisfied to be allowed to move along the transition. Constraints are expressions that have to be evaluated during runtime. Only if a constraint is met, an agent may pass through the transition. Ameli offers a function to retrieve the outgoing transitions from a scene, but this returns all transitions that have been defined in the specification without taking the runtime constraints into account. A constraint is evaluated by Ameli only at runtime when an agent actually moves through the transition. Imagine an user who approaches a door in the 3D EI with his avatar. The user's agent issues a call to Ameli to get all valid outgoing transition. One of them is the transition that is mapped onto the door the user is currently approaching. Since Ameli does not evaluate the constraints of the transitions it might return a transition as valid even though its constraint is violated at the moment. As a result the avatar in the 3D Virtual World is able to move through the door, but the agent in the EI gets stuck in the transition because the constraint is violated. As a result the agent can neither move forward nor backward and has to wait until the target scene becomes accessible. This leads to an inconsistent state between the 3D Virtual World and the EI.

Therefore the validation of constraints needs to be done before the agent actually tries to move through them. To overcome this shortage we introduced a pre-validation logic with so-called "Back-Transitions". Before an avatar can move through a door in the 3D EI, the agent first enters the corresponding transition in the EI. Only if the agent is allowed to pass through the transition, the door will open and the avatar can move through the door. If the user then decides not to walk through the door, the agent uses the "Back-Transition" to get back into the origin scene. In case the agent cannot pass through the transition, the "Back-Transition" is used by the agent to get back to the origin scene and the door will not open for the avatar. An illegal move of the user is also resolved by these "Back-Transitions". If a user slips through a door that has been opened by another user, the agent automatically enters the transition. If the agent is not allowed to move on, it uses the "Back-Transition" to get back to the origin scene. As a consequence, the avatar is teleported back to its origin position in the 3D Virtual World and an error message is shown to the user.

5. Usability

The easy participation of end users within an agent system was one of the goals in the Itchy Feet project. Considerable effort has therefore been put in the development of clear and concise user interfaces that are accessible to different types of user groups. For the development of the user interfaces we employed several well known usability heuristics, guidelines and best practices. These included the 10 usability heuristics of Nielsen [19] and the recommendations of the ISO 9241 standard part 110 on dialog practices [14]. The design and development of the 3D Virtual World and 3D interaction features was based on guidelines and methodologies that have been established in the Virtual Reality domain. The development and evaluation followed an iterative approach that had been proposed by Gabbard et al. [12]. Furthermore, we employed additional guidelines for the design and evaluation [16,28].

The Itchy Feet user interface is constructed similarly to other 3D Virtual Worlds where the different functions are accessible via buttons on the Head-up-display (HUD). This is illustrated in Fig. 5 which shows a screenshot of the 3D Virtual World as seen through the eyes of a user. In contrast to other virtual environments, the Itchy Feet HUD is distinguished by "static" and "dynamic" buttons. Static buttons are those that are shown at all times and which functions are accessible anywhere in the 3D Virtual World. In contrast, dynamic buttons appear dynamically depending on the functional context in which the user is currently in. When the user is standing on the outside only those functions are accessible that have been defined

in the `Ether` EI. Whenever the user enters a building or a room, the current functional context is evaluated and new buttons appear while existing buttons disappear on the HUD. For example, when the user enters the Travel Agency building, a new "Hotel Search" button appears. If the user then moves on and enters the payment area, the "Hotel Search" button disappears and two new buttons, namely the "Return Products" button and the "Pay Products" button appear. This approach mimics metaphors that people are used to from the real-world. For example, in a department store different services are available in different areas of the store. The separation of function by location also helps to keep the HUD clean. The user is not distracted or lost in a cluttered interface where all functions are accessible at once.

5.1. Usability evaluation

The usability and acceptance of the environment has been evaluated in June 2009 in a usability study. A total of 20 participants were recruited and participated in an one hour evaluation of Itchy Feet. An evaluation session started with a pre-interview in which users were asked about their experience with 3D Virtual Worlds and their travel behavior. Then they had to complete a user scenario in the 3D Virtual World which consisted of 18 different tasks. The scenario was based on an analysis of the most important user tasks with the goal to create a realistic real-world usage scenario of the system. In the scenario the user first has to do some research and find out her travel plans in the Forum. She learns that she is traveling with a fellow traveler and that she has to book two hotel rooms. Before she can do that she needs to collect credit card information in the 3D Virtual World by talking to other users and exploring the environment. A conversation with an employee in the Travel Agency then helps her to choose the best hotels. The first hotel room has to be purchased directly in the Travel Agency while the second hotel room has to be purchased in the Auction House. In the Auction House the user participates in an auction together with software agents following the auction protocol as defined in the EI specification. After the user has won the auction, the hotel room is to be paid with the credit card information and the scenario ends. The completion time of the scenario ranged from 15 to 30 min with an average completion time of 24.5 min. After the successful completion of the scenario the post-interview was conducted. Users were asked about their experiences, problems and opinions regarding Itchy Feet. The results of the usability study including a detailed description of the evaluation procedure will be published in a future article. However, a summarization of the most important results is presented in the following.

The results indicate that the goal of creating a clear and concise interface have been achieved. The test users could easily complete those tasks that involved interactions with the user interface. Furthermore, most people explicitly stated that they liked the user interface and had no problems using it. The ability to control the avatar in the 3D Virtual World was another interesting topic for observation. In general the test users did not have problems with the control of the avatar, could easily navigate around in the world and move the avatar from one location to another. This might partly be attributed to the fact that the majority already had prior experiences with 3D computer games or the like. However, we also observed that people who were not familiar with the control mechanisms and had major troubles in the first few minutes of the evaluation, did get accustomed to the controls quickly and were able to move around in the environment without any difficulty by the end of the evaluation.

The next interesting insight was the users opinion on the functional separation by area. We initially had concerns that people would reject this metaphor in a virtual world and rather prefer to have all functions available in one location. However, out of the 20 test subjects about three quarters did like this idea in the evaluation scenario. Even after further inquiries whether this would still be true in a real setting, they confirmed that they liked this approach and mentioned that the user interface might be too overloaded otherwise. The other quarter of the test users had a different opinion and would prefer to have all the functionality in one place. Their major point of criticism was the time it takes to go from one building to another. This disadvantage could be circumvented by letting the user jump from the exit of one building to the entry of another building. Such functionality could be implemented in a future version and would further contribute to the usability of Itchy Feet.

6. Related work

Alt et al. did a review of 31 consumer product e-Marketplaces [1]. They discovered that most of these marketplaces only provide electronic catalogs, simple auction mechanisms and functions for the exchange of goods. Just a few of the marketplaces provided content beyond the commercial process and encouraged the development of a community. Karacapilidis and Moraïtis developed an agent-based artificial market system and introduced *artificial employees* [15]. Such *artificial employees* perform tasks that have been delegated to them by users. These agents are not instantiated for a specific task, but reside in the artificial market system and execute a series of tasks which have been delegated to them. This is similar to our approach where every user is the principal of a software agent that can either be controlled by the user or perform delegated tasks autonomously.

Zeng and Zhang proposed an integrated approach for developing e-Commerce systems by using intelligent agents, multi-attribute decisions, web technology and a common ontology [33]. Intelligent agents either act as buyers or sellers and carry out tasks such as finding appropriate business partners and performing automated negotiation according to different negotiation strategies. Buyer and seller agents are itself composed of multiple agents such as interface agents, buyer manager agents, evaluation agents and mobile agents. They all work together to achieve the overall goal. To facilitate the data exchange between seller and buyer agent of different partners, a common ontology is defined. The agents use a multi-attribute

decision method to decide which product fits the needs of the buyer best. Pao-Hua et al. proposed an approach to use an intelligent agent for an e-Commerce bargaining system [23]. They use a Multi-Agent Framework to create bidding agents that assist the user in selling or buying items and browsing the product catalog on the e-Marketplace platform. Every agent contains components such as a mailbox, a message handler, an execution monitor, a co-ordination engine, a planner and scheduler and an ontology database. The agent uses the mailbox and the message handler to communicate with other agents in the environment. The execution monitor, co-ordination engine as well as the planner and scheduler are used to coordinate the internal tasks according to the priority determined by the agent's current goal. The ontology database stores the logical definitions of each fact, i.e. the vocabulary used and its legal attributes, the range of the legal values and any constraints and relations between them. Argente et al. did a survey of organization-oriented Multi-Agent System methodologies [3]. The authors state that it would be interesting to have human organizational designs, such as virtual organizations, matrix organizations, teams, hierarchy and bureaucracy taken into account in organization-oriented Multi-Agent System methodologies. Furthermore, the authors conclude that the similarities between the topological structures of human organizations and agent systems should be used for the analysis and design of Multi-Agent Systems. Cardoso and Oliveira developed a normative framework based on EIs for contract validation and enforcement in Virtual Enterprises [7]. These contracts are the result of the agreement of agents to jointly perform a specific business activity. The authors leveraged EIs to regulate interactions between parties engaged in business transactions and to maintain trust among participating parties. Ünal proposed an approach for dynamic information sharing between multiple business partners by forming supply/value/business chains amongst them [31]. These are used to share sales forecasts, manage inventories, schedule labor, optimize on-time deliveries and reduce total lead times. The proposed Triada knowledge networks extract and share information within the supply/value/business chains. In traditional supply chains information is shared efficiently within the organization but only with great costs and complexity outside the organization. The proposed system seeks to efficiently connect multiple distributed business partners securely via the Internet by using an XML protocol to distribute information and build inter-organizational supply/value/business chains.

3D Virtual Worlds have been used in research for the past 10 years and several researchers have worked on the more specific topic of combining Multi-Agent Systems and 3D Virtual Worlds. Smith et al. present an approach where the agent logic is incorporated in a 3D environment [27]. According to the authors most worlds are largely static and objects are used to trigger pre-programmed behavior. Agents are supposed to enrich the world and should make the environment more dynamic. The proposed framework consists of a society of agents in which each agent controls a 3D object. The Unreal Tournament Semi-Automated Force (UTSAF) project takes advantage of GameBots [17]. In this framework an agent system is used as the mediator between a military simulation and a 3D Virtual World. Agents monitor the status of the military simulation, filter relevant information and visualize entities of the simulation in a 3D Virtual World. Traum and Rickel [29] studied dialog models between humans and software agents in 3D Virtual Worlds. They concentrated on issues such as proximity and attentional focus of others, the interplay between speech and nonverbal signals and the ability to maintain multi-part conversations. A similar approach to seamlessly integrate agents and humans in a cohesive Multi-Agent System was introduced by Martin et al. [18]. In their work they describe a software prototype of a distributed collaboration and interaction system enabling humans to act as an integrated part of a Multi-Agent System. They introduced so-called liaison agents which support human interaction with other non-human agents by arbitrating between them. Payne et al. analyzed human–agent interaction and stated that agents can have different models of user interaction [24]. In their work they describe a case study of a Multi-Agent System containing different agents with similar functional capabilities, but different types of user interaction modalities. They argue that according to the type of user interaction a significant effect on the performance of the whole agent community can be ascertained. Bromuri et al. developed a virtual e-Retailing environment in GOLEM (Generalized Onto-Logical Environments of MAS) [6]. GOLEM is an agent environment that shares similarities with EIs. Instead of EIs to regulate agents behavior, GOLEM uses so-called containers which provide support for agents, objects, processes and environmental services inside a declarative context that constraints the interaction of all contained entities according to a set of declarative rules. Multiple containers may be connected to a single construct similar to the Federation construct of the EI methodology. The virtual e-Retailing environment uses a semantic registry which can be used by agents to query for entities of interest. The user is represented as an avatar within GOLEM and can interact with other entities via triggers and emitters. Products and services of the e-Retailing environment are browsed via the semantic registry. All agents store product preference profiles reflecting user searches and purchases that aid to provide suggestions of interest to users. In contrast, in Itchy Feet we use dedicated Sales Agents that provide advice and suggestions to users based on to their profile and past queries.

Aranda et al. created a MMOG (Massively Multiplayer Online Game) architecture based on a Multi-Agent System [2]. The architecture comprises three layers: the Human Computer Interaction layer, the Intelligent Virtual Environment layer and the MMOG layer. The game mechanics are modeled in the MMOG layer and EIs are used to run the game. In contrast to our framework, their architecture does not have a dedicated communication layer which causally connects the 3D Virtual World and the Multi-Agent System. The communication facility is included in one of the other layers. Furthermore, the authors introduce a common ontology based on the Web Ontology Language that is used to exchange semantic content among agents and which should aid in the standardization of these kind of systems. Debenham and Simoff have introduced the term "Virtual Institution" [8]. They define a Virtual Institution as a virtual place where agents and humans can trade securely by interacting naturally via a 3D Virtual World. According to the authors EIs and 3D Virtual Worlds complement each other by facilitating a high level of interaction but still retaining a certain level of regulation. A prototype of such a Virtual Institution has been realized by Bogdanovych et al. [5]. In contrast to our framework, that supports connecting multiple EIs

to form complex Virtual Organization which can be represented as single building in the 3D Virtual World, Virtual Institutions associate every building in the 3D Virtual World with exactly one EI. Fasli and Michalakopoulos developed the e-Game platform which can be used as a test-bed for trading agents [10]. Their main intent was to provide a platform where developers are able to run experiments with different bidding strategies. The platform offers an Java Application Programming Interface (API) for developers to create their own agent implementations. O'Grady et al. created a context-sensitive mobile tourist guide application named Gulliver's Genie by leveraging embedded intentional agents [20]. These agents have different tasks and interact to provide the tourist with information about different attractions in her vicinity. The spacial agent, residing on the mobile device, is responsible for tracking the tourist's position and current direction. The cache agent is needed because of the limited memory available on mobile devices and maintains relevant data to the tourists current position. The agents on the mobile device interact with the agents on the server, which collaborate to anticipate forthcoming requests and ensure that the cache of the cache agent always holds information that is relevant to the tourist's current position.

7. Conclusion

In this work we have utilized 3D Virtual Worlds as a new type of user interface for agent-based e-Marketplaces. The focus was placed on the creation of an easy to use interface enabling end users to participate in a Multi-Agent System and to interact with software agents. We showcased how organizations, realized as EIs, can be connected to form Virtual Organizations that are visualized as 3D EIs on the basis of the Travel Agency in Itchy Feet. To this end, a framework has been developed for the connection of EIs with 3D Virtual Worlds and a prototypical e-Tourism environment has been implemented. The marketplace in this environment is realized by means of auctions and fixed price product trade. The business processes are hereby implemented by software agents which are regulated by EIs. In particular, we have illustrated how auctions are conducted, how the user is able to participate in a natural way and how the connection between the user and the EI works. We emphasized the need for a construct that regulates the behavior of users when they are not inside a 3D EI. We introduced the Ether as an extension to the Federation construct, in order to facilitate inter-Electronic Institution communication and to create global functions that can be used by all member of the e-Marketplace. Furthermore we discussed the problems when having multiple instances of user controlled agents and showed how we resolved these problems. We presented our approach to maintain a consistent state between agents and their visual representation by introducing mappings between the 3D Virtual World and the Multi-Agent System. We concluded our work with the preliminary results of a conducted usability study.

In future work we intend to leverage 3D visualization for the presentation of products within the virtual environment. This opens new possibilities for providers to present their products and consumers are able to get more insights than with text and picture only presentations. Furthermore, a hybrid semantic search system for tourism related information is developed and will be integrated into the environment.

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