DESIGNING VIRTUAL WORLDS FOR 3D ELECTRONIC INSTITUTIONS

A distributed and heterogeneous multi-agent system

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Abstract. 3D Electronic Institutions (3DEI) are 3D virtual worlds that are dynamically designed in response to the users’ needs and the rules of an electronic institution. Electronic institutions can be modelled as multi-agent systems inspired by analogous physical institutions. This paper describes coupling of a multi-user 3D virtual world to an electronic institution. The resulting 3DEI is a distributed and heterogeneous multi-agent system that provides the advantages of both with the organizational structures imposed by the electronic institutions and the spatial characteristics provided by 3D virtual worlds.

1. Introduction

Contemporary living is inseparable from digital information and the web. As a result, our holistic living environments have been gradually expanding to include internet environments. Complementing the physical world, these networked environments become unique online places where we work, learn, shop, get social and be entertained. Current designs of internet environments are largely influenced by and with metaphorical references to architecture, web design or computer programming. They are often handcrafted because we lack formal design methods. Our research develops and demonstrates a multi-agent system that provides a model for designing 3D
virtual worlds that are inhabited by people and interact with electronic institutions.

Electronic institutions can be modelled as multi-agent systems inspired by analogous physical institutions (Esteva et al. 2004). This paper describes coupling of a multi-user 3D virtual world to an electronic institution. The resulting 3DEI is a distributed and heterogeneous system that provides the advantages of both with the organizational structures imposed by the electronic institutions and the spatial characteristics provided by 3D virtual worlds. A 3DEI is a 3D virtual world that is dynamically designed in response to the users’ needs and the rules of the electronic institution. After describing a model of a 3DEI, we describe a prototype implementation.

2. The 3D Electronic Institution

Virtual worlds are networked environments designed using the metaphor of architecture to support various activities online. This architecture metaphor provides a consistent and familiar base for designing the worlds and for virtual world occupants (commonly called citizens) to interact with the designed environments and with each other. Such multi-user virtual worlds are useful when it is prohibitive time-wise (such as for online meetings or remote surgery) or it is otherwise undesirable to travel (such as to avoid the hassle international air travel has become). With a virtual world we can access remote information, services and social interaction from where we are. They allow for anonymous interaction with others, for non-anonymous interaction with those that we would not otherwise meet, and can encourage design and interdisciplinary team collaboration (Rosenman et al, 2006). They let us experience or practice behaviours that would be hazardous or impossible, for whatever reason, in our world. A virtual world allows us to do things that we cannot do in the real world: fly, teleport, build and walk through building designs, explore non-3D-Euclidean worlds (imagine a virtualisation of Ian Stewart’s “Flatterland”) and so on.

Electronic institutions (Esteva 2003) are multi-agent systems inspired by analogous physical institutions like banks, travel agents, government organisations and academic institutes. We are interested here in facilitating behaviours of citizens that extend beyond the virtual world; in particular, to electronic institutions. Consider an example scenario: a virtual travel application. Some of the possible behaviours of virtual world citizens include:

- Chatting with others, for which a virtual world is ideal but for which an electronic institution is largely irrelevant
- Visiting virtual places like a virtual Lord Howe Island, for which a virtual world is ideal but for which an electronic institution is irrelevant
• Asking for information on trips, for which a virtual world is ideal and for which an electronic institution may or may not be useful depending on what information is to be supplied
• Purchasing flights, accommodation and goods, for which an electronic institution is suited and for which virtual world can be used but so can other web technologies.

The question is how to couple a multi-user 3D virtual world to an electronic institution. How do we facilitate a dynamic, interactive virtual world experience and at the same time keep citizens, resources and agents safe? There are 2 philosophies. The first is to prohibit everything not explicitly allowed: require that every agent ask a governor for permission to activate each action. An example of this would be a central bureaucracy called The Governor that controls citizen behaviour. If a citizen wants to buy bread they put in a request for bread purchasing rights to The Governor and if approved the citizen takes that approval along to a citizen or agent that has the corresponding bread sales approval. The second philosophy is to allow everything not explicitly prohibited: let agents and citizens activate actions autonomously but restrict them when they try to do specified prohibited things.

Consider an example scenario: a visit to an old fashioned bank that is in a physical building to withdraw money. The bank protects itself by having trained tellers that are able to access its resources (money, etc) and follow the bank’s rules. So a 3DEI that facilitates these same behaviours would need to somehow follow these rules. But only a part of the behaviour is explicitly in these rules. The structure of the bank building is equally important: barriers to encourage queuing, desk partitions that force the customer to use tellers to get to money, and so on. There are also behaviours of tellers and customers that are not and should not be in the rules, like walking into the building and straight back out again. The rules are just a protocol, not agent behaviours. When using an electronic bank, the protocols for the messages to and from the system that maintains the bank state (a database) enforce the rules. Other behaviours in the world need not be constrained.

We believe that a virtual world should be as open and unrestrictive as possible. It certainly shouldn’t be more restrictive than the real world. So we tend towards the second philosophy, but how is this to be done? We place resources to be safeguarded under the protection of agents, and each agent provides services for possible use by others. Agents act autonomously and should only be stopped when their actions break a protocol rule. These rules can be designed using a protocol editor like Islander (Esteva 2003), or designed manually as is desired. The protocols could be used for agent
learning, for a virtual world design grammar (see Section 3), or via a protocol server like AMELI (Esteva 2004).

So we want dynamic worlds that provide services to citizens related both to virtual and non-virtual worlds. A service is a request in an agent communication language (ACL) to an agent; the agent may be an avatar or other virtual world object we have assigned agency to, or may be a non-virtual world agent. There are three approaches to relationships between agents and services (Martin et al. 2004):

1. Agents use services: there are web services or otherwise servers in a client/server fashion, and agents make use of those services.
2. Services are agents: the only way to do anything is to send a request to an agent to do it for you.
3. Dynamic hybrid.

An example of approach 3 is semantic web descriptions of web services like WSDL, UDDI and SOAP, together with an agent factory to compose new agents as required by new service requests (Richards et al. 2004). In virtual world terms this extends naturally into launching sets of design grammar rules (Gu and Maher 2005) to change a world according to new requirements, but put as service requests that could also contain non-3D-design requirements.

In the prototype described below the design requirements derive partly from the formal description of an electronic institution. These formal descriptions provide a partial design specification for the design agents. Design considerations such as visual and spatial layout of objects and spaces, design constraints, and design styles are represented in the design grammars.

Not every agent is in a virtual world, and not every object in a virtual world has agency. In the Bank example, the carpet isn't an agent but there would be some agent from which we could request cleaning. The result is a heterogeneous system of virtual and non-virtual worlds, agents and services.

Not all users need to connect to an electronic institution via the virtual world. An authorised user should be able to write an external agent or website that interacts with our virtual world or electronic institution. An example is using JADE1 with an AMELI protocol server, meaning that authorised users could launch their own JADE agents to interact with both AMELI and the virtual world. Using an open agent framework such as this would also

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1 JADE is a Java implementation of the FIPA agent specifications that can be used as the communication layer for AMELI (Esteva 2004). The FIPA (fipa.org) is an IEEE standards organization that promotes and develops standards for inter-operable multi-agent systems.
provide a means for changing design grammars at runtime by representing designers by JADE agents.

Figure 1 shows an example institution agent that creates room agents. These agents communicate with the electronic institution to ensure that the users comply with the organizational structures and the institutional rules. The design agent society starts with design requirements from the electronic institution. The example in Figure 1 constitutes an institution agent and various room agents. These two different kinds of design agents taken together will dynamically design, modify and remove the 3D virtual world or a portion of the world as needed for the electronic institution.

The institution agent in this example is the “mega” agent that is responsible for the 3D virtual world designs for the electronic institution and the creation of room agents. Initially, the institution agent applies its design grammar to generate a 3D virtual world design based on the design specifications of the electronic institution. The design will comprise a series of rooms. Each room has a specific purpose supporting certain intended online activities in the electronic institution. A room agent provides a kind of intelligent agency to a particular room in the designed 3D virtual world. Each room is therefore unique and maintains its own history of reasoning and changes. Once the 3DEI is established, a room agent will monitor the activities and changes in a room and make necessary changes to the room as needed, during the online session.
Design knowledge is represented as design grammars. Design grammars have been applied for describing and generating 3D virtual world designs. Design grammars for 3D virtual worlds are inspired by the notion of shape grammars (Stiny and Gips, 1972). The way that shape grammars function lies in the unique view of designs. A design generated by a shape grammar is viewed as “elements in relations” (Stiny, 1999). To apply a grammar for design generation is basically to change (add, subtract or replace) the “elements” and define or alter the “relations” among the “elements” via shape rule applications. In this manner, grammars can generate rather complex designs based on simple design elements. This view of designs is accordant with the object-oriented nature of virtual worlds. A virtual world design can be viewed as “objects in relations”.

Most virtual worlds are object-oriented systems. They are among the examples designed using various commercial platforms, such as Active Worlds\(^2\), Blaxxun Platform\(^3\) and Virtools\(^4\). An object-oriented virtual world is constructed through the placement and configuration of objects. Each object can have an appearance of a 3D model in a virtual world, and together these models provide the visualisation of the environment. The objects then can be configured or programmed to have certain behaviours that allow the occupants to interact with the world and with each other. Therefore, a virtual world design basically comprises various objects in terms of the following two aspects (Gu and Maher, 2003).

- Visually/spatially, via the use of architectural metaphors, the 3D models are composed to form an ambient environment which virtual world occupants can inhabit and where the intended activities can take place online.
- Functionally, selected objects are ascribed with behaviours to support the intended activities online. Therefore, interactions become possible.

Similar to the way shape grammars formalise designs in general, in designing virtual worlds design grammars describe various virtual world objects and their properties, define the relations among them, and generate virtual world designs based on these elements. This compositional characteristic of design generation makes design grammars an appropriate design formalism for virtual worlds.

The stylistic characterizations of the generated designs have also been defined in terms of visualization, navigation and interaction (Gu and Maher, 2005). A design grammar \(G\) comprises design rules \(R\), an initial design \(D_i\),

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\(^2\) http://www.activeworlds.com
\(^3\) http://www.blaxxun.com
\(^4\) http://www.virtools.com
and a final state of the design Dr: G = {R, D, Dr}. The basic components of a design grammar are design rules R. The general structure of a design grammar for 3DEI comprises four sets of design rules (Figure 2). These are layout rules Ra, object placement rules Rb, navigation rules Rc, and interaction rules Rd: R = {Ra, Rb, Rc, Rd}. Following the structure of the generative design grammar framework, virtual world design styles can be considered in terms of visualisation (layout of places and visual forms of virtual objects), navigation methods and interactions. They are three inseparable parts for providing an integral experience of 3D virtual worlds. This general structure of a design grammar is determined by the four design phases of virtual worlds.

- To layout virtual rooms for the 3DEI: each room is represented by a room agent and has a specific purpose supporting certain intended online activities in the institution.
- To configure the virtual room: each room is then configured with certain objects, which provide visual boundaries of the room and visual cues for supporting the intended online activities.
- To specify navigation methods: navigation in 3D virtual worlds can be facilitated to consider the use of way finding aids and hyperlinks, for assisting the users’ movements from one room to another.
- To provide interactions: in general this is a process of ascribing behaviours to selected objects in each room, so that the users can interact with the 3DEI and with each other.

![Figure 2. Structure of a Design Grammar for 3D Virtual Worlds (Gu and Maher, 2005)](image)

The basic components of a generative design grammar are design rules. The general structure of our design rules is a replacement rule, LHS → RHS, which specifies that when a left-hand-side pattern (LHS) is found in the design, it will be replaced by a right-hand-side pattern (RHS). The
replacement of patterns is applied under a set of operations or spatial transformations. The patterns are labelled (the use of spatial labels and state labels) for controlling the rule applications. In our grammar, a design rule is defined as “LHO + sL → RHO” which specifies that when a left-hand-side object (LHO) is found in the virtual world, and the state labels sL are matched, the LHO will be replaced by a right-hand-side object (RHO). The term “object” used here can refer to virtual world object(s) including the 3D model(s) and/or object behaviour(s). The general structure of design rules implies that:

- State labels are singled out and expressed explicitly as sL in the structure. The use of state labels is essential to the application of generative design grammars as they direct the application to ensure that the generated design satisfies the institution agent’s current design goals. Each design rule is associated with certain state labels representing specific design contexts that can relate to the institution agent’s design goals. In order for a design rule to be fired, virtual world object(s) need to be found in the virtual world that match the LHO of the design rule, and the design contexts represented by the sL of the design rule need to be related to the institution agent’s current design goals.

- The basic components of design rules are virtual world objects. They are not entirely visual/spatial and contain functional and behavioural information. For the interaction rules and parts of the navigation rules, the replacement of LHO with RHO is applied under a set of general transformations.

3. Prototyping

The ideas described above have been prototyped, trialling the various parts of 3DEI as described without building an entire system. The prototype scenario is the “World Trotter” travel agency application to demonstrate the use of the 3DEI model and the design grammar. This demonstration provides the basis for evaluating the advantages, disadvantages, and limitations of the implementation platform, and the 3DEI on that platform. The platform chosen was Second Life5, a popular 3D virtual world supported by the typical client-server connection, which is most common to current virtual world platforms.

The institution is specified using Islander as the protocol illustrated in Figure 3. The “World Trotter” travel agency has the following “scenes”: reception, booking room, hotel room, auction room, and shop. Based on

5 http://www.secondlife.com
these scenes, the set of roles that users can play in each scene are determined. In this context a role defines a pattern of behaviour establishing the list of actions that the users are allow to perform. The “World Trotter” contains the following roles: customer, travel agent, auctioneer, receptionist and shop assistant.

The word “scene” comes from Islander. The electronic institution regulates “multiple, distinct, concurrent, interrelated, dialogic activities, each one involving different groups of agents playing different roles” (Esteva et al. 2004) through interaction protocols. Each interaction protocol is a directed graph whose nodes represent states of a dialogic interaction and arcs represent illocutions. Each protocol that connects any two scenes is unique. As shown in Figure 3, they are illustrated with specific symbols and annotated with different labels to distinguish from each other. While the word “scene” in common usage implies that entities that are serial and non-concurrent: a movie contains one scene, then another scene, and so on; there is nothing inherent in the interaction protocols that prevent an agent from engaging in multiple scenes concurrently (Esteva 2006), and the “allow everything not explicitly prohibited” principle means not unnecessarily constraining virtual world behaviours. For example, a student can sit in a lecture (scene A) while concurrently engaging in an online auction (scene B).

![Figure 3. Performative Structure of the “World Trotter” Institution](image)

These protocols are used to generate the design representations of the specified institution in the 3D virtual world. The institution agent applies its design grammars and transforms the design specification from the previous step into a 3D design in Second Life. In the prototype the “scenes” defined in the specifications become 3D rooms and arcs in the protocol graph(s) (in Figure 3) are transformed into doors between those rooms. Such design
automation is achieved by adopting a computational approach using design
grammars. Remember the “allow everything not explicitly prohibited”
philosophy, though. One scene maps onto one room in the grammar for this
prototype, but this is not necessarily the case. It is not necessary for virtual
world rooms to be used at all providing some other appropriate metaphor
replaces it. The design rules are selectively applied to generate suitable 3D
designs for the institution as needed. This process provides a linkage that
translates the “specification language” of the institution into the “design
language” of 3D virtual worlds.

The prototype designer is implemented in Java and Jess\(^6\). The 3D virtual
world platform selected for demonstration purpose is Second Life. Protocols
in XML are parsed, firing Jess rules that implement the design grammar. The
generated designs are stored in a design database whose format can be
flexibly adapted to suit different 3D virtual world platforms for
implementation. The database holds an assembly of 3D virtual world
objects, each of which has a name and a set of object properties like
primitive object shape, 3D location, 3D rotation and 3D extent. In a post-
prototype implementation this may not be the case. The vision is of a
distributed system of agents on an open, multi-agent platform such as is
provided by JADE. In such a case the design agents would communicate at
runtime with AMELI serving the protocols, and would communicate directly
with virtual world agents like the institution agent of Figure 1.

The four sets of design rules: layout rules, object placement rules,
navigation rules and interaction rules are written in Jess. According to Maher
and Gu (2002), the design space in a 3D virtual world, that is, the space of
alternatives from which components are selected and aggregated can have
two major categories of elements:

- 3D models of virtual world objects to be part of the world.
- Behaviours of these objects that provide simple and aggregate
  behaviours of the world. In Second Life, object behaviours are
  realised using Linden Script Language\(^7\) known as LSL. This
  scripting language follows the familiar syntax of C/Java.

These two categories of elements are represented as “facts” in Jess which
can be use to describe and generate designs of 3DEI. The LHO and RHO of
each design rule are made up of these Jess facts.

Figure 4 shows one of the generated designs. Our approach has a number
of advantages. Changes to the specification or the runtime environment (the
virtual world state, the electronic institution state or the state of an agents)
can be addressed dynamically as needed through the grammar application by

\(^6\) A forward chaining Rete engine written in Java.

\(^7\) [http://www.lslwiki.com](http://www.lslwiki.com)
alternating the choices and order of the design rules during the application. Changes to the virtual world platform used will only require a re-mapping between the designed elements and basic primitives of the virtual world, without undergoing any major system changes.

![Figure 4. A “World Trotter” Travel Agency Design in Second Life](image)

The institution agent activates actions through its various effectors so as to realize the design. Second Life is a proprietary platform that allows scripts to run on virtual world objects, but with constraints. Second Life has a centralised server farm and simpler clients. This necessitated running our agents outside of the world and communicating with the representations in the virtual world. But communication into and out of Second Life is restricted. XML remote procedure calls (XML-RPC) are implemented by the Second Life builders with prevention of denial of service attacks in mind. The result for project such as ours, however, has been the need for a pull-based architecture with polling to get information out of Second Life (Macindoe 2006). This is very slow. The Second Life implementation of HTTP requests has similarly been restricted.

4. Discussion

Electronic institutions are determined by three kinds of conventions (Bogdanovych et al. 2005):

- The communication language and ontology for agents to use.
- The kinds of activities that agents can participate in.
- The behaviours that agents are allowed.

While electronic institutions may do a good job of enforcing restrictions on agent activities and behaviours, they do not easily facilitate their use by human users. The use of 3D virtual worlds draws a close analogy between the virtual environments and the physical world, which enable people to better orientate and interact in the electronic institutions by applying knowledge and experiences that they have learnt and adopted from the physical organisations. Hence 3D electronic institutions are a method for
enabling electronic institution activities by human users from within user-friendly virtual worlds.

From our experience in implementing the 3DEI, we have found that the realisation of a feasible 3DEI is limited by a number of factors. Firstly, current virtual worlds have limits on in-world agent computation and communication with external processes. Secondly, the agent models of electronic institutions are influenced and constrained by known examples of physical institutions.

The distributed, multi-agent nature of the system being described clearly makes agent communication essential. The deliberate constraints on communication between out of world agents with in world objects in Second Life hampers the current performance of the prototype, but these performance constraints are of Second Life not of 3DEIs in general. Our long term view is of a massively multi-agent system that still works successively as a multi-user virtual world. Understandably, the main concern of most 3D virtual world designers is the realistic rendering of the 3D world across networks of large numbers of users.

Some entities in a virtual world need non-static behaviours. Some Second Life objects will be scripted but most will not, and of those that are scripted only a few require agency. We can imagine an entirely agent-oriented virtual world, but would that be desirable? Probably not given what is required to realistically render a 3D world across a large, distributed community of users in real time. Wouldn't it be nice, though, if we could have all of the benefits of a multi-user world like Second Life but without the limits on computation and external communication. With such a platform, avatars and scripted objects without computation limits could communicate with external agents via a standardised and open agent platform like JADE. Adequate performance of a 3DEI requires a virtual world platform like Second Life that is also powerful enough for non-trivial agents to run inside its world and that has good external communications. Additionally, an effective 3DEI requires an agent standard such as the JADE implementation of the FIPA standard, with a directory service on agents such that agents can be added dynamically at runtime. Ultimately, we look forward to a virtual world that will allow plug-and-play agents into virtual and non-virtual agent societies.

The notion of dynamically designing and redesigning a virtual world according to institutional requirements is something we believe has promise. The development of dynamic designs of 3D virtual worlds would be particularly useful for large-scale 3DEIs with users who would be engaged in a wide variety of online activities. Further development of the prototype may lead to a generic system for customers to realise their 3DEIs that are ready for use, according to different specifications. The approach could be extended to personalising 3DEIs by dynamically designing and modifying
them according to the needs of individuals. In other words, for each person in the institution, only those portions of the 3D virtual world relevant to their current activities would be designed and generated.

Further research into 3DEIs should further articulate the roles of agents such as the institution agent and the room agents, as well as consider the use of other design agents to enrich the current agent hierarchy. For this prototype we selected a particular metaphor: institutional architecture. This metaphor influenced the choice of institution and room agents but the model of a 3DEI does not assume this metaphor. Of particular interest are metaphors that do not unnecessarily require serial, non-concurrent access to protocol “scenes”. The example grammar developed in this research was likewise influenced by the particular architecture metaphor chosen for the prototype. More examples of design grammars need to be developed to look at their usability in other 3DEIs, and a design grammar developed to automate or partly automate the process of grammar design and implementation.

5. Conclusion

The contribution of this paper to CAAD lies in a model of 3DEIs as 3D virtual worlds that are dynamically designed in response to the users’ needs and the rules of the electronic institution. The formal description of an electronic institution provides a partial design specification for the design agents. Design considerations such as visual and spatial layout of objects and spaces, design constraints and styles are represented as design grammars. The dynamic design of 3D electronic institutions is an effective approach to designing and generating virtual environments as needed for supporting human activities online. This approach also provides solutions for practical issues such as instancing in large-scale multi-user networked environments.

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