5-10-2006

Artificial Societies, Virtual Worlds, and Their Meaningful Integration

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A departmental senior thesis submitted to the Department of Computer Science at Trinity University in partial fulfillment of the requirements for graduation with departmental honors.

April 19, 2006

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Abstract

Artificial societies and virtual worlds are two areas of interest to modern social scientists that are distinctly separate in modern academic study, and are yet undeniably related. Artificial societies are multi-agent systems comprised of autonomous social agents, programmed with their own set of rules and behavior. While virtual worlds are occupied in large part by human controlled agents participating in a collective virtual experience and space. Within both types of virtual environments there can be found a scarcity of resources and intricate cross-entity interaction. This often results in the development and evolution of complex economic and cultural structures. In addition, by examining the modern research and common history shared by each field, it is possible to compile a set of shared attributes. This work attempts to capitalize on these shared features and promote a new type of integrated analysis that holds potential for future development in both fields. The concrete implementation of these ideas takes form as a simple economic model containing meaningful computer and human interaction as well as a framework designed for future extensibility.

ACKNOWLEDGMENTS

I want to thank my advisor, Dr. Mark Lewis, for not only assisting with the direction of this project, but for being as enthusiastic about it as I was. I also want to thank Keller O'Hara for his assistance and patience, and every single one of my friends who helped along the way, either by offering feedback or just listening.

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1. Introduction

1.1. Background

Artificial societies and virtual worlds are two areas of study that are separate but undeniably related. Artificial societies are comprised of autonomous social agents; agents who have individual attributes and behaviors, and interact within a set of rules. These agents exist as part of a social experiment; often one in which the experimenters attempt to replicate “real world” social structures and bonds in an attempt to discover the rules that govern our own social interactions. Virtual worlds on the other hand are digital spaces occupied in large part by human controlled agents, known as avatars, participating in a collective virtual space. Within these virtual spaces there is often great deal of socializing along with a scarcity of resources, which leads to the development and evolution of complex economic and cultural structures.

Not only do these fields have individual merit for academic study, but by examining the major research done in each field it is possible to compile a set of shared attributes. This paper discusses the foundations necessary for an integration of the two fields of study. It will begin by covering the concepts needed to accomplish this goal and by pointing out the key work already done, then conclude with the construction of a simple economic model and a discussion of the immediate steps for future development. Specifically, the work detailed within consists of the construction of a modular and extensible economic society featuring both computer and human controlled agents. Therefore, the social behavior and results will be represented in a way that is both understandable and meaningful, while at the same time in accordance with the previous work done in the both fields.

1.2. Virtual Worlds

Virtual worlds are characterized by expansive digitally rendered spaces. They are occupied by hundreds, if not thousands, of "avatars"; digital agents whose actions are human controlled from a remote location. These avatars engage in actions such as harvesting, creating, and trading goods or possibly just spending time hunting virtual monsters. Modern popular virtual worlds include Norrath as represented in the online game *Everquest* or Azeroth as represented by the online game *World of Warcraft*. In these worlds players spend most of their time hunting monsters, by themselves or with friends. However that is not the only option for those who seek a digital realm in which to spend their time. *Second Life*, developed by Linden Labs, is a space in which the primary non-social activities include avatar and landscape construction.

Gaming and play is only a small facet of the growing culture of virtual spaces. The modern virtual worlds, such as those listed above, grew out of the text based MUDs(Multi-User Dungeons) of the early 80's. In his book, *Designing Virtual Worlds*, Dr. Richard Bartle outlines what he considers to be most important features of virtual worlds; these features include: underlying rules (or *physics*), user representation, real time interaction, a shared world, and world persistence. Dr. Bartle is also the co-creator of what is heralded as the first true virtual world – "MUD1" (Bartle, 2004, p. 3-4).

These virtual worlds have not only evolved from text based to graphical but they have also begun to depart from existing as spaces to play to social meeting places. For instance, *Second Life* offers the ability to purchase real estate and the option to exchange "real world" currency for virtual currency. Each of these worlds has very real culture and economic systems. In fact, the business success of these worlds has been reliant upon keeping these diverse elements balanced. In addition, virtual social networking tools such as Facebook or MySpace are growing in popularity at exorbitant rates, creating virtual social structures that are entirely based around networking with peers online. They do, however, lack many of the attributes which are considered vital to be a virtual world, and so will not be given further consideration in this work.

1.3. Artificial Societies

There are several types of socially demonstrated problems that are important to consider when developing an artificial society simulation. The first to consider is the use of social computing in order to solve problems found in the social sciences. Examples include the impact of economic theories, how cultures are transmitted and developed, and the uses of trade routes to build social bonds. Secondly, social computing has been used in order to solve traditional computer science programs such as high node traveling salesman problems. In addition, there is a growing field demanding realistic and human interpretable behavior; for example, the multi-agent simulation "boids" consists of agents which act in tandem in order to give the illusion of a flock of birds (http://www.red3d.com/cwr/boids/, April 17, 2006).

Dr. Joshua Epstein and Dr. Robert Axtell are among the leading thinkers and developers of artificial societies. In their book, *Growing Artificial Societies*, they express that, "We apply *agent-based* computer modeling techniques to the study of human social phenomena, including trade, migration, group formation, combat, interaction with an environment, transmission of culture, propagation of disease, and population dynamics" (Epstein & Axtell, 1996, p. 2). This way of thinking will be covered in much greater detail in the section covering their work on the artificial society Sugarscape.

1.4. Why Integrate?

Individually, the study of artificial societies and virtual worlds has worth, some of which is outlined above. However, they each have flaws. Virtual world studies are at the mercy of the virtual world in question and its inhabitants, and artificial societies are constrained by artificial rules. These flaws are acceptable in many cases, but there exists the possibility of more. It is possible to combine a virtual world and artificial society in such a way as to have human controlled avatars and computer controlled agents interacting through a common medium. By coexisting, rules conceptualized through the study of artificial societies could be validated by adding human nature and behavior. Alternatively, by comparing two societies, one made up of agents and the other comprised of avatars, there would be the possibility of demonstrating meaningful differences between the behaviors of each. Given a modular design there is always the possibility of new emergent behavior to occur that causes of yet unseen results. In short, there is much to be learned by designing a model for common action and interaction between avatars and agents. As Dr. Timothy Burke of the Swarthmore College Department of History has to say, "the concept of 'emergence' and associated ideas about autonomous agents, complex adaptive systems, artificial life and complexity theory are important underpinnings in two discrete academic projects, work on ‘artificial societies’ on one hand and the study of ‘virtual worlds’ on the other”(Burke, 2005).

The goal of a successful cross-simulation would be to design and implement a multi-agent system that is capable of modeling human societal behavior in such a way as to be meaningful to a human as well as fundamentally useful as a building block towards experimentation on relevant social structures. This simulation would need to represent connections between agents that were recognizably human and have an interface designed for use as a means of propelling an avatar in the virtual space. Another important step would be to standardize the fundamental building blocks needed for such an endeavor and attempt to create a working set of vocabulary that could be used towards further development in this area. In order to accomplish these tasks it is vital that one first understand the development of these two disparate fields. The previous work in these areas has been varied, but often specific. Many ideas must be adopted, each from different sources, in order to finally arrive at a working framework for developing meaningful integrated social structures.

2. Research

2.1. The Academic Interest of Virtual Worlds

Ethnographic study, the practice of studying a complex society by living amongst its people was previously only found in the domain of Anthropologies. However, recently the ethnographic study of virtual worlds has begun to gain momentum, with work being done on subjects ranging from economics to politics. Nicholas Yee, currently a Ph. D. at Stanford University, had this to write about the importance of virtual worlds to social science as a whole, "the structure and design of these environments make them good candidates for a host of alternative uses for social scientists. For example, traditional personality assessment techniques are typically transparent and reactive. Because actions in massively multi-user online environments can be tracked unobtrusively by the server, every users' attitudes and personalities may be tracked using behavioral measures. And because users are personally invested in their avatars and the environment, every decision they make is personally revealing"(Yee, 2004, p. 25).

Unfortunately, as of yet no virtual worlds have been created that cater purely to academic interests, so it is therefore necessary to rely on commercial virtual worlds; often designed as games or spaces in which to play. If further convincing is needed to understand why these worlds have value to the social scientist, Dr. Edward Castronova of the Department of Economics at Cal State Fullerton has this to say about his experience with virtual worlds, "economists believe that it is the practical actions of people, and not abstract arguments, that determine the social value of things. One does not study the labor market because work is holy and ethical; one does it because the conditions of work mean a great deal to a large number of ordinary people. By the same reasoning, economists and other social scientists will become more interested in Norrath and similar virtual worlds as they realize that such places have begun to mean a great deal to large numbers of ordinary people" (Castronova, 2001, p. 2). As time passes and modern virtual worlds become more accessible and mainstream, the value of these virtual social spaces is growing and as a result they are becoming increasingly accepted as areas worthy of academic interest.

2.2. The History of Emergent Behavior and Agent-Based Modeling

Emergent behavior is the emergence of a complex pattern from simple rules. Emergence is not only a fundamental principle of both virtual worlds and artificial societies, but it is the area in which there has been a great deal of work done as a way to explain cultural, economic, and competitive systems. In short, it is essential to understand the background behind emergent behavior in order to build upon it. According to James Kennedy and Russell C. Eberhart in the introduction to their book, *Swarm Intelligence*(2001), the line between "real life" and "virtual life" is becoming continually blurred. The varying studies and discussions related to emergent behavior, from cellular automata to memetics, each serves as an example of an artificial rule set that exhibits life-like properties.

The history of modern cognitive sciences is important; not only because it provides the stage for where the work today is being done, but because it gives some insight into where widely accepted beliefs about social behavior originated. Kennedy and Eberhart provide a clear and concise version of this history, which is as follows. Kurt Lewin, one of the forefathers of social-psychology, developed the idea of “life space”; the idea that all social space could be mapped out by “facts”. These facts represented specific “areas” which could be moved through, although not in a physical sense; rather, this movement represents a change in the social being of a person. Related to this was the idea of conformity and social influence. The social studies done in this area were pioneered (albeit independently) by Musafe Sherif and Solomon Asch. These studies showed two very important things. First of all, Sherif’s study showed that people will tend to come to a middle of the road censuses about an ambiguous topic if attempting to do so collectively. Ache’s results were even more fascinating, showing that one third of a sample population would choose an answer that was obviously wrong if they believed that it was the answer that was believed to be correct by the others in the vicinity (Kennedy & Eberhart, 2001).

Research stalled in the 50’s. According to Kennedy and Eberhart, it has since picked up; with new theories and applications being developed into present day. Robert Axelrod’s seminal work in the area of the *prisoner’s dilemma* was one of the first examples of how computer simulation could be used by social psychology. The basic premise is that there are two prisoners, each with two options. They can either choose to defect or to cooperate. If they both defect, their payoff is low; however, if they both cooperate, then the payoff is high. Alternatively, if one defects and one cooperates, then the payoff is very high for the one who defects and very low for the one who cooperates. When executed only once the game holds no particular significance, and the best option is clearly to defect. When executed over multiple iterations, then it becomes interesting, and two different types of strategies begin to develop. First of all, there is the “nice” strategy; one in which cooperation ensures payoff for all players. Then there are several “mean” strategies; such as a pure-defect strategy, or one in which one of the prisoners uses cooperation to order lull the other player into a false sense of security and then defects for a higher gain. Following the publication of his work on the prisoner’s dilemma, Axelrod held a computerized competition, asking for submissions of strategies that people believed would win a series of iterated competitions. The winner of the competition, titled “TIT-FOR-TAT” employed a strategy which would match the opponent’s moves, either by cooperating or defecting depending on what was employed against it. Axelrod pointed out that although this one won, there were several other strategies that would actually have done better (these were: “TIT-FOR-TWO-TATS”, which would wait to see change in behavior over several occasions before switching, and “LOOK AHEAD”, a strategy used for chess that would have anticipated moves ahead of time, but wasn’t submitted for this competition). Due to the fact that these results matched closely with what social psychologists already held to be true, the results were accepted by mainstream social psychology (Kennedy & Eberhart, 2001).

This work was only the beginning; Axelrod’s work served to show how iterative gain and loss is played between two people, but there were greater social problems than that to tackle. Kennedy and Eberhart continue on to discuss a second problem; this one proposed by the economist Brian Arthur. In this problem, titled “The El Farol Problem”, Arthur proposes that there are 100 Irishmen all of whom want to visit the very popular Thursday night at the local bar, El Farol. These Irishmen all want to go as often as possible; however, they will only be happy if there are fewer than 60 other Irishmen at the bar. Otherwise they believe it is overcrowded and not at all an enjoyable experience for them. They have the past history of the bar attendance at their disposal and their job is to figure out which nights to go. There are a variety of strategies they could use, such as basing it on last week's attendance, using the inverse of that number, averaging the last month's attendance, predicting by trend, or any number of others. The problem is that they all can't be using the same method for decision making or there will constantly be unhappy Irishmen. In order to examine the behavior of these fictional Irishmen, Arthur ran a computer experiment. This simulation allowed the "Irishmen" to choose their strategy and change it at will. He found that the strategies and attendance fluctuated wildly; yet over time it settled around an average of 60 or so Irishmen in attendance. As a follow-up, Bruce Edmonds (of the Centre for Policy Modeling at Manchester Metropolitan University in Great Britain) created a set of "Irishmen" who could evolve strategies for the El Farol problem. They do all that Arthur's agents could do, and with more freedom; they could participate inter-agent communication. This resulted in agents evolving strategies that involved lying (reporting things that they weren't going to do) and trying to figure out based on past information whether or not they were being lied to. The results of this mimicked Arthur's results, the average again hovered around roughly 60 Irishmen at the pub, demonstrating a certain amount of organized behavior through chaos. It does bear mentioning, however, that not all studies have agreed that cohesion is the natural result. Evolutionary computations done by David Fogel and Pete Angeline using autoregression parameters failed to show the same results as the above two experiments (Kennedy & Eberhart, 2001).

These are all fantastic examples of how intelligent agents make decisions that are human in scope, and yet it is also limited. These “human-like” agents make decisions completely based on their own welfare and with complete freedom. Another series of studies also outlined in Kennedy and Eberhart’s work deals with the concept of transmission of ideas and culture throughout a society, and what happens if the agent is not the one in control of changing their own point of view. In addition, it is important to consider the impact over time; that changes in culture and the transmission of ideas are equally important. Robert Boyd and Peter Richerson, in their work *Culture and the Evolutionary Process*, tackle these subjects with vigor. Their theory is that human behavior is driven by two things, genetics and culture. In other words, our behavior is modified both by what we learn as well as our innate behavior. They postulated that the relative impact of each was dependant on the type of environment a person was placed in; social learning is more prevalent when self analysis of the surrounding is impossible, and biological learning occurs when it is possible to simply gather the material oneself. These two forms of learning and behavior affecting concepts can come into conflict and cause certain types of behavior to result from this conflict. Behavioral choices could be made simply because their parents chose to do things a certain way and so that choice will be made, rather than making the best choice. There was also the possibility that they would choose a non-optimal behavior if by doing so it would conform with the rest of the cultural participants. The problem that arose in the preliminary computer simulations is unsurprising; any prevalent cultural behavior that gained any widespread traction would quickly overtake the entire population. As a result it was necessary to implement a set of variables that could be used to modify how an entity would decide where to “learn” behavior from. The variable termed “L” represented, on a scale from 0.0 to 1.0, how much learning would be done (learning happened purely from experience at 0, and purely from observation at 1). In addition, the variable delta was placed on the same scale and determined bias (this related only to cultural learning, and determined whether or not an agent would learn by pure imitation at 0.0 and pure observation at 1.0). They concluded that the more dynamic an environment, the less a successful population would rely on social learning and the more a population would rely on individual learning (Kennedy & Eberhart, 2001).

The essential element of social computing theory is the idea of Memetics. Kennedy and Eberhart are again responsible for covering this in depth. The term *memes* was coined by Richard Dawkins as a way to describe a socially transmitted “gene”. There are some important differences to note, such as the fact that Darwinian evolution is continuously branching; whereas the evolution of ideas is merging, branching, or stagnating at all times and based on its own needs. Genetic imprints are like fingerprints; they don’t change over an organism’s lifetime. Contrastingly, memes are constantly “colliding” with each other and mutating. More important than concept of memes themselves is the problem solving capabilities of memetic and cultural algorithms. If evolutionary memetic algorithms can not only change throughout their lifetime but also mate with each other as part of their evolution, then it means that they can solve some problems that traditional methods cannot. In order to solve a particular problem, these agents contain “genes” which comprise part of a search solution. The agents compare their genes (by way of an outside quality metric) in order to mate. Through this method new solutions can be found that are a mixture of two high quality solutions. Taking this one step further the logical follow-up (based on the previous discussion) is then to include culture in the mix. Culture represents a spatial memory space that can be tapped by any of the individual agents and can be used when choosing their next evolutionary step. It is this meshing of organic properties with traditional algorithmic problem solving that paves the way for the future of agent based problem solving (Kennedy & Eberhart, 2002).

2.3. AlphaWolf

A good example of these principles in action on a small scale is the work of Bill Tomlinson and Bruce Blumberg of the MIT Media Lab. In their work on *Synthetic Social Relationships in Animated Virtual Characters* they focus on creating a "multi-agent system based on the social behavior of the gray wolf."(Tomlinson & Blumberg, 2001). This work used the naturally social behavior of the grey wolf to exhibit the impact of iterative social interaction within a small community. Their implementation allowed for user interaction, but in a limited capacity. The user could by using a microphone to howl, growl, or bark to cause his or her pup to howl, dominate, submit or play; based on context. These actions would then affect how each of the social participants would view the actor in the future, giving the action importance over time. The graphical interface displays in what social light a user's pup regards the other pups; thusly giving some indication to the user in which way their "orders" to the pup will be enacted with regards to any given social partner. The experience was inherently short lived, lasting a mere 5 minutes, in which time a pup would grow to maturity under the guidance of their user and learn their place in the pack. The underlying mechanics of this model were based on a cross-section of emotion, perception, and learning; the implementation is taken directly from animal studies, and translates into a meaningful social structure. In addition, Tomlinson and Blumberg write, “We believe that the novelty of displaying this social relationship mechanism in a 3D-animated virtual world represents a significant step with regard to the explicability of synthetic social relationships. The interactive experience of *AlphaWolf* proved to be quite engaging for participants and helped them understand the social relationships of the virtual wolves. We believe that systems like *AlphaWolf* could serve a significant role as platforms for simulation, education and entertainment.”(Tomlinson & Blumberg, 2002).

2.4. NEW TIES

“NEW TIES” stands for “new and emergent world models through individual, evolutionary, and social learning”, and is one of the most ambitious modern social computing research projects. This project is under the guidance of Dr. A.E. Eiben; it is funded and developed by a consortium of European universities, and it has a development period of three years and a budget of 1.55 million euro (https://www.new-ties.org/mambo/, January 17, 2006). The goals read from the mission statement, “The original aim as formulated in personal discussions is to create (initiate + have evolve/emerge) an artificial society with high mental and linguistic capabilities. In particular, it would be great to see whether/when/how they start wondering about the origins of their world and themselves”(Eiben, 2006). As development is running from September 2004 until September 2007, the project is only half complete at the time of this writing, and thusly there has yet to be published results. It simply bears mentioning as an example of a large scale investment in social computing.

2.5. Sugarscape

The work of Joshua Epstein and Robert Axtell cannot go without mention; specifically their book mentioned earlier and titled *Growing Artificial Societies: Social Science from the Bottom Up*. One of the distinctions made early in their work is on the three ingredients of an artificial society: agents, environment, and rules. Agents are of course the "people" of constructed artificial societies; they have any number of traits, from sex to vision to wealth. The environment is anything outside of these agents that also exists in a "physical" capacity to be operated on and interacted with by the agents. The rules comprise "everything else"; these are either modes of behavior for agents, or the physical rules of the environment itself. After introducing these concepts Epstein and Axtell then introduce their model, "Sugarscape". The idea is simple; agents exist in an environment comprised of varying amounts of "sugar". Their movement is assigned a "metabolism rate" which represents how much sugar they burn when they move. In addition, if their sugar level falls below zero then they die. One of the goals of this project was to "grow" a history (titled a *proto-history*); theoretically allowing for the ability to observe social evolution as it occurs. The inclusion of a second resource (spice) with its own separate metabolism rate allowed for the meaningful implementation of trade. Trade allows for a more explicit model of society, and in fact when two otherwise identical societies are run simultaneously the society with trade prospers, and the one without trade fails. The models were also further extended in order to include markets of non-neoclassical agents (i.e., evolutionary agents), credit networks, and social computation. Social computation is especially fascinating in this case, as it allowed for the mapping of trade within a society. There was also the implementation of disease and immunity throughout a given society. By combining all of the above listed elements Epstein and Axtell were able to create a set of emergent behaviors that were fascinating and complex. (Epstein & Axtell, 1996).

As they conclude their introduction Epstein and Axtell cover the traits which set their artificial society simulation apart from other artificial life and traditional mathematical models. What follows is a summary of their work. In addition to this summary, each example has a virtual world equivalent which is outlined in an attempt to further solidify the parallels between artificial societies and virtual worlds. First of all, there is the concept of heterogeneous agent populations. This is a sharp contrast to the homogeneity found in mathematic populations, and in the case of Sugarscape each agent is distinct and individual; much in the same way that individuals in a virtual world each act with individual motivations and with individual traits. Likewise, in virtual worlds each avatar is controlled by a human who has different talents and individual rules of behavior. Secondly, they point out that space is distinct from agent population. In mathematical models space does not play a significant role. Space not only exists in artificial societies (and virtual worlds), but is essential for human interpretation of a model as a meaningful social structure. The third point is that all interactions happen according to simple local rules. This hits on the essence of emergence; that there exists decentralized behavior and the study of the resulting pattern. The fourth point made is on the focus on dynamics. A social system is not only interesting when at rest, but is worth studying throughout the process of social development; as opposed to mathematical systems which focus on populations at rest. Virtual worlds are likewise represented as systems in action, and although statistically analyzed on occasion are often interesting because of the social structures that build over time. Their fifth point is then that the Sugarscape model is “beyond methodological investigation”; meaning that the focus is again on the individual and is completely bottom up. However, Sugarscape still works around the idea of institutions; they can have feedback effects on the population and are therefore worth categorizing and studying. This is similar to virtual worlds in that user organizations have a great deal of impact on the behavior of individuals, the most common example being the player organizations known as “guilds”. Finally, they bring up the concept of these collective structures emerging from the bottom up. Growing social behavior from the bottom up used for precisely the same reason that it is similar to virtual worlds; human agency is inherently bottom up (Epstein & Axtell, 1996).

3. Development

3.1. An Overview

As demonstrated, the applications and results from agent-based modeling are diverse in purpose and implementation. The first steps taken were to develop a model that would abstract each element into the component pieces. For this purpose the agent, rules, environment model from Epstein and Axtell's work seemed ideal. It could be used to represent all key portions of both artificial societies and virtual worlds. The agent is represented by the user avatar in a virtual world. The environment is the world itself, the space in which the user-guided avatars interact. Finally, the rules are the actions the avatars can take, the "physics" of the virtual world. The model would therefore need the capability to be graphically represented, it would require independent agents, and it would require behaviors and means for them to interact with each other as well as the environment. This is nothing unusual, and is in fact the basis of the Sugarscape work. The second set of criteria then comes from virtual worlds, and how to build towards an artificial society that could interact with user avatars in a meaningful way. There would need to be a system of communication and rules that was built around basic "commands" or "actions". In addition the representation of the agents and their actions would have to be meaningful and understandable in a human-readable way. Finally the environment would need to exist in a way that would also be human-comprehensible and meaningful.

When looking at this problem from a technical standpoint, it becomes apparent that the solution will need to be modular, easy to expand, and possible to test iteratively. Each piece could then be modified independently and tested across different rule-sets. In addition, pieces could be added or removed from sets of agents, in order to facilitate the creation of each of the different models. For instance, the work on game theory could be simulated by two non-mobile agents communicating and a scorekeeper keeping track of the respective success or failure. Finally, it would be necessary that any significant change would be easily communicated to the client, be it motion, a change in state, or a change in attributes. The real motivation of doing this work is to facilitate the creation of and experimentation with more complex models. This implies that agents would need the means to store any amount of data and be easily extensible. In addition, agent behavior would need to be easily added, and yet separate from the agent implementation itself so it could be added and removed from simulations with ease. As a result of these considerations, Java was chosen as the programming language of choice due to its extensive API and object-oriented programming environment. This would allow a solution that would be both extensible and robust.

The concrete implementation itself was developed next. Towards this end a simple human understandable economic model was constructed. It would be sustainable indefinitely, have the potential to evolve over time, and would be extensible. The goal was to model each of the points of connection between artificial societies and virtual worlds outlined in the Sugarscape overview above. Essentially this means that the model would need heterogeneous agents, distinct space, and interactions according to simple local rules, a focus on dynamics, a focus on the individual with an eye on institutions, and bottom up emergence. The model would also need to take into account considerations that plague both virtual worlds and artificial societies. In many ways it would be more limited than Sugarscape; which can act without consideration of layperson comprehension or interaction on the micro-scale.

3.2. Keller O’Hara’s Platform

To begin with, a platform for development would be required. Fortunately for this work, Keller O’Hara was simultaneously developing a multi-agent system framework that would be ideal for these goals. His goal was to provide a graphical multi-agent simulator in Java. It was to be easily extensible with a documented API. In addition it would have a fully functional display window, along with methods that would allow the easy importation of entities. He planned to implement ways to “save” a world state, a logging system, and a way to run the software over a network, so a “world” would be run on a server, with clients connecting from remote locations. He quickly had a prototype up and running, and development began by using his early versions. It was written in Java and thereby easy to implement the conceptual model. In addition it was created in such a way that multiple sets of agents could easily co-exist in the same “world”, so not only would comparative analysis be easy; it would be equally simple to add code that would cause either conflict or collaboration between two sets of entities that had been previously examined independently. In short, using a newly developed framework would be taking a risk in that it was untested and untried; however, the requirements weren’t extensive, and the gains would make the risk worthwhile.

3.3. The Concept

The first cues in development were taken from the concept of game theory. Therefore the first consideration was modeling iterative interactions which had the possibility of influencing future decision-making. This iterative decision making shows up again and again, from AlphaWolf to Sugarscape, and was important to take into consideration in this work. Essentially it is from this repeated interaction that a society will evolve over time, from changes in perception and knowledge to the simple exchanging and transmission of goods. In the case of a simple economic model this iterative interaction is based on trade. Due to the fact that the environment existed in 2D space and with mobile agents, agents would remember where they traded with instead of remembering who they traded with. In this way they would return to the same location repeatedly; if there were other trades going on it would reinforce the importance of the location, and if barren then they would widen their search for other trading partners.

If trade was to exist then goods too would be required. In order to engage the environment in the same way as Sugarscape, these “resources” were to be harvested from the environment itself. This would make the distinct space important, causing resource clustering and making location an important consideration. The most basic resource was “bread”, essential for the life of each agent, and consumed at a variable metabolic rate. Bread, however, wasn’t simply collected as sugar was in Sugarscape; it would require wheat and a bakery. Wheat would be harvested from “farms”, which would be another feature of the environment. It would then be necessary to provide agents with some means of gathering these materials, and so the concept of skills was born. Agents could each be capable of one or more skills, each which would provide a resource from one of the environmental structures. As a result there would be a functioning, if basic, economic model. The resource types and connections should be intuitively graspable by anyone observing the system and the inter-agent action meaningful. In addition, this was structured in such a way that new connections and resources could be added easily and quickly integrated in to the existing system. Figure 1 features the three resources that were used in the model implementation, and their connection to the other elements of the economic system.

Resource	Required Skill	Required Resource	Required Terrain
Bread	Bake Bread	Wheat	Bakery
Wheat	Harvest Wheat	~	Wheat Farm
Ore	Mine Ore	~	Ore Mine

Figure 1 - Table of Resources

3.4. Concept to Model

Once the basic concept was outlined, the next goal was to design it in such a way that it would be able to be modeled as a Java program. This was implemented using O'Hara's framework; so the environment and basic agent structure already existed. His environment was two dimensional, and it was important to implement the agents and environment within that constraint. In order to be extensible, follow with the environment/agent/rules model, and to use the concept raised in AlphaWolf of a fixed number of quantifiable actions, the possible choices of agent behavior were each classified as an "action". The purpose behind this was twofold: it was extensible and easy to implement a new action and it also provided a framework that would make it simple to replace an automated agent with a human controlled avatar with the same possible set of actions. Examples of actions include movement, searching the local area, and requesting a trade. The class diagram for the Action superclass and its subclasses (including several not used in the final implementation, such as construction and asking about wants) can be found in figure 2.

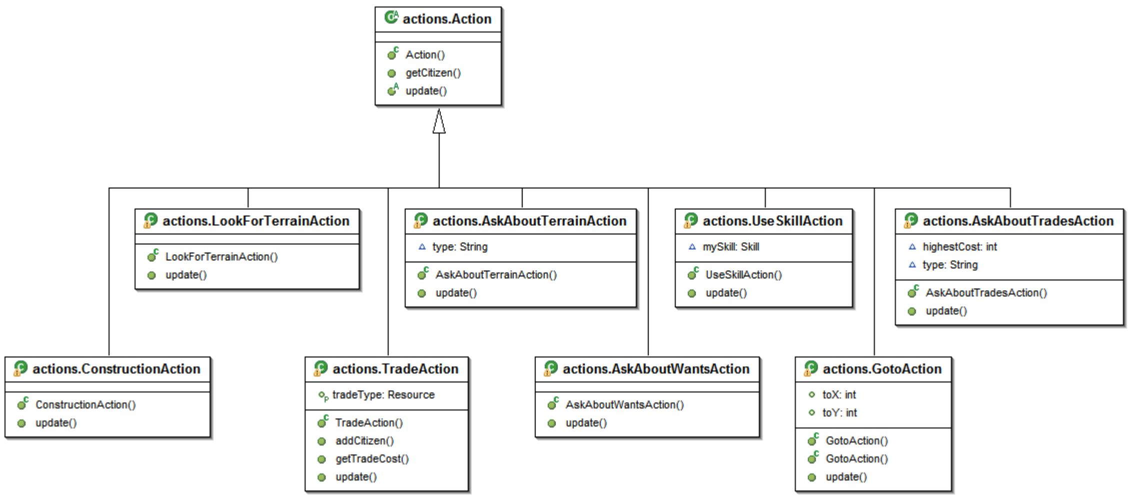

Figure 2 - A Class Diagram of the Action class and its subclasses. These are used to implement the possible actions for agents and avatars.

The metabolism and requirement for bread was implemented as a “need”. This need was passed a parameter, in this case bread, and a value that indicated rate of consumption. In addition, if certain basic needs were not sated, then the agent would find itself removed from the environment (i.e., dead). A basic need would be conveyed to a human user in the same way, with a threshold for survival. The normal needs were simply goals to be met, and could easily be conveyed in the same fashion; they had no relation to survival, but gave alternative goals to the agents. The agent was also assigned one or more “skills”. These skills would indicate one of two things: either the ability to gather a resource if positioned at the correct environment point (i.e., wheat from a wheat farm) or the ability to exchange one resource for another if positioned at the correct environment point (i.e., wheat for bread at a bakery). In order to enact a skill it would simply require the "SkillAction" class to contain an instance of the skill in question. Therefore, the concept of skills is easily molded to fit into an avatar-based model as well as an agent-based one. The class diagram for skills and citizens can be seen in figures 3 and 4 respectively.

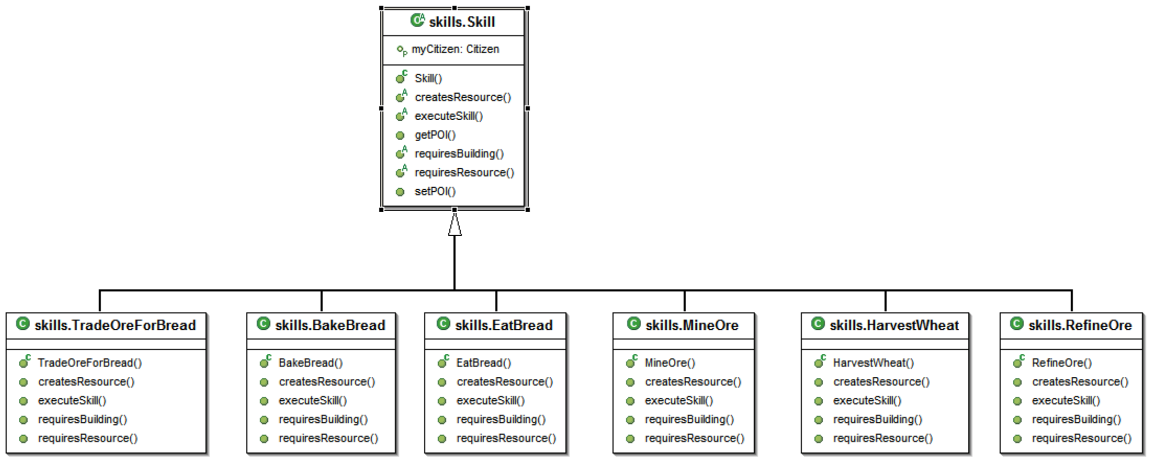

Figure 3 – The class diagram of the Skill class and its subclasses. Skills are used by agents to harvest resources from the environment.

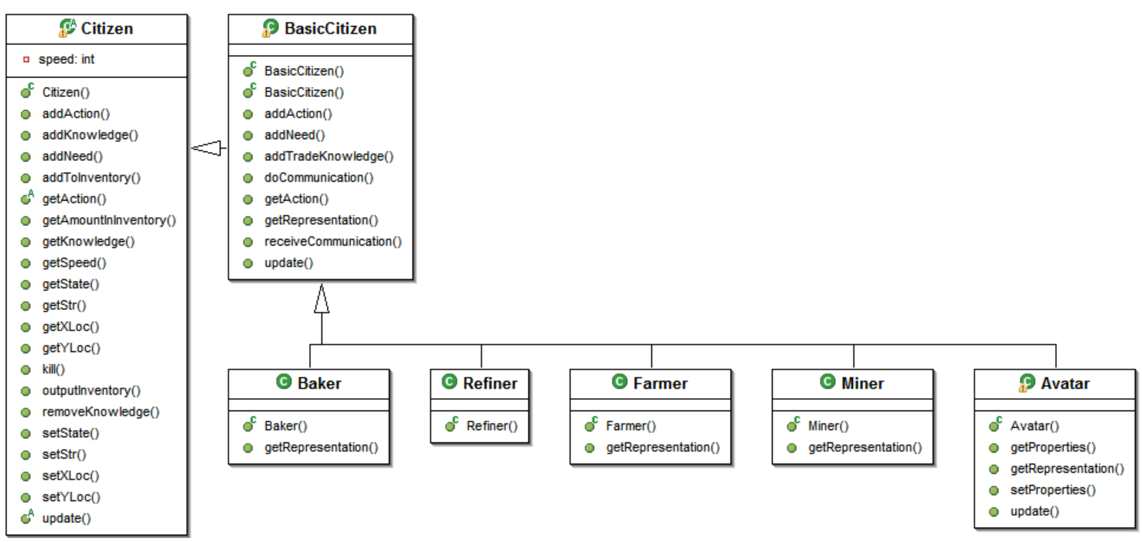

Figure 4 – The class diagram for Citizen, BasicCitizen, and its subclasses. Citizen defines an agent in general, and BasicCitizen expands upon that by adding rules for behavior. The subclasses define the agents that can be added to the simulation and they are differentiated by their known skills.

There is one major difference between artificial societies and virtual worlds that must be reconciled before an appropriate middle ground can be achieved. This difference is that virtual worlds must be "readable" by a human. Granted, in many cases, such as Sugarscape, it would be possible to explain the meaning behind the symbols and let it go at that. However, it should be taken into consideration that a meaningful user interface allows for a more natural decision making process, and would allow for human participants to have a more rapid acclimation to the system, especially given a more complex implementation. The final consideration is that iteration speed must also be slowed to a human comprehensible rather than computer comprehensible level.

3.5. The Code

The following is a technical discussion of how each piece of this code is implemented in Java. This covers the specifics of how this model is implemented; as well as providing an opportunity to return yet again to the environment, agent, and rule model. In addition in each case the potential for extending this model is explained, and where it would fit into the existing code.

The environment was reasonably simple, and consists of two parts. The plane of movement was coded as part of the platform, and exists as a simple 2D plane that facilitates movement and little more. In addition there are additions to the environment that add meaning for resource gatherers such as farmers or bakers. These features, termed Terrain, share a common abstract class that each specific type of terrain inherits from. The only method of note that Terrain subclasses must implement is getType; which returns a string representing the type. This abstraction allows agents to "ask" what type of entity the terrain represents and get a reasonable response that isn't tied to the class name itself. In addition, it is possible to add new types of terrain in the future; one such option is the possibility of agent-created terrain types. These "buildings" can have values such as build time, ownership, resource cost, and durability. In addition, each type of environmentally displayable object has a property built into the framework which allows for the resources to deplete over time (similar to how sugar and spice in *Sugarscape* is consumed), and has the potential to change the environmental features, resulting in a shift in agent/avatar behavior.

Agents themselves are implemented as an extension of the superclass provided by O'Hara's framework. The agent superclass is titled Citizen and contains the rules which govern the necessary mechanics of actions as well as the list of Needs and Skills that each agent is granted. The subclass of Citizen, BasicCitizen, implements a set of rules that governs the behavior of the agents used in the economic model. The code is designed in this way so that a separate set of behavioral rules could be developed independently by inheriting the basic mechanics found in the Citizen class. The motivational agent features are added to an agent by appending an object of type Need to an array in the class constructor. The update method checks and updates each Need for each iteration of the simulation. In addition, skills influence their own needs based on a connection made between needs, skills able to produce those needs, and trading possibilities. Whichever resource is given priority is either then skilled for or traded for depending on local availability. The majority of the extensibility in this area takes place as part of the interplay between skills, resources, and environment. It is a simple matter to introduce a new subclass of Need, Skill, or Citizen that further extends this network of exchange. The following text is a pseudo-code representation of the update() and needCheck() methods containing the behavioral rules governing the BasicCitizen implementation:

```
update(){
        Increment all needs.
        Call current action's update method.
        if(action is done) then
                Get the next action if there is one,
                        otherwise call needCheck().
}
needCheck(){
        Loop and check for all needs, store the greatest need.
        Check to see if it's possible to skill for the need.
        Check to see if the entity knows where to use this skill? If so,
                queue the action to move there and harvest.
        If not,
                ask nearby agents, then
                search if there isn't a pressing need (imminent death).
        If it isn't possible to skill for the need, then trade.
        Check to see if trade knowledge exists. If so,
                move to that location and deincrement value of knowledge.
        If not,
                queue an action to move a short distance then look.
        If another trader was found, then
                increment value of knowledge, move, and trade.
        If nothing is found, simply repeat and continue to search until
                eventual success or death.
}
```

Each action has its own update method, which acts upon the given entity. Actions included the classes AskAboutTerrainAction and AskAboutTradeAction, which poll nearby agents for information. In order for movement to occur there is the class GotoAction and to gather resources the class UseSkillAction is used. Actions are queued by the agent, and the top action has its update method called each iteration. Once completed, the action is popped from the queue and the next action's update takes place.

This allows for an easy implementation of any new types of actions (for example, a BuildAction class could be implemented to construct one of the buildings mentioned above), and therefore limitless extensibility. Once human controlled avatars are introduced, then they too make use of any of these actions with equal agency. The Avatar class is a subclass of BasicCitizen, but overrides the update method to only perform queued actions and not perform any of the behavior modifying rules. It is implemented in this way so that the trade knowledge can still be stored and then displayed for the avatar's controller.

4. Results

4.1. Overview

The analysis and measurement of success which are used for this project are not the same as the social projects with which it shares many characteristics. In the virtual societies such as *Sugarscape* or *Alphawolf*¸ a set of rules is devised attempting to explain human social phenomenon, and is then tested by attempting to “grow” the proposed result. Although with the framework developed in this work that is certainly possible, it is not the focus. As a result, the following results will each demonstrate how the building blocks of a growable society are created, but will not attempt to formalize rules or draw conclusions relating to the social sciences. These building blocks consist of meaningful inter-agent interaction, interaction with the environment, and institutions; avatar control and interaction within the system is included as well.

4.2. Graphical Representation

Below are two images. Figure 5 is of an early build without representational symbols, and figure 6 features representational symbols instead of simple colored circles:

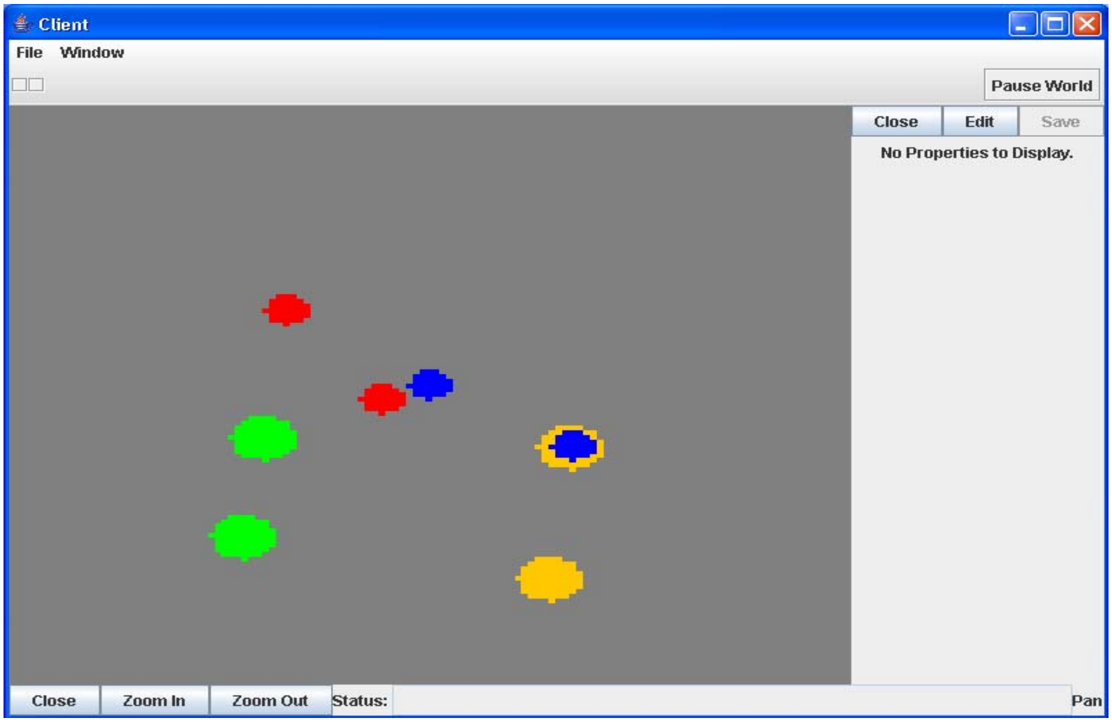

Figure 5 – This is a simple graphical representation. The Green circle is a bakery, the red are bakers, blue are farmers, and the yellow are wheat farms.

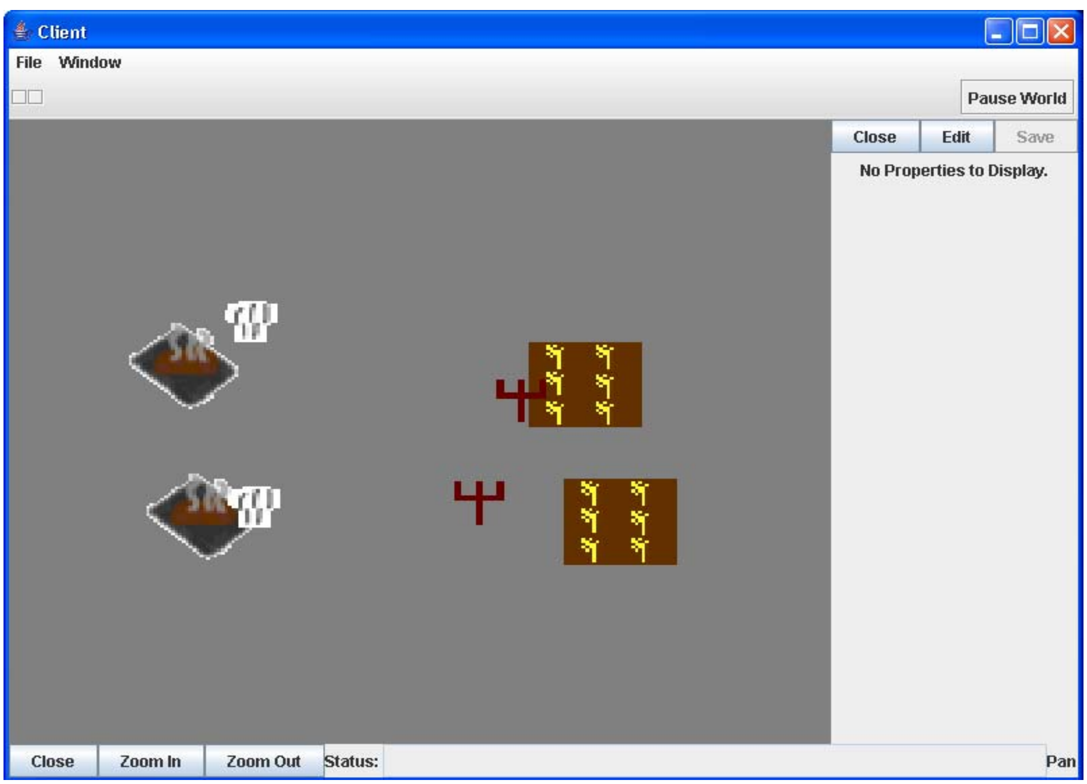

Figure 6 – This is a symbolic representation of the same setup as figure 5. From left to right the symbols represent bakeries, bakers, farmers, and wheat farms.

As you can see, the user interface is simple and uninvolved. Meaning comes from the environment display section of the screen. Most simulations simply use colored cubes or spheres to represent their agents, but in this case the agents have been replaced with icons representing their function (from left to right: bakery, baker, farmer, wheat farm). This is an important feature if human avatars are to be integrated in easily. While it is certainly possible that a given set of participants could be taught to comprehend the meaning of a more basic model, it would hinder initial decision making and make for a steeper learning curve and a higher chance for error. A symbolic graphical representation allows human users to quickly grasp meaning and make more informed decisions.

The other features of the window include zoom buttons, the ability to add new agents, and a properties panel. The zoom buttons can be used to adjust an avatar's "field of vision" and the property panel is used for control of the human-directed agent. It is also important to note that the client features allowing for manipulation of the environment in "non-agent" ways (such as the inclusion or removal of agents or avatars) would be disabled or disallowed when the client is being used as a point of control for an avatar.

4.3. Inter-Agent Interaction

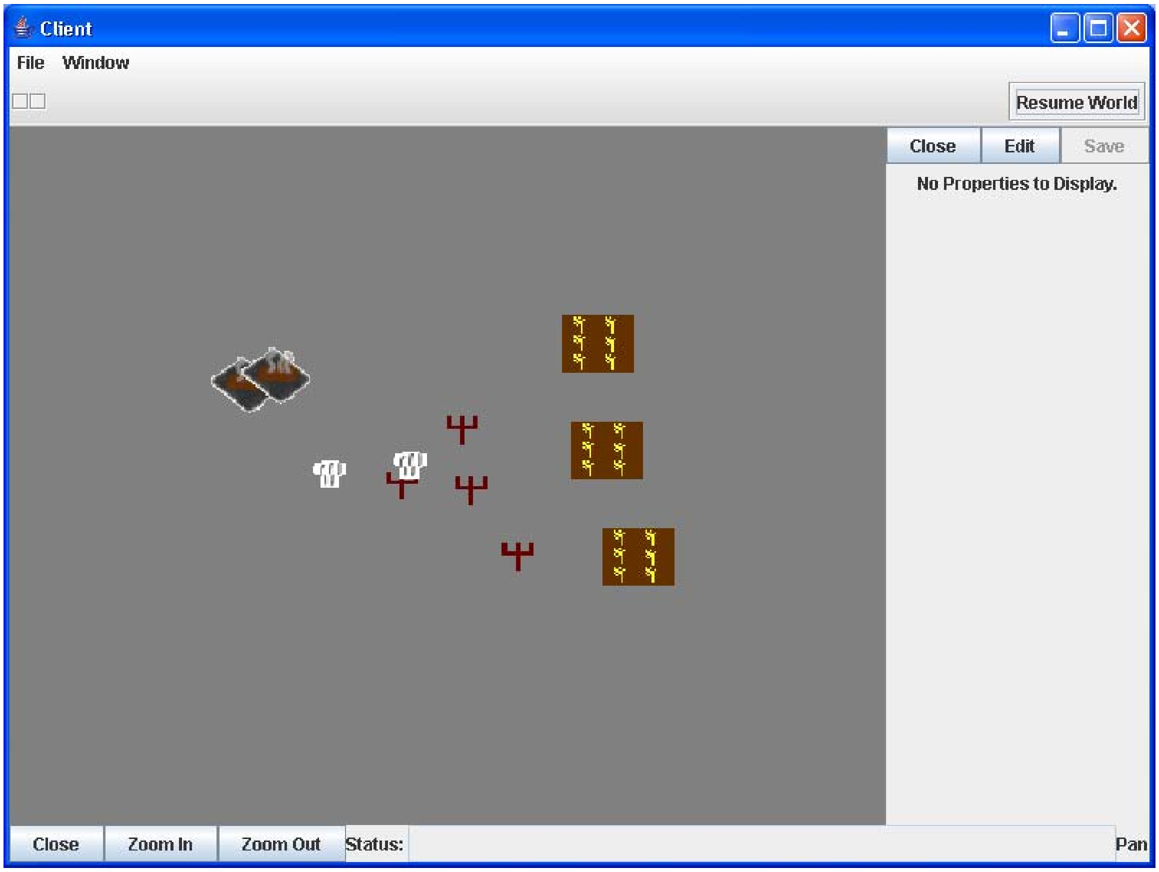

Figure 7 – Bakers and Farmers harvest and produce their goods then continue to trade in a bid to survive.

Figure 7 portrays a competition for resources among the agents. The starting condition consisted of two bakers, ten farmers, two bakeries, and three farms. The Baker and Farmer classes both inherit their rule oriented behavior from the BasicCitizen class; with the key difference that Baker has the BakeBread skill and Farmer has the HarvestWheat skill appended to their skill array as part of their constructor. The results in figure 7 were caused by a scarcity of a certain skill (BakeBread), resulting in farmers surviving only if they managed to quickly optimized their trading behavior. This is important to note as it represents an optimization of agent behavior. Alternatively, a similar trial was performed where a human controlled agent replaced one of the farmers (in form as well as function). When attempting to survive it was essential that the avatar perform optimally, as it is constrained by the same set of world rules. This is an example of human behavioral rules mimicking the simple agent rules as the means for survival. Figure 8 shows this second experiment in action (the smiling yellow face represents the avatar).

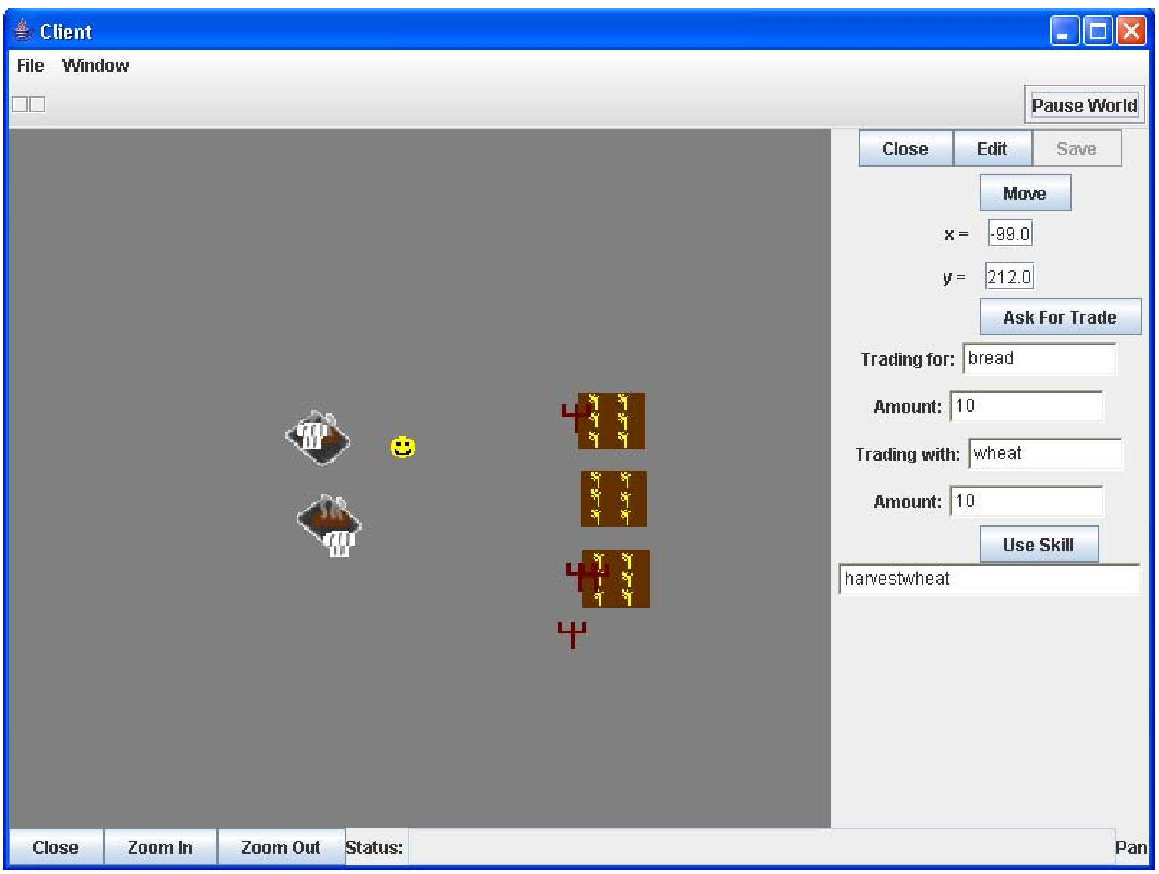

Figure 8 – The yellow smiling face represents the human-controlled avatar. The panel on the right allows for actions to be added to the avatar's action queue.

4.4. Interaction with the Environment

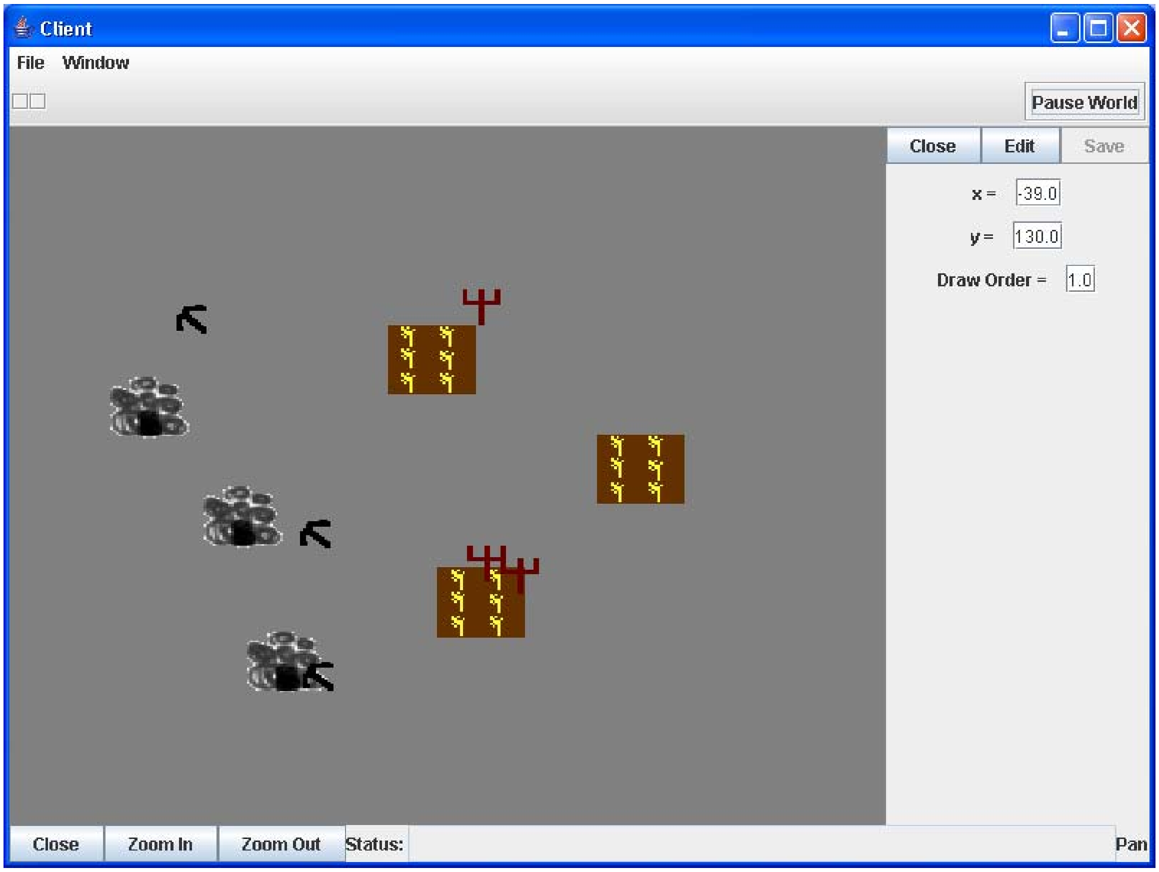

Figure 9 – Mine and miners are introduced (from left to right respectively). Miners cluster around mines and farmers around wheat farms.

In figure 9, a random distribution of two different types of agents began to cluster by resource type. The newly introduced agents are miners and are represented by pick-axes. Miners operate with the BasicCitizen rules and have the skill MineOre. This skill requires an ore mine to operate, and these are also represented in figure 9 as piles of rocks. The need for ore itself was implemented in such a way that it neither grew nor shrank; agents would simply attempt to acquire ore only when they had recently satisfied their need to for bread. Ore was implemented in this way as a means of representing accumulated wealth.

The clustering found in figure 9, although ostensibly insignificant, represents a meaningful interaction between agents, rules, and environment. A virtual world example of this is how player-controlled avatars flock to the sites that give the greatest reward, often resulting in overcrowding and avatar collision. Of course, the example in figure 9 leads to the eventual demise of each agent involved (as there is no food source), but is important to note nonetheless. When an avatar is included in such a “no-win” scenario, his or her goals are what determine behavior. If instructed prior to the experiment that the goal is to maximize resource generation, then they too analyze their abilities and gather at the nearest environmental resource point. However, if given no such goal, then aimless wandering and experimental “play” exhibits itself as users find themselves without direction.

4.5. Institution Formation

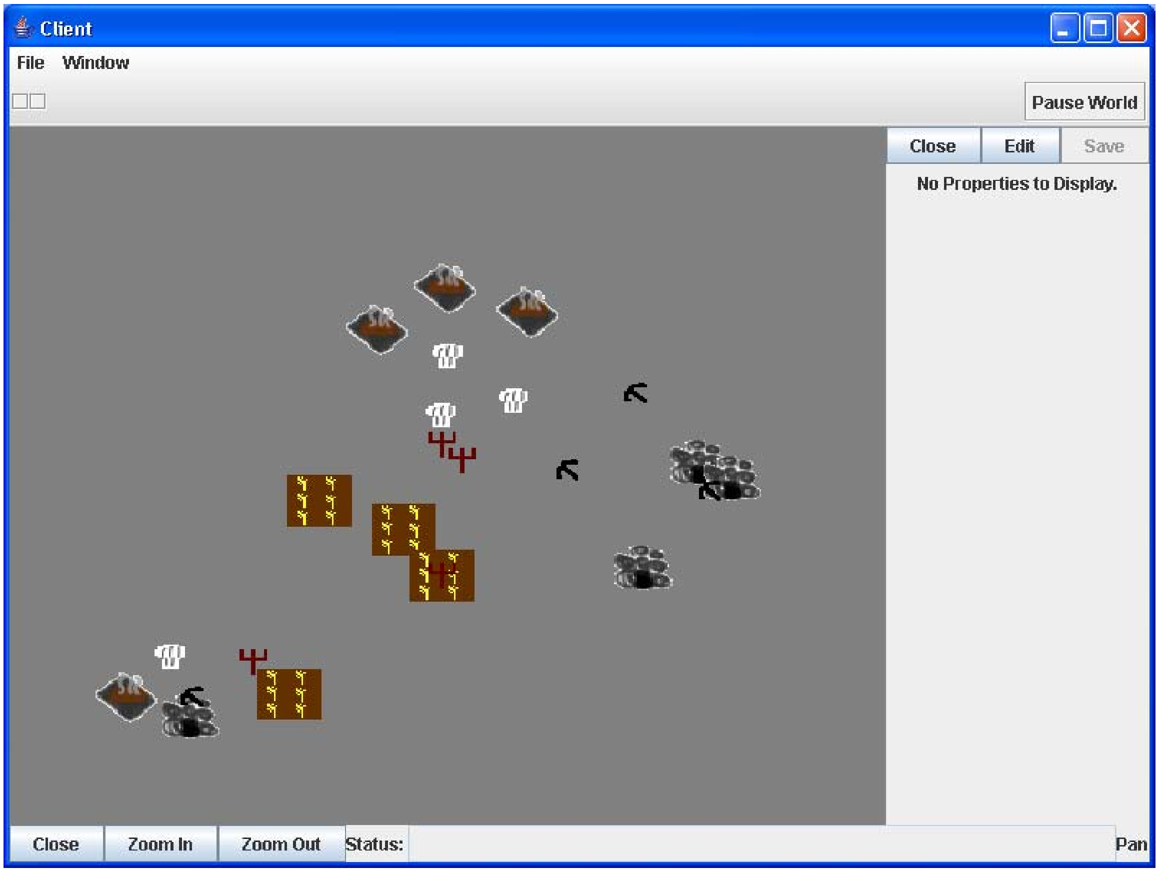

Figure 10 – Marketplaces form as entities build up trust that they will find goods to trade at a specific site.

By far the most complex social building block to mimic is that of institutions emerging and affecting behavior. The most comprehensible result that occurred was when the environment was placed in such a way that multiple trading hubs would emerge. By existing close enough to be within a local search range, behavior eventually equalized in such a way that movement was refined and two communities developed. This is comparable to the de facto “trading zones” that sprang up in *Everquest* prior to the implementation of sectioned trading zones. The competition for resources and social connections can also be likened to the required social connections to be a meaningful part of any given virtual world. In figure 10 above the agents were initially placed grouped in the center of the screen. As they began to spend time developing trade relationships, they expanded outward and eventually solidified their actions as part of several “marketplaces” as represented by the groupings in figure 10. It is also important to note that this formation of institutions was dependant the location of the terrain features. Due to the rules by which these agents act and their constraints these marketplaces will form regardless of terrain placement; however, it should be noted that the location of terrain affects the location of the marketplace.

It is also possible for a human-controlled avatar to become a part of these institutions and have much the same impact. Assuming they are behaving using the roughly the same rules as the agents, then institutions of roughly equivalent agents will still spring up predictable locations. However, with an avatar there is always the possibility of un-optimized or creative behavior. For example, he or she could decide to exhibit behaviors not existent in this rule model, such as “muscling in” on another’s trade environment by offering trades at a more frequent interval in order to drive another agent “out of business”.

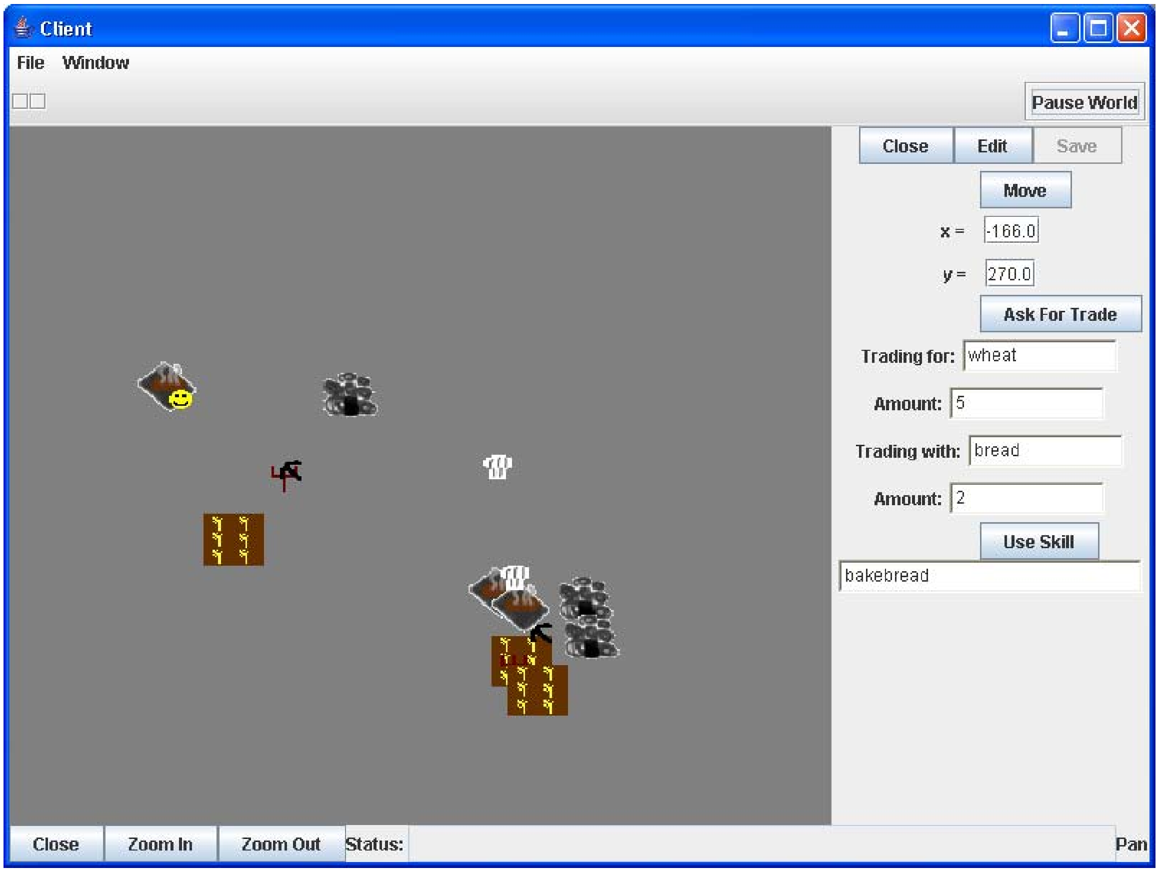

Figure 11 – Avatars can be introduced to institutions and cause new and unexpected results.

For example, in figure 11 by using the BakeBread skill the avatar has gained control of the "market" found in the North West portion of the screen. As a result he or she has begun to use this monopoly to ask for more wheat for bread. Due to the baker's position in control of the necessary resource of bread, it is possible to hold out longer and thus force the market to bend to the need for bread.

5. Conclusion

This work covers only a small portion of the potential that exists in combining human and virtual agents in a shared space. The rules outlined ouch only superficially on emergence and go into no great depth with regards to solving any particular problems, social or otherwise. There is a great deal more research on the underlying subjects both in agent based modeling and in virtual worlds, far too much for the scope of this project. In terms of study focused around agent-based modeling in the social sciences, the guide for newcomers written by Dr. Robert Axelrod and Dr. Leigh Tesfatsion and found at the http://www.econ.iastate.edu/tesfatsi/abmread.htm contains a great deal of information related to all avenues of artificial society research. Alternatively, for up-to-date research and discussion on the issues surrounding virtual worlds, the *Terra Nova* academic web log found at http://terranova.blogs.com/ provides a great deal of academic discourse and intelligent discussion. Neither site is comprehensive, but they both offer a great deal of varied insight that touches on the main issues surrounding each field of interest.

Despite the lack of a complete solution to any given social problem, the project itself does succeed in several ways. It demonstrates a working model containing both agents and avatars, it displays a significant number of the building blocks necessary for further development and use to the social sciences, and it is entirely extensible and open to modification. In short, it succeeds as a proof of concept, and it is only limited by the scope of the work done in this paper. The future holds a great many things for both fields, virtual worlds and artificial societies, and there is little doubt that more systems of this ilk will begin to take shape.

To further enhance the value of this work, there are some changes which should be made in order for the next model of this type to be put to greater use. Primarily, the graphical feedback needs to be more comprehensive. Agents' needs and wants should be represented in a meaningful way, and their behavior should be communicated to human users more thoroughly. This communication would allow for greater complexity to be added without significantly increasing the amount of effort needed to understand the outcome. In addition, this sort of communication could allow for the possibility of agents "lying" to avatars and to each other, making for even more in depth interactions. Another improvement would include more iterative work on the agent rule sets. In the case of this work the avatars were added at the end of the project, leaving less time than necessary to fully explore their potential. Through iterative rule building, "rules" that human-controlled avatars develop (such as the sketchy business practices outlined in the trading institution example above) would be added to the agent rule base, and once included on a wider scale, then further analysis of behavior would be done. This would allow for the development of an evolved set of rules that would hopefully represent a more meaningful way of acting for the agents, demonstrate which rules are indeed beneficial for populations as a whole to adopt, and which "anti-social" behaviors are only optimal if a small number of the community participates.

In addition, the future of this area holds a great many implications. It could simply be used as a way to introduce human agents into traditional artificial societies, providing validation of the rules encoded therein. Or perhaps meaningful agents will be included in traditional virtual worlds, although in the case of worlds designed for entertainment purposes this requires a good deal more balancing in order to keep the interaction “fun” as well as meaningful. At the very edge of this research there is the possibility of memetics being transmitted from virtual agent to human and back. The possibility of ideas being developed in virtual space by virtual agents then finding their way into the “real world” in a meaningful way is the stuff of science fiction, but with a reasonable human and agent interactive model this is a real possibility for the future.

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