Agent Street: Agent-Based Modelling in Second Life[1]

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Abstract

Virtual worlds offer a new arena to explore agent-based modelling (ABM) for the social scientist. Within this paper we introduce virtual worlds and map the similarities between such worlds and agent-based models, and their potential for outreach and communication of such models. We introduce Second Life and describe how it gives one a sense of place through a series of geographic examples. A brief review of agent-based models within Second Life is presented highlighting how many of such applications are rooted in biology and not the social sciences; nevertheless they demonstrate how agent-based models can be created in such an environment. We then turn to social science ABM applications. For this we present three basic models to show 'proof of concept.' The three examples we chose are Conway's Game of Life, Schelling Segregation model and a simple pedestrian evacuation model. These examples demonstrate the potential of creating agent-based models for social scientists in virtual worlds especially as such worlds give us powerful visualisation tools and additionally allows for wide dissemination of such models. The paper concludes with some final comments and problems with current virtual worlds and future avenues of research.

Key Words: Agent-Based Modelling, Pedestrian Evacuation, Segregation, Virtual Worlds, Second Life.

1: Introduction

Virtual worlds are increasingly reaching a level of sophistication whereby they can be viewed as digital laboratories. While the main purpose of systems such as Second Life, World of War Craft and ActiveWorlds, to name but a few, is entertainment, the virtual world phenomena opens up a plethora of opportunities for modelling and spatial analysis. The purpose of this paper is two fold, firstly to introduce the social science simulation community to virtual worlds and secondly to highlight the potential of these worlds for agent-based modelling (ABM) specifically focusing on

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social science research. To this extent we provide a brief review of ABM and its similarities with virtual worlds before moving onto introducing Second Life, the most popular and powerful virtual world currently available. The second part of the paper focuses on the development of agent-based models inside of Second Life to create models which are not only highly visual but can be used to collaboratively explore the ABM paradigm. The technique offers a unique tool for communication, collaboration and education in the modelling process. We conclude with a brief discussion and future avenues of research.

The structure of a typical agent-based model is composed of agents/objects/components which interact with each other and with their environment(s) (see Castle and Crooks (2006) for such a discussion). This structure is broadly mirrored within virtual worlds with avatars (e.g. people) and objects which interact with each other. Both can be considered as ‘synthetic worlds’ but in the case of virtual environments they are populated by both synthetic and real people, in the form of avatars. This is an important aspect of the work and in the use of virtual worlds in general for ABM, as behind avatars are real people who can interact with the synthetic model environment, adding another dimension to the level of possible analysis and outcomes.

Agent-based models are usually considered as forming a miniature laboratory where the attributes and behaviour of agents, and the environment in which they are housed, can be altered. In turn they can be experimented with and their repercussions observed over the course of multiple simulation runs. Similarly virtual worlds provide electronic environments that are designed to visually mimic complex physical spaces, where people can interact with each other and with virtual objects and where people are represented by animated characters. The ability to simulate the individual actions of many diverse agents and measure the resulting system behaviour and outcomes over time means that agent-based models can be useful tools for studying the effects on processes that operate at multiple scales and organisational levels (Brown 2006). Such models thus roughly approximate the notion of ‘generative social science’ (Epstein and Axtell 1996) demonstrating that certain sets of micro-specifications are sufficient to generate the macro-phenomena of interest. Epstein (2007) proposes that such models should be ‘grown’ within such simulation laboratories, thus explicitly rooting such models in temporal dynamics. ‘Generative social science’ is widely regarded as one of the grand challenges of the social sciences (Buchanan 2006).

Virtual worlds are making it increasingly possible to move from an artificial laboratory on ones desktop into a more collaborative 3D environment comparable to a real-world laboratory accessible by others, who are able to visualise and discuss models in real time. This environment provides an effective medium to clearly communicate models and results between the developer offering a unique way for the exploration and understanding of social processes by means of computer simulation. Not only does this aid understanding of such models but it also provides a unique opportunity for outreach to the wider scientific community. Before we turn to the development of agent-based models in Second Life, our chosen development environment, we take a look at its background and features.

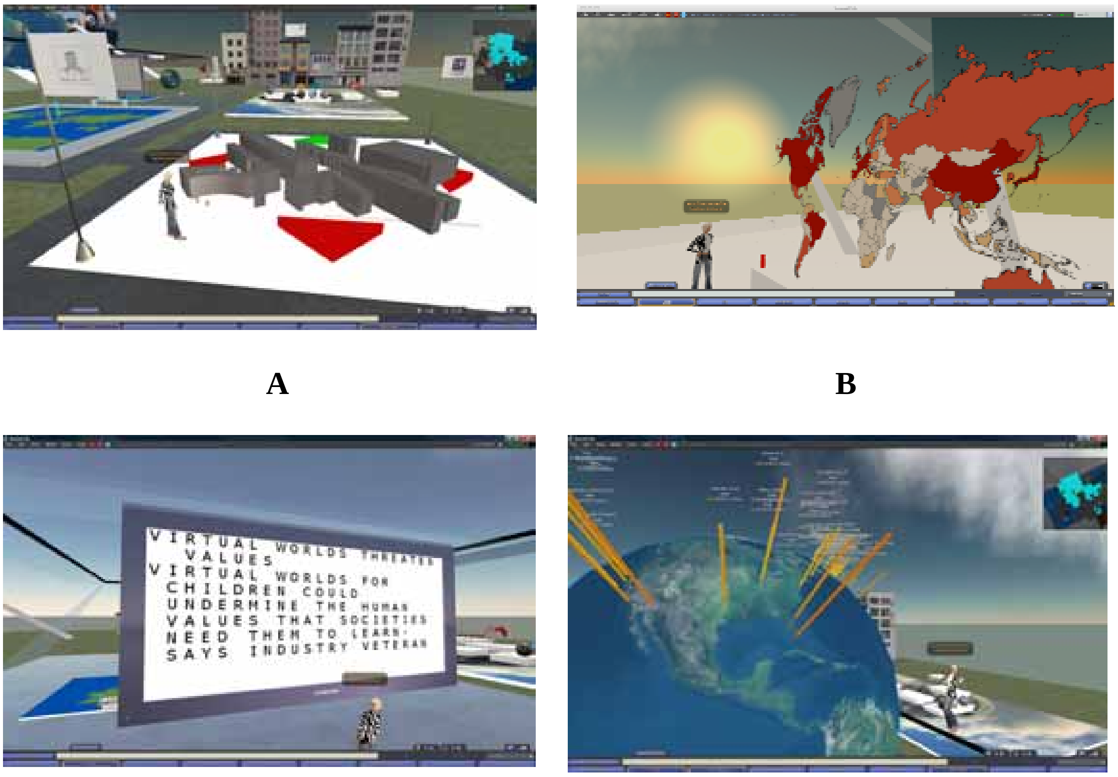
2: Second Life

Second Life currently represents the most successful social/visual environment on the web, at the time of writing Second Life had over 14,000,000 registered users with over 400,000 visitors a week (Linden 2008). Launched in 2003 with little more than a few kilometres of simulated computer space, it now covers more than 750 km^2 (Ondrejka 2007). Initiated by Linden Labs, the world of Second Life has been created almost in its entirety by its users. For example, residents spend a total of 23,000 hours a day creating things (Hoff 2006), and therefore represents an excellent example of crowd sourcing (Howe 2008). The users have created digital geography in its purest geographic sense. The rolling fields, rivers, valleys, mountains, hamlets and towns that occupy the ever growing space have been created piece by piece by the millions of users and every part of Second Life’s visual space is editable.

It is free to enter Second Life, chat and begin exploring but if one wants to start ‘building’ one has to register and purchase land. Players spend an average of $350,000 a day, or $130 million a year (Avasthi 2006). Many companies, organisations and academic institutions have bought land in Second Life, including IBM, Sony-Ericsson, Oxford University, and Nature Publishing, to name but a few, building store fronts, virtual campus’s or head quarters where their employees’ avatars can do business or promote science (see Hackathorn 2006). Second Life provides a rich environment for teaching, learning and outreach. Our section of land in Second Life can be found on Nature Island (Nature 2008), a plot of land set up by Nature publishing group to encourage scientific research and outreach.

Our interest in Second Life is exploring this geographic space and to what extent we can use it as an urban laboratory, exploring issues of urban planning and public debate in a visually collaborative environment. To this extent we are working on four main themes within Second Life. The first is the importation and visualisation of geographically tagged data including buildings such as our Virtual London model (Batty and Hudson-Smith 2005) as shown in Figure 1A, and maps (Figure 1B), the second is the acquisition of real time data feeds. For example, Figure 1C shows RSS feed running on a text board within our section of Second Nature Island. For example, linked to the BBC News feed, updating every second with the latest news. We also link near real time feeds to geographic places. For example, in Figure 1D we show weather data in Second Life - global maps in our space on Second Nature Island displaying temperature, rainfall, wind speed, barometric pressure and humidity round the world. The global data is updated every 15 minutes with the data for the UK on the local map updated every 3 seconds, allowing the 3D visualisation to morph between values. The third area is the visualisation of the built environment including building facades and 'step inside' urban spheres, all of which provide a sense of place.

The work illustrated above demonstrates Second Life potential as a medium for outreach and communication which was unimaginable ten years ago. It offers a vast range of possibilities. While it is still experimental, there is a major challenge in assembling information coherently and then using it collectively. Most of our work is largely static but updatable, but Second Live provides a means to model dynamic behaviour of the 3D objects in virtual worlds therefore making it ripe for the creation of 3D agent-based models (our forth area of interest) which are highly visual and interactive; it is to this we now turn.



A B C D

Figure 1: Visualisation of data within Second Life.

A: *Importing and Visualising Virtual Cities.* ***B***: *Visualising Geographical Data.* ***C***: *RSS Feed Running on a Text Board.* ***D***: *Real-time Weather Feeds from around the World.*

3: Agent-Based Models in Second Life

ABM in Second Life has mainly focused on biological systems to date[2], specifically evolution and the change in the inherited traits of a population of organisms from one generation to the next. A core example is on the island Terminus where 'living' creatures survive, reproduce and interact according to simple rules. Through these simple rules its goal is to implement the simplest possible features of an organism in a way that still allowed for flexible and varied behaviour (Hart quoted in Inman 2007) and therefore allowing for a fully functional ecosystem develop. Similar is the island of Svarga where rain makes plants grow, bees pollinate the plants, and plants slowly evolve. The simulation allows for experimentation, by turning off the clouds or

[2] However, this is not to say that these are the only agent-based models within Second Life, for example, others have focused on changing the configuration of rooms depending upon the number of avatars within whereby the walls and floors are agents, if there are small numbers of avatars the rooms are smaller and as more avatars join the room the room itself becomes larger (Maher and Merrick 2005) or the exploration of norms and social dynamics (Rehm and Rosina 2008).

wiping out the bees, results in a chain reaction, killing the entire ecosystem, delivering a subtle conservation message. Another example of a biological agent-based model within Second Life is ant foraging (Tectonic 2007) and finally Merrick and Maher (2007) have explored herding behaviour of sheep and the resulting flocking characteristics using motivated reinforcement learning. The sheep are agents with sensors allowing them to monitor objects (the environment and other sheep), avatars and their location in the world.

These ecological models demonstrate that Second Life has the potential to create immersive science learning experiences from virtual experiments and simulation through to real-time collaboration and virtual lectures. Perhaps its greatest contribution – intentional or otherwise – to the real world therefore might be as a learning tool. While it is clearly possible to create agent-based models in Second Life, little research has been done on more intricate social simulations within the system. Indeed, there is little reason why Second Life cannot be used as a platform for design and collaboration of simple agent-based models. Before we introduce our take on social agent-based models, we will first take a look at how one creates objects within Second Life and certain limitations of using Second Life for ABM in general.

3.1: Building Blocks of Second Life

Second Life, as with other virtual worlds, users are provided with open-ended modelling tools with which they can create and modify world content (Merrick and Maher 2007). Many virtual worlds including Second Life have the following features (Hudson-Smith et al 1998): insert/delete objects in scenes at run time; track and communicate the state/behaviour of objects on real-time; allow (sets of) objects to be ‘driven’ by users in real-time; let imported objects become persistent; support persistent roles (for people) and rules (for scenes); link objects dynamically to external data/functions; and support the free exchange of information among objects.

Within Second Life, the virtual landscape can be extended using a combination of primitive shapes and textures to create new buildings, plants, animals and other artefacts. Linden Labs allows access to its application programming interface (API) which in turn allows agents and other objects to be written in Linden Scripting

Language (LSL) an internal, event-driven, C/Java-style language. LSL has much of the functionality of a full programming language therefore allowing for agent-based models to be integrated into the system. Through LSL rules can be assigned to objects and sub-objects therefore allowing one to control objects and avatar behaviour and thus creating dynamic behaviour The use of the LSL also has the added advantage of allowing one access to over 3300 built-in functions including collision detection, physics simulations and communication between objects to name but a few.

The basic building blocks within Second Life are known as primitives, or ‘prims,’ a prim is a basic 3D geometric object which makes up all Second Life objects. Prims are one of several 3D shapes: a box, a cylinder, a prism, a sphere, a torus, a tube, or a ring, we illustrate these basic building blocks in Figure 2. Objects are linked groups of individual prims. Objects can contain anywhere from 1 to 255 prims (Rymaszewski et al 2007). This allows for objects to be built, for instance, a Second Life user can build a functional piano object out of virtual building blocks (prims) endowed with various physical and behavioural properties. Furthermore, textures can be mapped onto the objects to give them a more realistic appearance. As mentioned earlier, to build objects in Second Life, one needs land. A basic parcel of land measures 512m by 512m and supports approximately 14160 prims (or for every 4.3m of land you get 1 prim) with a maximum size imposed of one prim being ten meters. This is imposed by Second Life to allow for servers to operate efficiently.

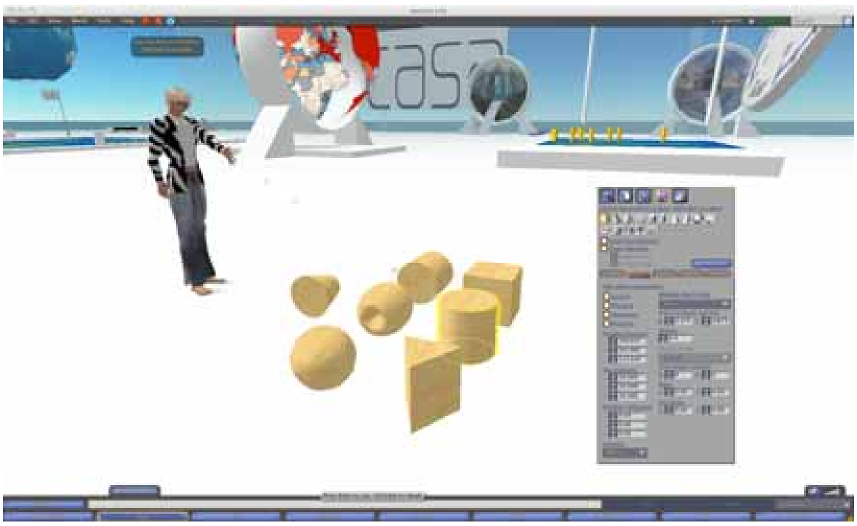


Figure 2: Prims – The Basic Building Blocks of Second Life.

Like other simulation and modelling systems, there are disadvantages associated with using Second Life for ABM. Not only is there a limitation on the number of objects and therefore the number of agents that can be created within Second Life for a given piece of land but there are three further issues. First, there is a limit on the size of a script file (currently this is 64KB), scripts can be chained together but this still limits the ability to deal with the thousands of commands required for large-scale models or for agents to learn. Secondly, complex simulations are slow to run due to server side delays on certain built-in global functions. Thirdly, for models to remain persistent, one needs land which has an associated cost. These are notable limitations but it should be noted that this paper is aimed at highlighting the future potential of virtual worlds of ABM, the concepts therefore hold true despite current restrictions.

While agent-based models can be created directly using LSL, the limitations noted above have lead some researchers to take a loose coupling approach (e. g. Merrick and Maher 2007)[3]. Such an approach allows agent-based models to be created in another language such as Java or C#. Such models are communicated with Second Life via remote procedures such as XML-RPC or HTTP requests with the Second Life server. Second Life is only used to collect and display information, however despite this approach limitations remain, relating to execution speed and bandwidth limits. For example, Merrick and Maher (2007) comment that with this loose coupling approach there is server side delays as only 256 characters per message can be sent between the client application and the Second Life server, thus reducing the number of properties each object can have. Merrick and Maher (2007) envisage that these limitations will disappear with improvements in virtual world technologies. One advantage of an isolated system is that it is easier for debugging due to the relative ease in locating execution errors in linked systems. With these limitations acknowledged, our models to which we now turn, are completely written in LSL, we only take the isolated approach to record agents movement and to create graphs within a feedback loop.

[3] For a discussion on coupling approaches the reader is referred to the work of Castle and Crooks (2006).

4: Example Models

To highlight how Second Life can be used for social science ABM we will present three simple models, first Conway's Game of Life, secondly a Schelling's segregation model and thirdly a prototype pedestrian evacuation model. These models were chosen as they highlight how classical automata styles of models, which have inspired a generation of modellers, can be created and explored in Second Life. The models can be seen on our "Agent Street" as we highlight in Figure 3. All the models were created using LSL and all the agents behaviours and rules are executed within Second Life. We provide the model code, further technical details and movies of the models in action at www.casa.ucl.ac.uk/abm/secondlife or alternatively visit the street in Second Life and go to the model vending machines as shown in Figure 4, where the models can be downloaded and saved. Due to the confines of space what we present below is a description of each model, its main elements and some basic results highlighting how such models can be created in Second Life. For more detailed information the reader is referred to the web site above.

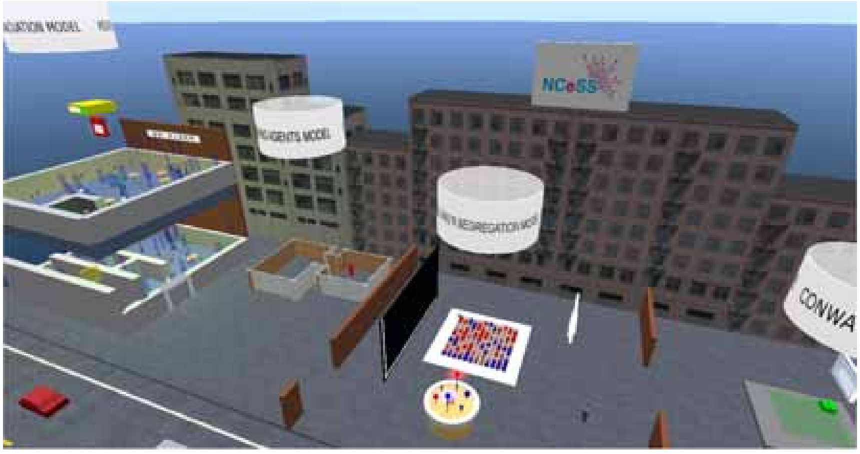


Figure 3: Agent Street: Agent-based Models in Second Life.

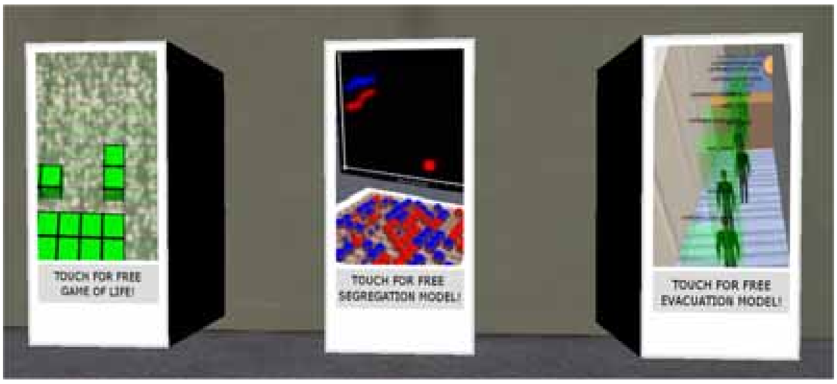


Figure 4: Model Vending Machines: By touching the Machines Visitors can Download and Save the Models.

4.1: The Game of Life Model

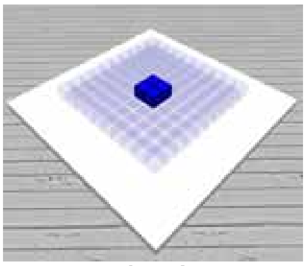
The purpose of the first model is to demonstrate how a simple automata based model can be created using prims and how their behaviours can be modified leading to the emergence of more complex structures within Second Life. We chose John Conway's 'Game of Life', a 'classic' cellular automata (CA) model, for several reasons. First, it was one of the earliest examples of emergence and self organisation; secondly, it has been an inspiration to numerous scientists and thirdly it demonstrates how the initial state (distribution of automata) determines the evolution of the system.

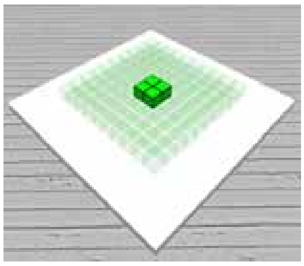
As with the original game, we use a 2D grid of square cells (10 by 10), each of which has two possible states 'alive' or 'dead.' Each cell interacts with its surrounding eight neighbours (Moore Neighbourhood) and at each iteration (time step) of the model the following transitions occur:

- Any live cell with fewer than two live neighbours dies (e.g. loneliness).
- Any live cell with more than three live neighbours dies (e.g. overcrowding).
- Any live cell with two or three live neighbours lives, unchanged, to the next generation.
- Any dead cell with exactly three live neighbours comes to life.

From these simple rules and the initial configuration of 'dead' and 'alive' cells, it is possible to generate the emergence of numerous patterns as we demonstrate in Figure 5. These include static patterns, repeating patterns ("oscillators"), and patterns that translate themselves across the board ("spaceship").

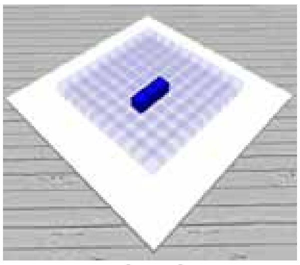
To provide users with the opportunity of interacting with and learning from the model, we have designed a control panel with a series of initial configurations (as shown in Figure 6A which are based on patterns from Figure 5) which the user can select and see how the system evolves. Additionally we allow the user to start off with a blank board and add their own 'alive' cells as we highlight in Figure 6B, and then start the model, thus demonstrating to the user how initial configurations of the model impact on the patterns that emerge.

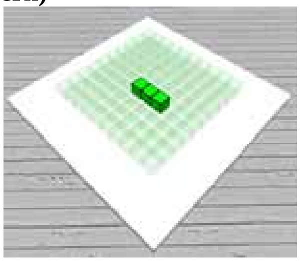




Initial Condition *T1*

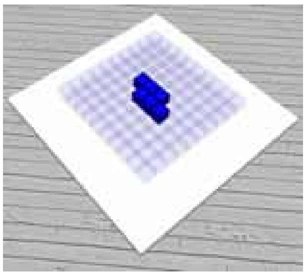
Block Pattern (Static Pattern)

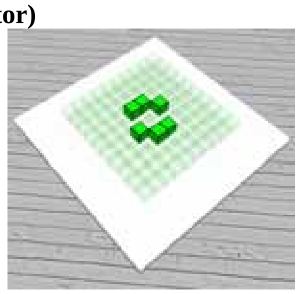




Initial Condition *T1*

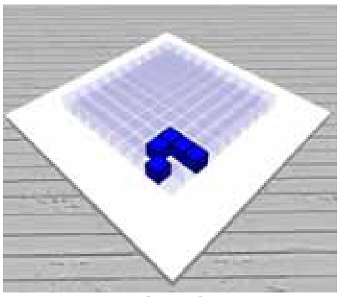
Blinker Pattern (Oscillator)

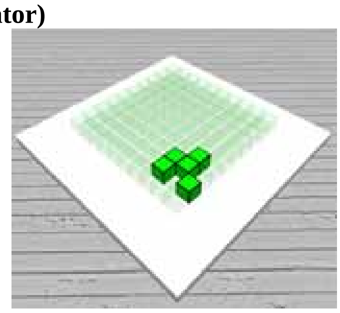




Initial Condition *T1*

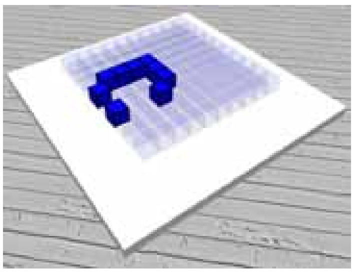
Toad Pattern (Oscillator)

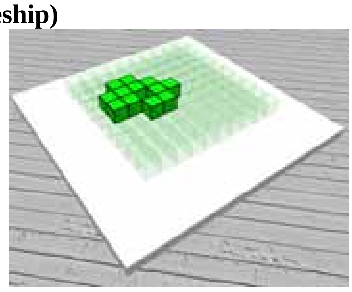




Initial Condition *T1*

Glider Pattern (Spaceship)

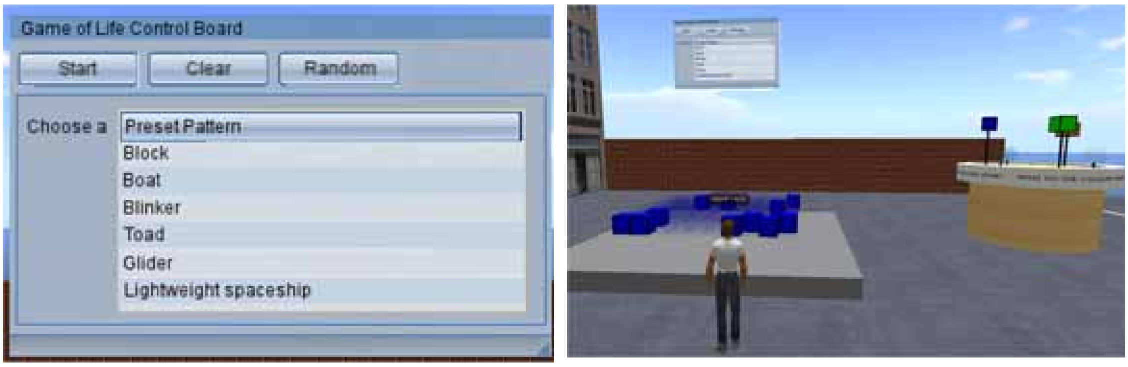




Initial Condition *T1*

Lightweight Pattern (Spaceship)

Figure 5: Examples of Patterns From the Game of Life.



A B

Figure 6: The Game of Life Model in Second Life.

***A**: Allowing the User to Select a Preconfigured Distribution of 'Alive' Cells From the Control Panel.*
***B**: User Starting with a Blank Canvas which 'Alive' Cells can be Added.*

4.2: Schelling s Segregation Model

In our second example we move from CA based models to an agent-based model operating in cellular space, that of Schelling’s (1971) model of segregation. Unknowingly, Schelling was one of the pioneers in the field of ABM (Schelling 2006) and has generated and inspired large amounts of research around the segregation phenomena (see Crooks 2008 for a discussion). Schelling demonstrated how geographical segregation along racial lines could result from mild discriminatory choices by individuals.

As with Schelling’s original work we use a two-dimensional checkerboard (12 by 12 grid), which could be imagined as representing a city, with each square of the board representing a house or a lot, in which equal numbers of two types of agents (48 of each type) representing two groups in society. Within this model we use red and blue agents but these types can be used to represent different social classes, racial groups, sexes, etc. Initially these agents are placed at random across the board, with no more than one per square and a small number of squares left vacant (to avoid studying the effects of restricted movement Schelling (1971) suggests 25-30% vacancy to allow for freedom of movement, within this model we have 48 empty cells). The rule of the model involves whether an agent decides to move or not. The agent decides to move from its square to an empty one if less than a specified percentage of its neighbours (based on a Moore neighbourhood) are of the same type as itself (we consider an agent living by itself to be satisfied). The game progresses in a series of steps, where at each step, an agent is given the option to move[4]. An agent is chosen at random and can decide whether or not to move. Agents move if they are dissatisfied with their current neighbourhood. If the agent decides to move, the agent moves to the nearest vacant square that meets its demands for a specific neighbourhood configuration (Schelling 1971). The simulation progresses until all agents are satisfied with their neighbourhood configuration.

To further aid the users understanding of what is occurring we use two different sizes to represent agents. Large agents are satisfied and smaller agents are dissatisfied with their current location as highlighted in Figure 7. Figure 8 represents such a progression from where the agents are randomly scattered across the board until all agents are satisfied with their neighbourhood configuration. In this case, agents want to be located in areas where at least 50% of their neighbours are of the same type as themselves. As the simulation progresses, the two types of agents divide themselves up into sharply segregated groups and the number of smaller (dissatisfied) circles decreases. The model shows that segregation emerges through mild preferences to locate amongst like–demographic or economic activity groups, and that strict segregation emerges unknowingly.

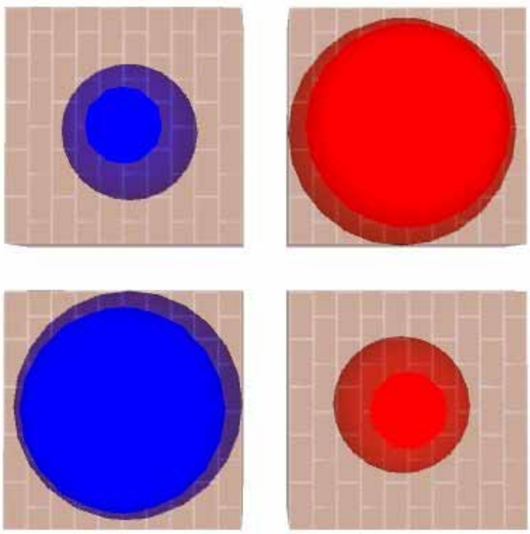


Figure 7: An Example of Satisfied and Dissatisfied Agents (Satisfied Agents are the Larger Circles).

[4] Agents only move to areas where they will be satisfied. If there are no suitable areas the agent does not move. This only becomes an issue when segregation preferences rise above 90%.

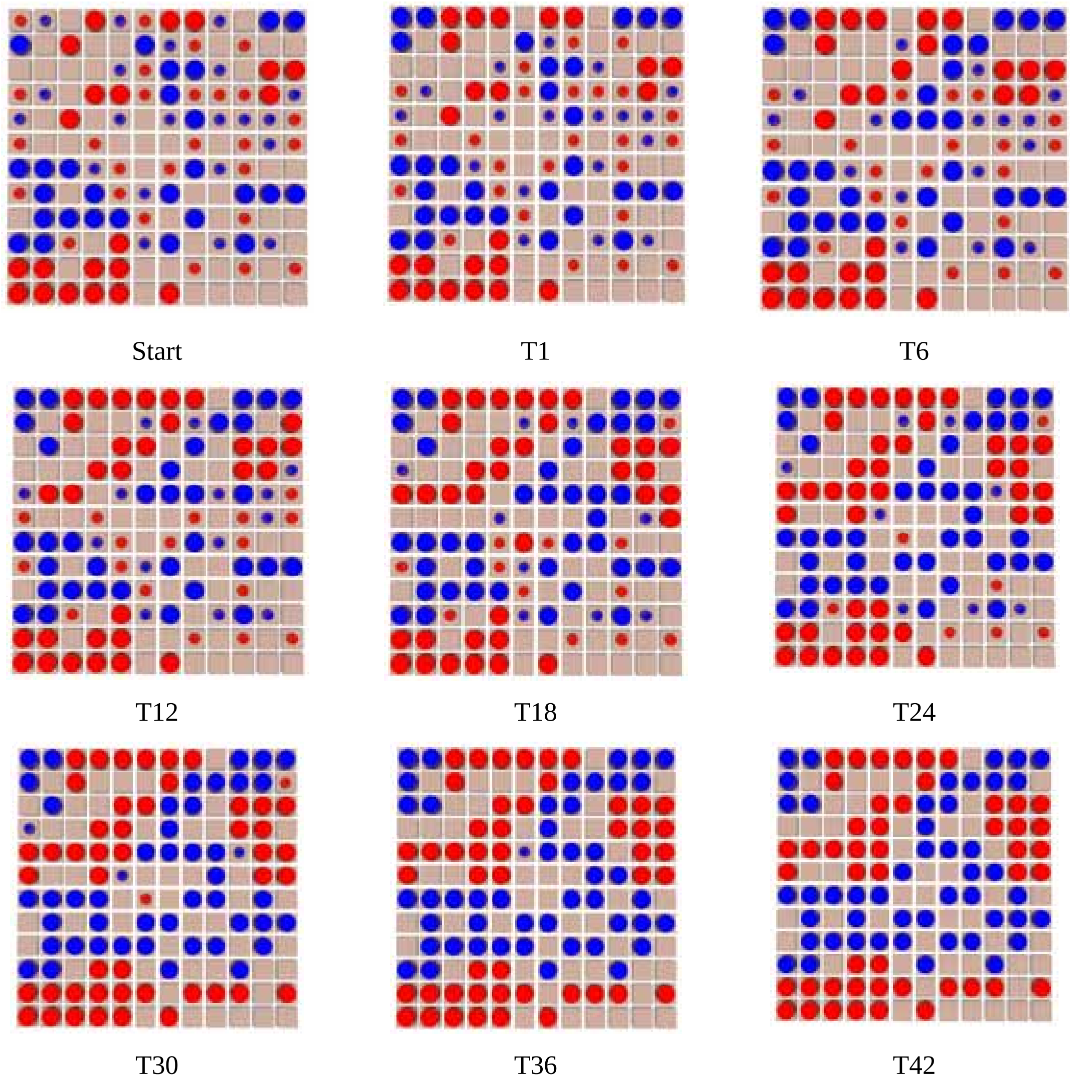


Figure 8: The Evolution of Segregation when Agents want to Live in Neighbourhoods where 50% or More are Like Themselves (Small Circles Represent Dissatisfied Agents).

Visualisation is one of the most effective ways to communicate key model information (North and Macal 2007). The highly visual medium for experimentation and user interaction of Second Life provides for such communication, as it allows decision makers to see the model running in near real time. Figure 9 highlights the segregation model itself, including the two-dimensional checkerboard, the graph and the control panel. The graph was included to provide the user with further insights about the agent-based model. It records the number of satisfied agents of both types during a simulation run (on the y axis). This was included to show that over time (x axis) the number of agents dissatisfied with their neighbourhood changes. The aim was to demonstrate how neighbourhood preferences impact on the pattern of segregation. The control panel allows users to select the agents' preferences for specific neighbourhood configuration at the start of a simulation run. Under different neighbourhood preferences different degrees of neighbourhood segregation can be seen to emerge as illustrated in Figure 10. As one would expect, higher preferences not only result in more segregated neighbourhoods but the model takes longer to stabilise, with 90% neighbourhood preferences not reaching equilibrium. This is caused by agents moving from one area to another area and potentially causing the other agents in the new area to become dissatisfied and the lack of empty areas.

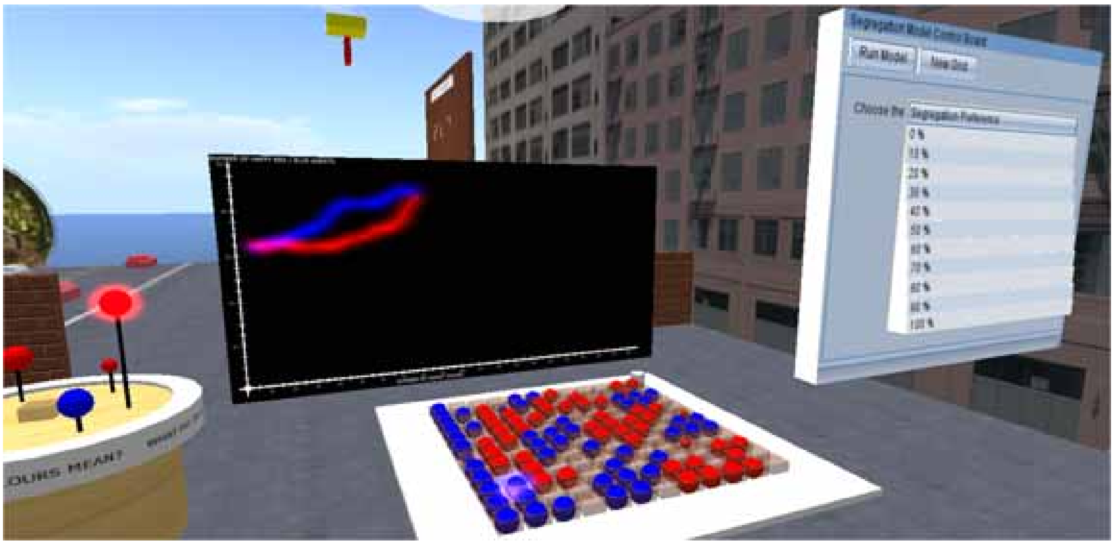
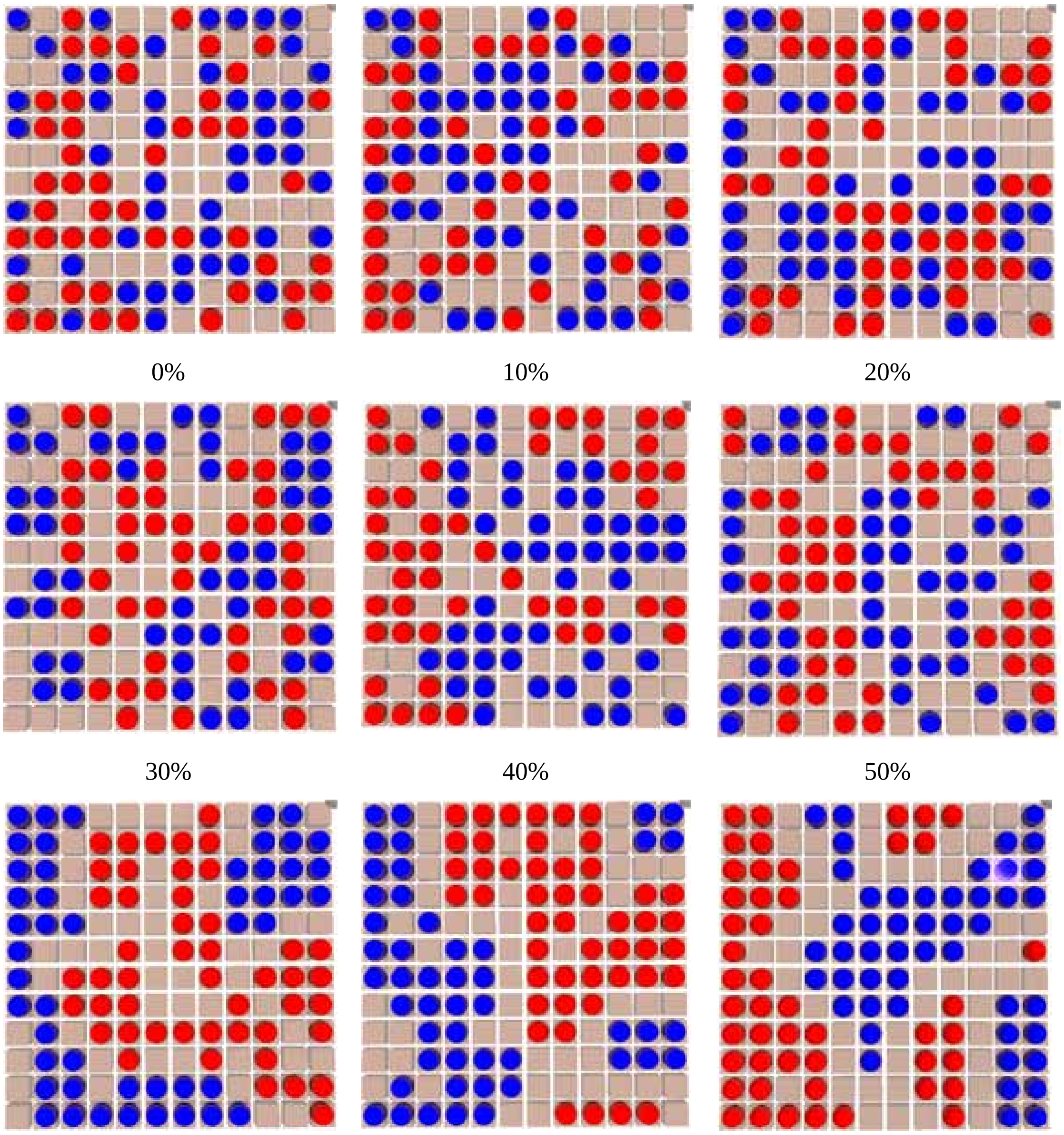


Figure 9: Schelling's Segregation Model within Second Life. With the Graph in the Background, the Checkerboard in the Middle and Control Panel in the Foreground.

4.3: Pedestrian Evacuation Model

ABM is particularly suited to topics where understanding processes and their consequences are important (Gilbert 2007). As noted above, agent-based simulations serve as artificial laboratories where we can test ideas and hypothesis of phenomena which are not easy to do in the real world. One such example is pedestrian evacuation. For example, without actually setting a building on fire we cannot easily identify people's reactions to such an event. ABM, as with simulations in general, allow for such experiments. Rather than setting a building on fire, we can recreate the building in an artificial world, populate it with artificial people, start a fire and watch what happens. Such simulations allow the modeller to identify potential problems such as bottle necks and allows for the testing of numerous scenarios. At the same time, Second Life allows others to explore such simulations in near real time and provides a sense of place.



0% 10% 20%

30% 40% 50%

60% 70% 80%

Figure 10: The Role of Preferences on the End Pattern of Segregation that Emerges.

In our third model we present a basic pedestrian model. The purpose of this model is twofold, first to show how such models can be created in Second Life. The previous models were essentially 2D table top models, we now move to the third dimension using actual ‘life-size’ building blocks whereby agents interact with each other and their surrounding environment. Secondly, this model allows the exploration of how basic room configurations can impact on evacuation time. This model is more complex than the previous two as agents have different walking speeds and awareness of more features such as walls, exit signage and stairs.

As the model is more complex than our previous two, the following subsections will provide brief details of the model including the environment (Section 4.3.1), the agents (Section 4.3.2), the key processes within the model (Section 4.3.3), and some basic model results (Section 4.3.4). As with the previous two models, the actual code and technical details describing the inner workings of the model can be accessed at www.casa.ucl.ac.uk/abm/secondlife. The provision of code additionally allows for replication and docking the model with other programming languages and software. However, before introducing the model a caveat is needed. That is the model was purposely kept simple, agents have simple rules governing their behaviour and movement (see Castle and Longley (2008) for a review of several more complex pedestrian evacuation models that have been developed). The intention is not to evaluate actual buildings, but to demonstrate Second Life's ability to carry out a range of modelling styles.

4.3.1: The Environment

We represent the enclosure as a continuous space opposed as the more common regular lattice (grid) or coarse network enclosure representations (see Castle 2007b). Agents are not restricted to discrete cells nor represented as flows, enabling us to simulate pedestrian movement more explicitly. Castle (2007b), comments that the pedestrians movement is defined by an individual's walking speed and a velocity vector corresponding to their orientation, where orientation is determined by a pedestrian's location in geometrical space with respect to their individual goal (i.e. nearest exit). Stationary obstacles such as tables and walls, as well as non-stationary obstacles (i.e. other pedestrians), will have an effect on occupant movement. Generally, pedestrians assess a local area to themselves (e.g. a buffer of a specified size) in order to adjust their walking speed (e.g. decelerate when approaching congestion), and a minimum personal space that stationary and non-stationary obstacles cannot encroach within.

Within Second Life it is relatively easy to build and alter structures. In our example we have three preconfigured room configurations from a simple layout, a more complex layout with internal walls and tables as obstacles (both of which have 50 agents) and a two story building where the floors are connected by a staircase as shown in Figure 11 (with 50 agents per floor). Each room measures 20m by 20m. Emergency exit signage is important when it comes to evacuation of buildings, exit routes need to be simple and clearly visible for greatest exit efficiency (Nelson and Mowrer 2002). Within the model we use emergency exit signage for way-finding (see Section 4.3.2). The pedestrian follows such signage to the exit. The three layouts allow us to test how internal building layouts impact on evacuation time.

4.3.2: Pedestrian Properties

Each pedestrian is defined as a moveable object and we have attempted to make the agents look a little ‘life like’ as we highlight in Figure 12. Furthermore, we give the agents real anthropomorphic dimensions which are defined by shoulder breadth and chest depth. These are set to 43 cm and 25 cm respectively, that is values that correspond to the medium anthropomorphic dimensions of an unclothed British man or women (Pheasant and Haslegrave 2006). The height of the agents is 2m, this reflects avatars in Second Life which on average are 2m tall.

People also walk at different speeds; the speed at which a pedestrian can walk is dependent upon their available space (i.e. density of pedestrians in a local area) and the local terrain (e.g. upstairs, level surface) as demonstrated in Figure 13. Clearly walking speed increases up to a certain point when there is more available space. For example, Ando et al (1988) lowest walking speed is approximately 0.35m/second when available space is 0.25m^2/person rising almost linearly before plateauing at approximately 1.35m/second when available space is 1.5m^2/person. Walking speed is further complicated by purpose (e.g. shopping, commuting, evacuation), nationality, age and gender (see Castle 2007a for such a discussion). Nelson and Mowrer (2002), also note that humans have a psychological preference to avoid bodily contact defined by Fruin (1971) as ‘body ellipse’[5].

[5] As an interesting side note such interpersonal distance preferences have already been observed in virtual environments between avatars (see Yee et al 2007).

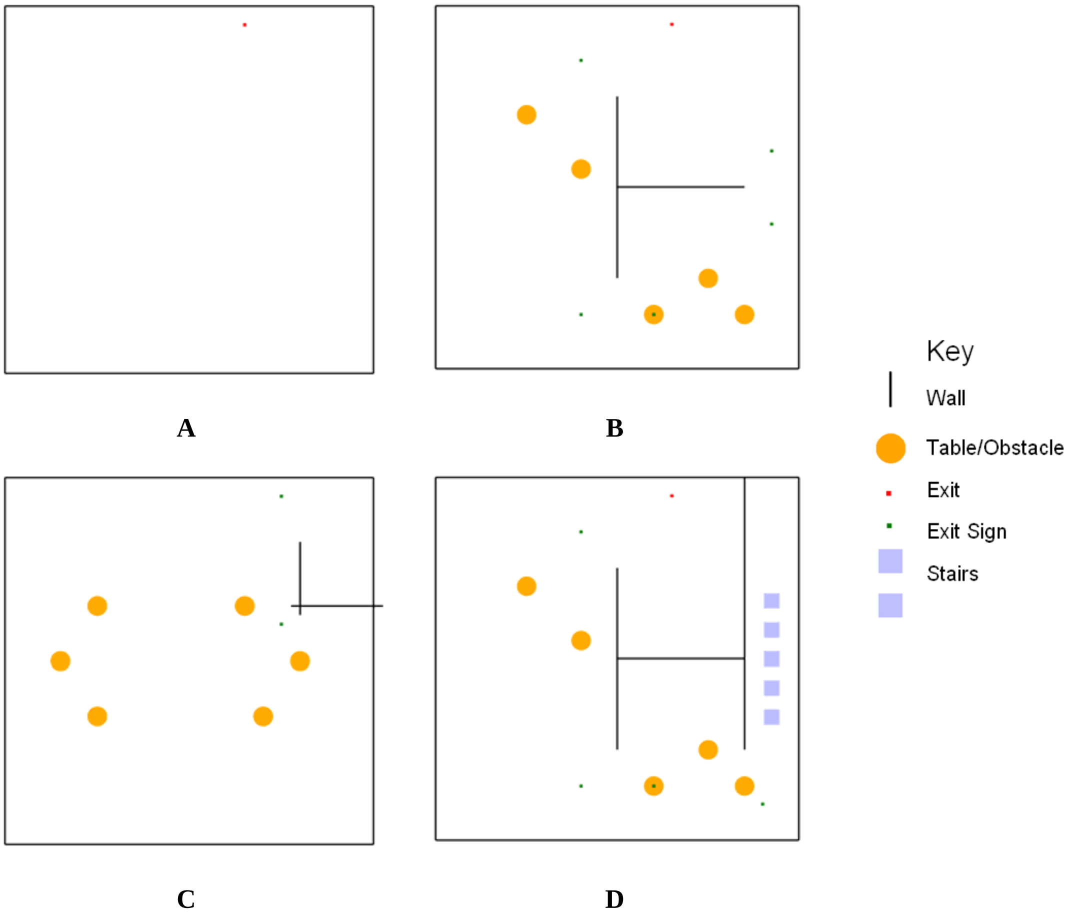
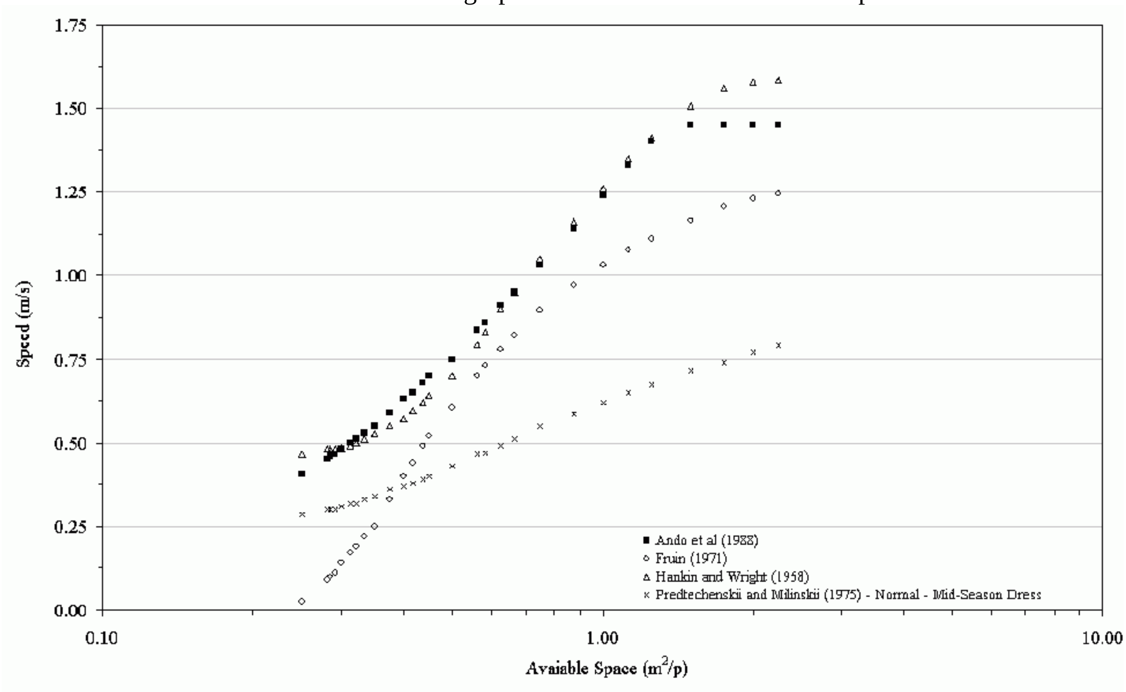


Figure 11: Different Internal Room Configurations

*(**A**) Simple Room, No Obstacles; (**B**)Complex Room Layout, with Obstacles, and Internal Walls; Multi-Story Connected by Stairs with Obstacles and Internal Walls (**C**=First Floor, **D**=Ground Floor).*

Figure 12: Pedestrian Agents with Texture Mapped Features.

A: Level Surface Walking Speed as a Function of Available Space.



B: Comparison Upstairs Walking Speed as a Function of Available Space.

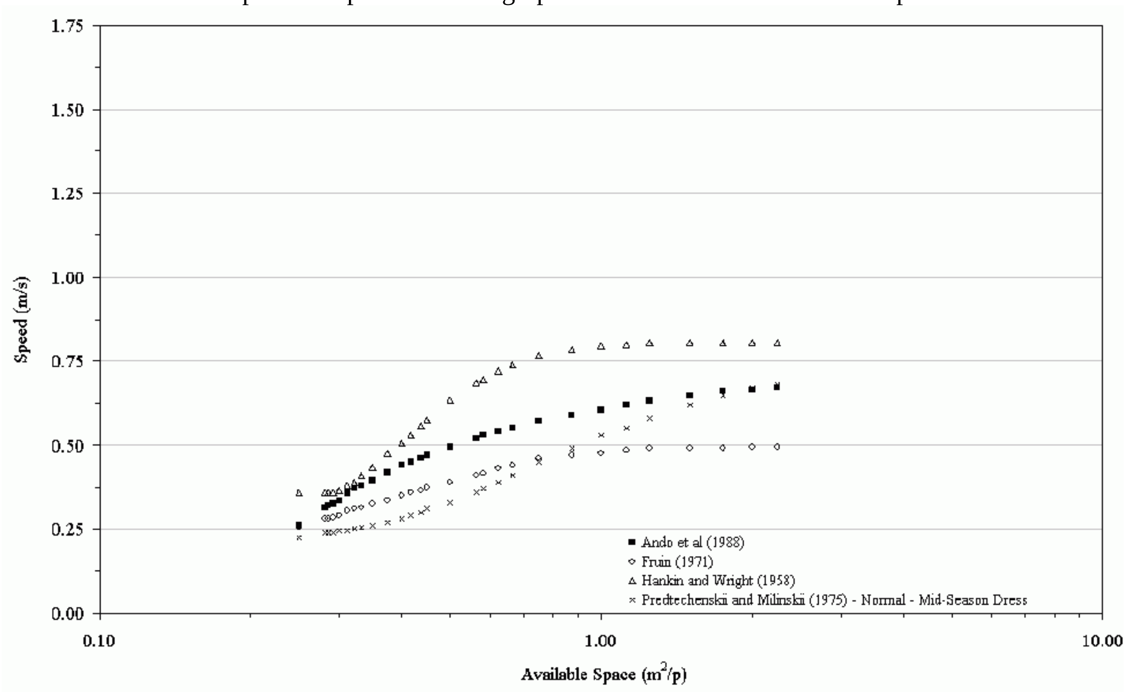


Figure 13: Comparison of Ando et al.'s (1988), Fruin's (1971), Hankin and Wright's (1958), and Predtechenskii and Milinskii's (1978) walking speed data as a function of available space. (Source: Castle 2007a).

Within this model we use Ando et al (1988) walking speed and use the agents anthropomorphic dimensions to act as their body ellipse for simplicity. An avenue of future work includes experimenting with different walking speeds and body ellipses and exploring how this affects simulation outcomes (such as evacuation times). It would also be possible to give agents different anthropomorphic dimensions, gender, age and walking speeds dependent upon the above, thus permitting to a heterogeneous population. Furthermore, the model does not consider the propagation of smoke, a process well documented (e.g. Proulx 2002), as this is beyond the scope of this study.

Pedestrians route-choice is an important consideration when it comes to evacuation of buildings. However, since a pedestrian chooses a route from an infinite set of alternatives this leads to a series of challenges, both in terms theoretical and practical problems in describing pedestrians behaviour (see Hoogendoorn and Bovy 2004, for a summary of route-choice behaviour research). Two common approaches for route-choice are shortest path or following emergency signage. The shortest path approach is based on the notion that individuals will want to minimise the distance they have to walk which is not necessarily the route indicated by emergency signage. Both approaches relate to the pedestrians enclosure perspective, for example, if they know or do not know their environment. People used to the building would have global knowledge of the building (i.e. able to calculate the shortest path) while visitors would have limited knowledge of building layout and more likely to follow emergency signage (Castle 2007a). We chose the simplest option that is pedestrians follow emergency signage to the exit.

4.3.3: Pedestrian Model Processes

As noted above, the pedestrian evacuation model is more complex than the previous two models and therefore we trace out the simulation key processes. To start the model, the user needs to choose one of the building layouts. Once this is done, the building is created; agents are placed within it and wander randomly until an alarm is sounded (Figure 14). Once the alarm is activated, it takes 20 seconds for the agents to react to it. At each model tick (model second) all the agents have the option to move and simultaneously check to see if they are at a specific destination (e.g., fire exit sign, stair case, exit etc.). For each agent, if the answer is yes it then checks to see if it is the exit, in which case the agent is removed from the building. If it is not an exit, the agent chooses a new direction to walk based on its line of sight. If the agent is not at its destination, it checks whether it can move to a new location without colliding with other agents. This decision is made by calculating its maximum walking speed, a process based on the density of surrounding agents and their walking speed. Once the agent moves, its new position is recorded and sent to PedTrace (see Section 4.3.4). When agents have made their move, they remain stationary until the next model tick (which occurs when all the agents have had the option to move) before repeating the process.

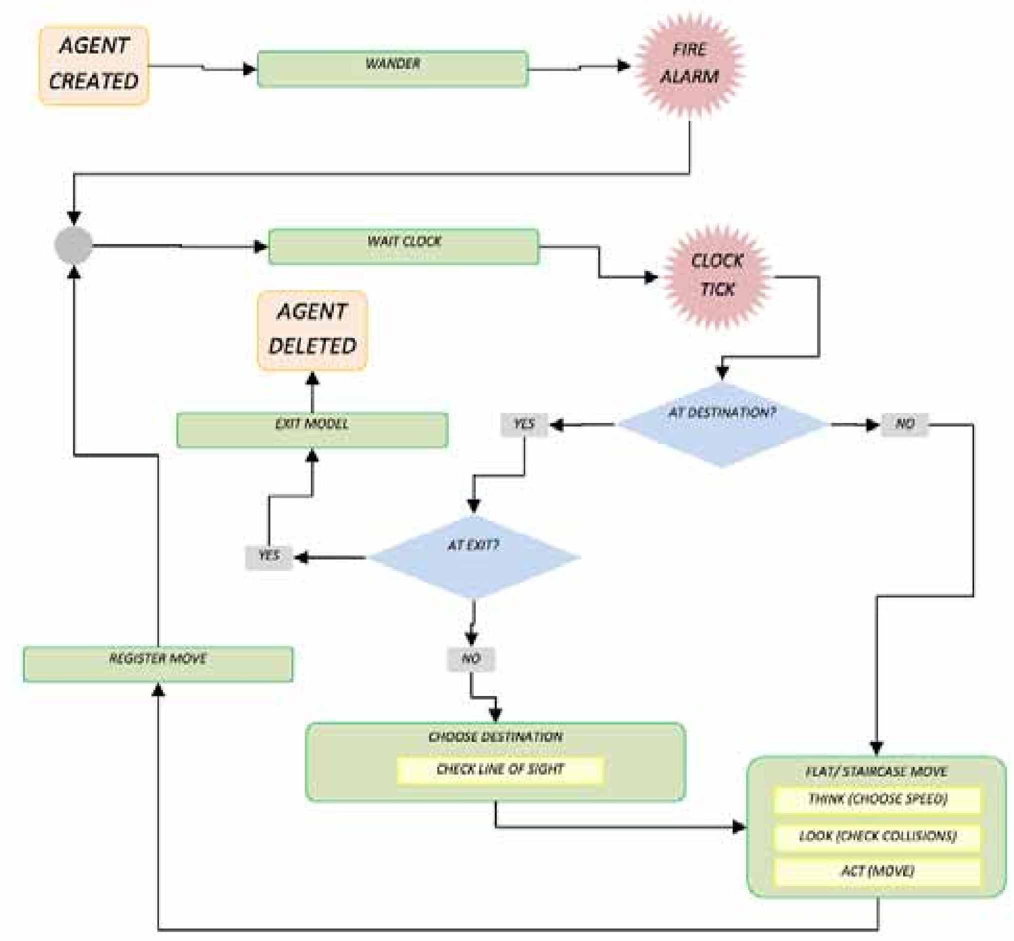


Figure 14: Flow Chart of the Pedestrian Agent Key Processes Pertaining to Movement.

As time within Second Life equates to 'real' time, watching any agent-based model in Second Life is 'real'. However, the execution of one second (tick) of model time takes longer than one second of 'real' time due to server requests, delays etc. While every effort was made to make the script as efficient as possible, recent advances on Second Life server have made the model run faster; the authors believe that the only way to run the simulations in 'real' time is to wait until the Second Life server speeds up substantially through technological advances or until the model itself is loosely coupled with Second Life, whereby the model is written in another language and Second Life is only used for visualisation.

4.3.4: Preliminary Results and Discussion

We are not able to validate the model *per se,* except through testing its plausibility in commonsense terms, however, this is an avenue of future work but we can verify the structure. This was achieved by building the model iteratively and unit testing the model code at every step during the model development process. To help verify and validate the model we linked it to a custom built web application called PedTrace running on a web server outside Second Life. Messages are sent between the two via HTTP messages. The web server records the position and speed of each pedestrian at every second of the model. PedTrace then uses this data to generate movement trace images and two graphs: total number of agents exited graph and an average walking speed graph. Thus we are able to track the simulation history as advocated by Axelrod (2007) and map the outcomes to see if it 'looks right' (Mandelbrot 1983).

Through PedTrace we are able to visually interpret how the different room configurations can help enhance our understanding of how the model works and test model sensitivity. For instance, we can explore how the density of pedestrians results in congestion near exits and doors, impacting on walking speeds and evacuation time. Figure 15 displays three typical simulation runs and information from PedTrace for the three different room configurations[6]. These include all paths walked, average walking speed (metres per second), and the total number of agents that have exited the simulation during a simulation run. In the simple layout example, once the alarm is sounded agents walk to the exit. It takes 27 second for all the agents to leave the building with walking speeds ranging from 0.9 to 1.7 metres per second, as there are less agents in the room. For the complex building layout where agents have to avoid obstacles including tables, the total time for all the agents to exit the building is 57 seconds. This is a result of the agents not being able to walk straight to the exit due walls and tables being placed in the room. Similar to the simple layout walking speeds range from 0.9 to 1.7m per second. In the multi floor example, it takes 184 seconds for all the agents to exit the building once the alarm is sounded. This is a result of

[6] The reader is referred to http://www.casa.ucl.ac.uk/abm/secondlife/ for animations and higher resolution images of these simulation results from PedTrace application.

more agents (100 instead of 50 as in the previous two examples) and a more complicated layout where agents need to walk further to exit the building. The average walking speed varies between 0.7 to 1.5 metres per second. From the traces one can identify bottlenecks such as top of the staircase. Such a model demonstrates that the speed of occupant movement is dependent upon surrounding space available, terrain and the characteristics of each pedestrian.

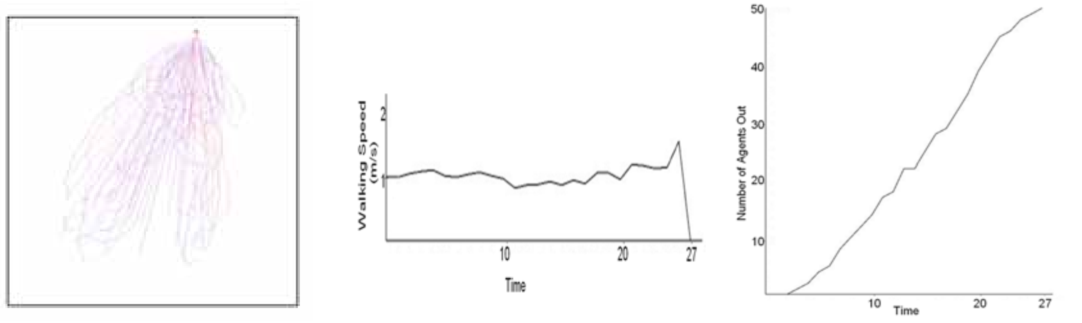
From the examination of the pedestrian traces especially in the multi floor example one issue we feel needs to be briefly discussed is the route choice and collision detection mechanism which we use. In our model we allow the agents to walk towards the exit but if they encounter an obstacle they randomly choose to go left or right. This occasionally leads agents to walk a longer route to the exit rather than following the straightest path which is apparent in the pedestrian traces[7]. However, when an agent does not take the most direct route, for example, due to loosing sight of the exit signage, it is still restricted by walls and tables. This problem could be overcome with the agents being forced to check their route direction (line of sight) every time they move and not every time they reach their destination and choose a new route as described in Section 4.3.3.

5: Discussion and Conclusion

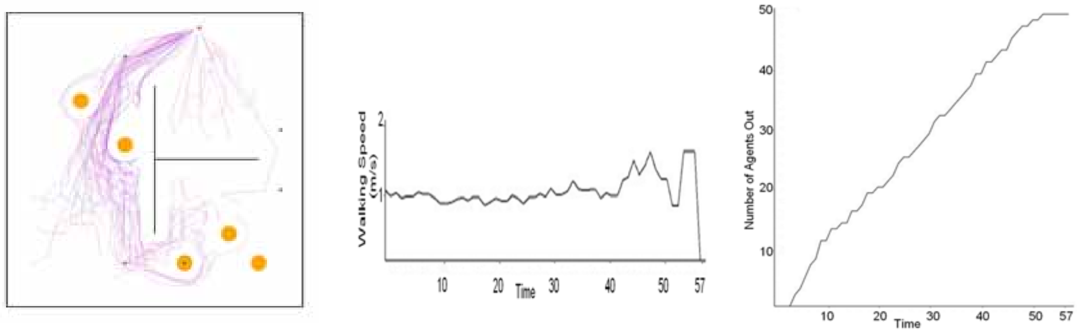
This paper has introduced virtual worlds and highlights their research potential for social scientists specifically focusing on ABM. The fact that virtual worlds combine both agents and human controlled avatars allow many experiments to be carried out (Bainbridge 2007). Not only does Second Life provide an area for entertainment, we have demonstrated its educational usage for displaying geographic information and for ABM. The models we have presented were purposely kept simple and their purpose is only as a pedagogic demonstration. The aim was to simply highlight how such a style of modelling could be communicated to a wide audience. To further this outreach potential we have provided all the code and detailed model descriptions, movies of simulation runs at www.casa.ucl.ac.uk/abm/secondlife.

[7] To see this process occurring the reader is referred to the movies of multi floor simulation at www.casa.ucl.ac.uk/abm/secondlife

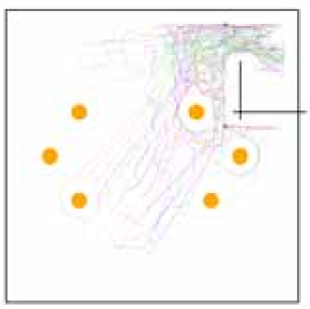
Pedestrian Paths **Average Walking Speed** **Number of Pedestrian Exiting**



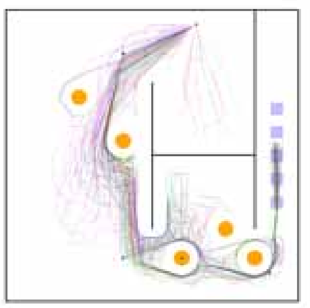
Simple Layout



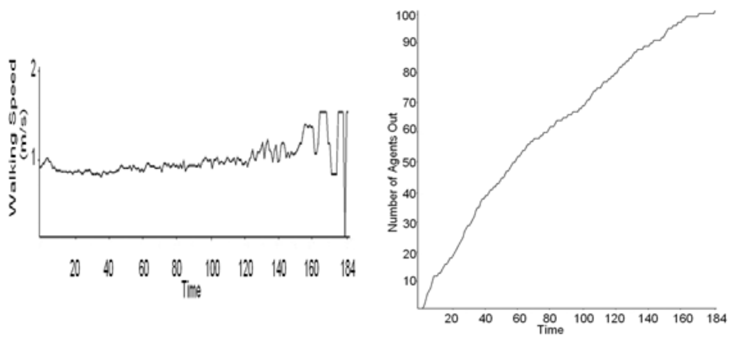
Complicated Layout



Upper Floor



Ground Floor



Multi-Floor Layout

Figure 15: Typical Simulation Results from PedTrace when all the Agents have Exited the Three Different Room Layouts.

Second Life offers something which is not easily achievable with many other ABM platforms: that of powerful visualisation and communication tool for models in a totally immersive environment which has the potential to greatly aid our understanding and dissemination of such models. The visualisation and communication options provided allows us to address the challenge modellers face on how we might communicate and share agent-based models with all those we seek to influence (Crooks et al 2008). In the past, this was mainly done through discussion of model results. Through Second Life, it is possible to share modelling processes and its outcomes with various non-expert participants and potentially allows non-experts to participate in actual model construction. Therefore in the future it could offer an environment for rapid prototyping of ideas in near real time, engaging both modellers and multiple stakeholders under which key policy initiatives could be tested on large scale populations simulated at the individual level.

However, there are disadvantages with using Second Life as a medium for the creation of agent-based models. As with other virtual worlds, there are limitations which illustrate the deficiencies of the internet (Chen et al 2006). These include its high latency (slow packet delivery speed) and low bandwidth (the amount of information that can be delivered in a given period of time), constraints imposed by the technology (i.e. limited number of objects, server side operations, etc.), scheduled downtimes. However, as discussed in the introduction, the purpose of this paper is to show the potential of virtual worlds for ABM and the problems mentioned above should decrease over time.

Pertaining to offering a platform for ABM, Second Life has a lot of in-built functionality which reduce the burden modellers face programming parts of the simulation which are not content specific (e.g. the GUI). As with any type of models, increasing the complexity of the model by integrating more rules, generally results in models that take longer to run, which is an issue for real time simulations. Furthermore, Second Life is not open source, it is difficult therefore to tell if bugs within the code or the software exist, such as collision detection errors noted in the pedestrian evacuation model. Additionally, Second Life is not particularly well suited from graphing and storing model information. While simple graphs are possible, such as in our Schelling model, for more complex data storage a loose coupling approach is needed, where information is passed between the Second Life server and a local computer (as in the case with PedTrace). Some of these issues may disappear with technology advances and Second Life server updates. However, perhaps the largest limitation is the associated cost required for a persistent piece of land. This issue is not encountered when using other ABM toolkits or other web-based agent-based models such as NetLogo or HubNet, a component of NetLogo (Wilensky and Stroup 1999). While initially our land was provided free of charge from Nature, due to reorganisation within the company, the area we need for the street of simulations is now rented.

While such limitations exist, this paper has shown the potential of virtual worlds for ABM. Additionally, while the models are only abstract, acting as a 'proof-of-concept', they demonstrate a unique environment that virtual worlds offer in which to explore, visualise and interact with agent-based models. We cannot see why such models could not be taken further in Second Life or inspire other research into ABM and virtual worlds. For example, real-world buildings could be used in the future for pedestrian evacuation modelling. Already in Second Life there are models of the Burj Al Arab hotel in Dubai and the Ajax soccer stadium in the Netherlands. Our previous work described briefly in Section 3 demonstrates the potential of importing other geographical data which could be used for actual buildings or environments which could then be populated by agents and avatars. Furthermore, the models presented in this paper demonstrate how agent-based modellers and participants could potentially explore scenarios such as pedestrian egress from buildings in near real time and in 3D, thus identifying bottle necks etc. in such buildings. Moreover, one could envision avatars interacting with agents and agents interacting with avatars (such as avoiding each other in a pedestrian egress) in mirror world locations which we are currently exploring.

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