Using Agent-Based Models to Simulate Complex Geo-Spatial Systems-Towards Monitoring HIV/AIDS Transmission in Uganda

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Abstract

Agent Based Modelling (ABM) has become a common paradigm for simulating human and natural complex systems. The purpose of this study was to demonstrate the use of ABM approach to simulate the spread of HIV/AIDS through a given population over a given time period. Two approaches were considered. The first, allowed infected agents to interact with the rest of population, while in the second approach, the infected agents were quarantined so as not to allow continuous infection. Complex data simulation was carried out using selected initial immune and infection levels. The results overall, showed an increased number of infected agents over a given period of time. On the basis of the observed results, it can be concluded that, although, modelling such complex systems faces challenges, the ABM nevertheless, provides the basis for understanding the spread HIV/AIDS diseases.

Keywords: ABM, HIV, Complex systems, simulation

1. Introduction

Coupled human and natural systems in which humans interact with their environments are well known to be complex systems (Liu, Dietz et al. 2007). Modelling, which is defined as a design effort for structuring models (de By and Huisman 2001), can be applied to simply and abstract reality of these complex systems (Longley and Batty 2003). Models allow exploration of real world phenomena through simulation and computation (Gimblett, Daniel et al. 2000). Different scenarios of the real world can be visualised by altering the data in the model. This provides the basis for understanding the various systems by monitoring changes in the environment, as well as answering the "*what if*" questions (de By and Huisman 2001).

The models used for simulating complex systems can broadly be classified as either spatial form or process models (Heywood, Cornelius et al. 2006). Spatial form models are suitable for performing data analysis operations but do not provide adequate information on the process responsible for creating changes of spatial form. In contrast, process models attempt to provide information on the processes responsible for creating or changing spatial form (Gimblett, Daniel et al. 2000; Parker, Manson et al. 2003). However, processes that impact on spatial form including: population change, consumer spending patterns, and soil erosion, are complex and hence, difficult to represent (Heywood, Cornelius et al. 2006). Some examples of the models that have been developed to represent the complex spatial phenomena are the equation-based models, system models, statistical techniques, expert models, evolution models, cellular models, hybrid models and agent based models (Burrough and McDonnell 1988; Heywood, Cornelius et al. 2006; Longley, Goodchild et al. 2001; Parker, Manson et al.

2003). This study focuses only on the latter for simulating complex geo-spatial systems.

2. Agent or individual based modeling

Agent- Based modelling (ABM) has become a dominant paradigm in social simulation due to the view that complex systems emerge from the bottom-up and composed of heterogeneous objects called agents (Crooks, Castle et al. 2008). Agents, interact in time and space resulting into an emergent order, often at higher level than that in which the agents themselves operate. The ABM approach describes a computational study of social agents as evolving systems of autonomous interacting agents (Benenson 2004; Janssen and Ostrom 2006). Accordingly, the Agent Based Models (ABMs) are models in which the basic unit is an agent (Schelhom, O'Sullivan et al. 1999) and can be used to describe the individual organisms (Grimm, Berger et al. 2006). Generally, individual agents can comprise of software, networks, people, and machines. However all agents have common properties that include: autonomy, heterogeneity, active, reactive, bounded rationality, interactive, mobility, and adaptive (Benenson 2004; Parker, Manson et al. 2003).

The development of ABM techniques has been facilitated by a number of factors including the desire to model processes that alter the spatial form (Heywood, Cornelius et al. 2006), and the developments in computer technology, particularly, the computing power of computers (Castle and Crooks 2006). Some of the available software that implement process modelling techniques are the RePast, Swarm, Cormas, Mason, Simile, Anylogic, RBSIM, GeoDa, Netlogo and Starlogo. The ABM has been applied in diverse areas of inquiry, for example, modelling the movement of people through shopping centres, underground station or supermarkets (Bandini, Manzoni et al. 2003; Zhu and Timmermans 2008); spread of diseases (Bagni, Berchi et al. 2002; Bilge and Saka 2006; Perez and Dragicevic 2009; Perrin, Ruskin et al. 2006; Perrin, Ruskin et al. 2006; Scarlat and Maracine 2008; Teweldemedhin, Marwala et al. 2005), growth of urban areas (Augustijn-Beckers, Flacke et al. 2011; Ettema 2011), woodland management (Metsaranta 2008; Premo 2006) and agriculture (Schreinemachers, Berger et al. 2007).

Odell (2007) presents that agent technology has become an ingredient to reduce costs; improve efficiency and effectiveness between individuals, groups, companies, and universities as they collaborate globally. Furthermore, agents can be used to: 1) capture emergent phenomena; 2) provide a natural environment for certain systems and 3) develop geospatial systems (Parker, Manson et al. 2003). The main objective of the study was to develop an application for monitoring the spread of HIV/AIDS within a given population comprising of both women and men.

3. Methodology

The methodology adopted for the study is shown in Figure 1. Key components of the conceptual model were: 1) definition of the population of interest, 2) setting the rules for the initial infection rates, 3) setting the rules for the spread of the disease and changes thereof, which also forms the basis for monitoring the spread of the disease over a given period of time. The resulting conceptual ideas were used as inputs for building a logical model using the Starlogo TNG 4.2 software.The Starlogo TNG software, although still at the development phase, has been used for simulating complex systems.

Basically, the software comprises of an interface with two main windows i.e. the *Starlogoblock*s window and the *spaceland* window (Figure2). The *Starlogoblocks* window provides an environment for building programs that perform specific tasks, and has two main parts i.e. the block and canvas parts. The block area has a number of blocks which are logically arranged in the canvas area. The canvas is further divided into five parts i.e. the turtle, setup, global, runtime and patches. There is also edit breed component for creating and editing the turtles. The spaceland on the other hand provides and environment for the agents to interact.

In order to investigate the spread of HIV/AIDS across a given target population, the target agents were defined, which in this cases consisted of both men and women. The initial number of men and women was set to 100 and 150 respectively. These numbers were subsequently varied through quarantine operation. Initial infection for both the men and women was selected on the basis of a random process. The idea was to have some members within the population infected with the HIV/AIDS virus. Similarly, the immunity was also considered for both women and women. The number of women and men with initial immunity was also selected on the basis of a random process. The essence of this was to have some members of the population having initial immunity to the disease. This was considered appropriate especially for HIV/ AIDS disease.

In this study, the initial infection and immunity proportions were set at 5% of the original target populations. Under the assumption that a person who acquires the disease has no possibility of recovery and such a person will continue spreading the virus until quarantined, the model was run for 25 and 50 seconds. Therefore, two different scenarios were considered. In the first case scenario, the agents were not quarantined after infection while in the second case scenario the agents were quarantined after infection. Based on these criteria, different patterns of the model output were observed.

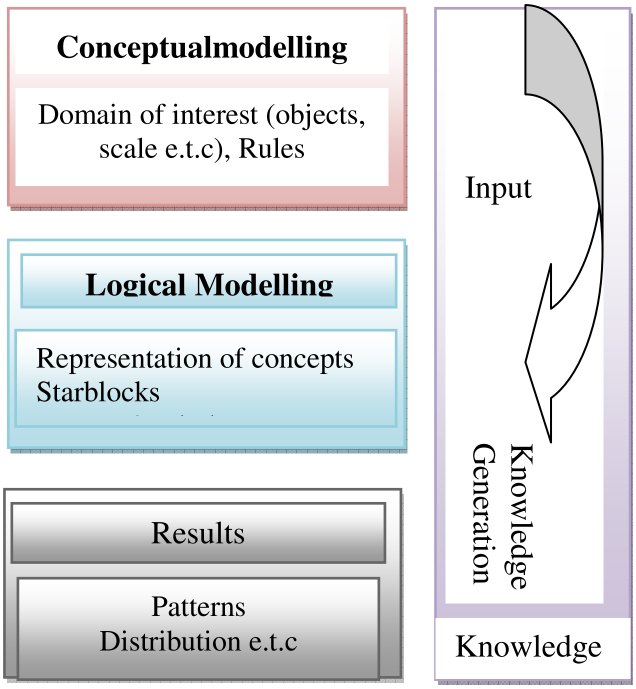

Figure 1: Research methodology

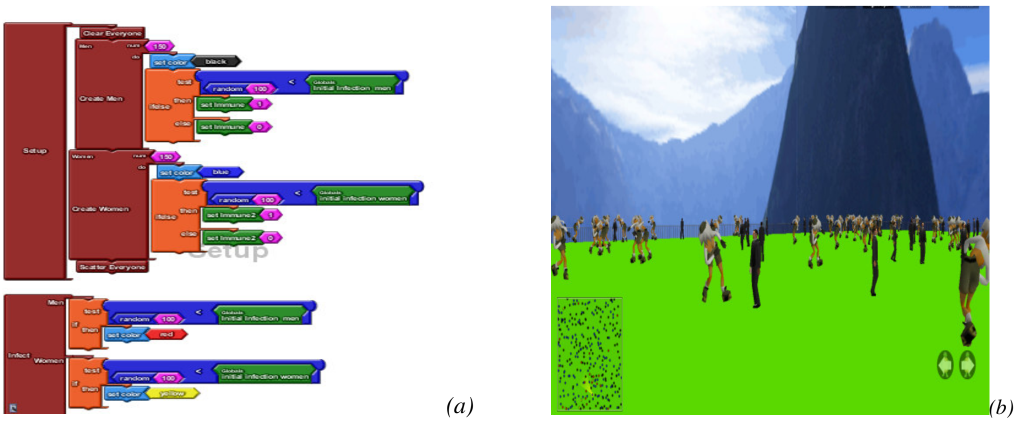

Figure 2:10Starlogo blocks (a) and spaceland (b)

4. .Results and discussion

Figure 3 shows a graphical representation of the spread of HIV/AIDS among agents at given time periods. It can be observed that that, for the process model in which no quarantine operation was implemented, the rate of infection increased with time. Related results of the observed patterns are shown in Figure 4. In contrast, no much difference was observed for the case of the quarantine process model. There was however, a very significant difference between the non-quarantined and quarantined infection rates. In general, the quarantine operation minimised the spread of the

HIV/AIDS virus.The flexibility to allow the alteration of parameters that may have an effect on the rate of HIV infection is plausible. This enables an in-depth understanding of the factors that cause HIV/AIDS. However, modelling the parameters or factors that cause HIV infection is not an easy task. For example, modelling individual movements as well as the actions that result into HIV is difficult. Additionally, it is difficult to model what happens when one acquires the virus. Should the person be quarantined as the results in the experiment would suggest? Should a person be allowed to die, and if so, what should determine when a person is to die? This adds to the complexity of AB modelling of HIV in any given population. Unfortunately, there are also no available studies demonstrating the use of ABM for HIV infection. Further research is therefore necessary to compare the results obtained in this study.

5. Conclusion and recommendations

The study has explored the ABM in the context of disease monitoring. A StarlogoTNG application was developed and tested. The results obtained indicate that ABM can be useful for modelling HIV/AIDS. While the study was success, a lot however, needs to be done to make such models operational. There is also a need to explore such studies based on observed data. Further research into the application of ABM for monitoring the spread of HIV/AIDS in Uganda is therefore envisaged.

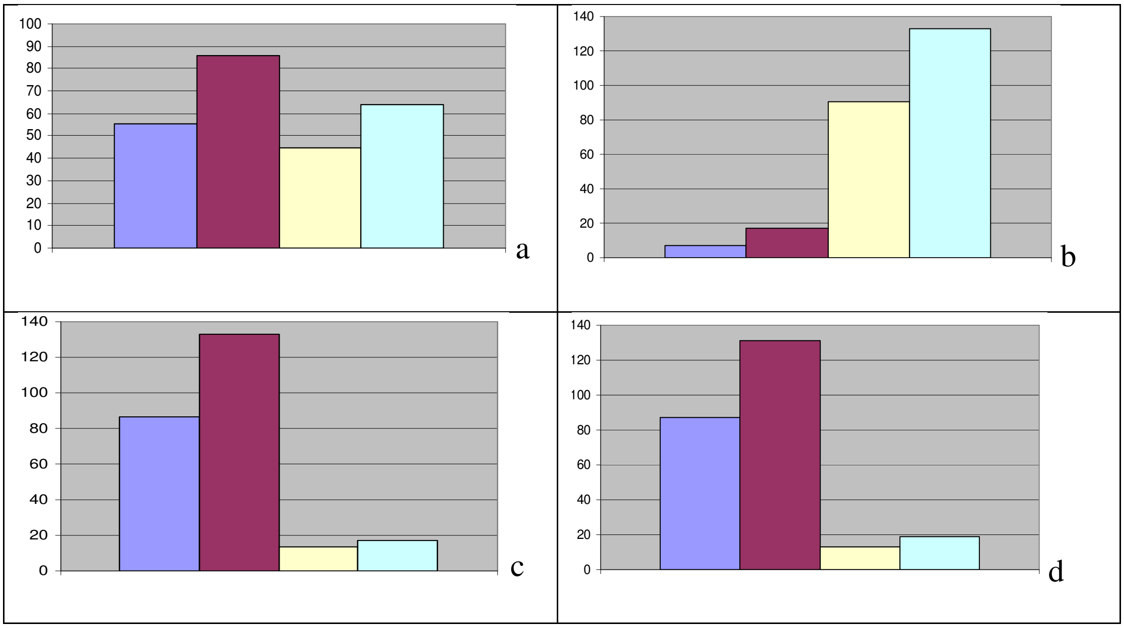

Figure 3: The graphs show the distribution of agents with HIV infection after 25 seconds (*a, c*) and 50 second (*b, d*). Safe men (purple), safe women (brown), infected men (yellow), infected women (cyan). Both graphs *a* and *b* were obtained assuming no quarantine

operation. In contrast, the distributions in *c* and *d* were obtained with quarantine after infection.

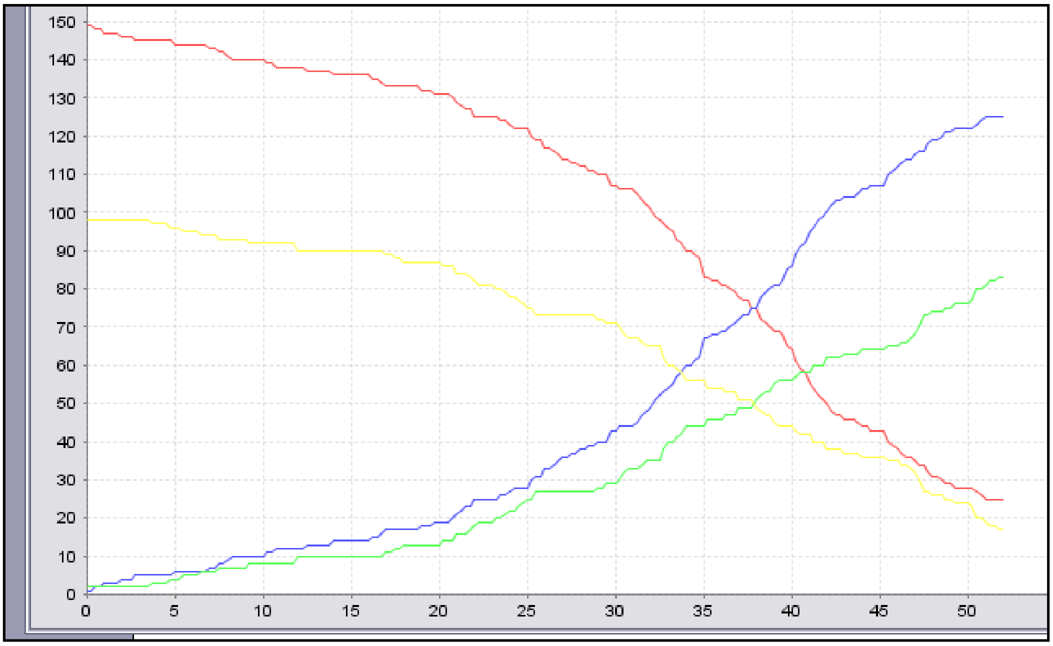

Figure 4: Progression of HIV infections through time. Red (safe women), Yellow (safe men), Green (infected men) and Blue (infected women).

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