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AGENT ORIENTED METHODOLOGY FOR MALARIA TRANSMISSION MODELLING AND SIMULATION

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ABSTRACT. Epidemiology study like malaria study is receiving much attention among the researchers nowadays. To model the epidemiology study like malaria, one can adopt different equations to formulate the problem. Alternatively, individual based modelling is started to emerge and useful for epidemiology study due to the nature of flexibility ad emergence behaviour of individual based modelling. Since various epidemiology mathematical models has been introduced and implemented, can we reuse the models in individual based modelling? In fact, it is possible but not a straightforward process. This paper presents a systematical approach for individual based epidemiology modelling and simulation by reusing the existing mathematical models on epidemiology study. With the systematic approach, a rapidly prototyping of epidemiology study is introduced. Also, it promotes the comprehensiveness and model transformation across technical and non-technical person.

Keywords: agent oriented modelling and simulation, epidemiology modelling

INTRODUCTION

Epidemiology study like malaria transmission model is used to simulate malaria outbreak which can aid in creation of a disease control systems that are appropriate for vector control units and health ministries. According to Jane (Kon and Jane, 2013), malaria transmission model describes spread of malaria in terms of flow of humans and mosquitoes between two states: Susceptible and Infectious. Susceptible represents the state of human and mosquito that are not infected yet but vulnerable to infection. Infectious represents the state of human and mosquito that have been infected with disease and are capable of spreading the disease to susceptible. The cycle of disease transmission begins when a Susceptible mosquito is feeding on blood of an Infectious human. This mosquito will become Infectious and continues spreading the disease to another Susceptible human through bites. The cycle of transmission repeats again when another Susceptible mosquito bites this recently Infectious person.

To model the epidemiology study like malaria, one can adopt different equations to formulate the problem. The differential equations is among the famous mathematical modelling technique. In this case, the transmission model is formulated as four separate but interconnected equations that represent populations of human and mosquito at specific health states. Alternatively, individual based modelling (IBM) or agent based modelling and simulation(ABMS) is started to emerge and useful for epidemiology study. Agent based modelling and simulation belong to a class of discrete mathematical approaches in which entities (agents) sense local information and react according to predefined rules (Chiacchio et al., 2014). The ABMS is flexible and suitable for non technical person. Also, it can be used without rely on a strong mathematical theory. The ABMS is known as a bottom up modelling approach in which each agents are interact and describe individually (Chiacchio et al., 2014).

Since various epidemiology mathematical models has been introduced and implemented, can we reuse the models in individual based modelling? In fact, it is possible but not a straightforward process. Among the possible reasons are, 1) the adoption of mathematical model do require strong mathematical theory 2) gaps of communication between domain expert and non-technical person 3)lack of engineering and systematical process on individual based modelling. In order to overcome the gap, a systematic approach to reuse existing mathematical model is introduced. This paper presents a systematical approach for individual based epidemiology modelling and simulation by reusing the existing mathematical models on epidemiology study. With the systematic approach, a rapidly prototyping of epidemiology study is introduced. Also, it promotes the comprehensiveness and model transformation across technical and non-technical person.

The following sections are arranged as following. First, the background study on the proposed agent oriented methodology for epidemiology study is presented. This is followed by the mechanisms to develop agent based epidemiology modelling and simulation. Then, the extended AOM with a run through example of malaria modelling and simulation is presented. Finally, the quantitative analysis of extended AOM is presented.

BACKGROUND

Agent Oriented Methodology (AOM) is a methodology that is introduced for complex system development (Sterling and Taveter, 2009). The AOM consists of three phases. They are conceptual domain modelling, platform independent design and modelling and platform specific design and modelling. The conceptual domain modelling also known as motivation layer in which it models the system from owner perspective. This involve understand the goal of the system without further details on how the system is design and implement. The platform independent design and modelling involve designing the system without looking into any particular implementation platform and language. The PSM layer is the lowest level of the system design. The design description at this layer allows the system to be deployed and executed in a particular environment like specific platform, hardware, technology, and architecture. To date, the AOM has been used in collaborative learning (Shiang et al., 2016), games development (WaiShiang et al., 2015), rural ICT (Shiang et al., 2016) projects, sustainability engineering (CheeWyai et al., 2015).

RELATED WORKS

The current development of IBM involve building a mathematical model and then simulation; and adopting engineering mechanism like UML then simulation and ODD protocol. (Dion et al., 2011) presents a model to study the effect of vaccination decision in disease modelling through individual based simulation. The work started with building a mathematical model, build a flow chart that characterize the individual based behaviour disease model and develop it using agent based simulation tool like netlogo. ODD (Overview, Design concepts and Details) protocol is used to build an individual based model for tuberculosis study (Grimm et al. 2010). In the ODD, the modeler involve in answering the following questions (Grimm et al. 2010). 1. What is the purpose of the model?; 2. What kinds of entities are in the model? What are the temporal and spatial resolutions and extents of the model?; 3. Who does what and in what order?; 4. Which general concepts, theories, hypotheses or modelling approaches are underlying the model's design?; 5. What key results or outputs of the model are modeled as emerging?; from the adaptive traits, or behaviors, of individuals?; 6. What adaptive traits do the individuals have?; and etc. Also, the modeler can adopt UML diagram like class diagram and sequence diagram to design the model as stated in (Dion et al., 2011). Inline with the success usage of ODD protocol, this paper introduce an alternative way for agent based epidemiology modelling and simulation through agent oriented methodology. According to (CheeWyai et al., 2015), methodology is vital to aid in communication between stakeholders and modelers regarding desired structure and behavior of the complex system. As a result, we argue that there is a gap in adopting individual based modelling in epidemiology study.

AOM FOR MALARIA TRANSMISSION MODELLING AND SIMULATION

We extend the AOM in order to copy with the replication of mathematical model in into ABMS. The methodology for reusing existing mathematical model consists of four layers. They are requirement elicitation layer, the real world conceptual domain modeling layer, the real world conceptual domain modeling, the agent simulation design modelling and the agent simulation development modeling.

In requirements elicitation layer, extended HOMER (or eHOMER) is used as a requirements elicitation technique to comprehend requirements from domain experts or mathematicians. In this case, the elicitation is focused on understanding mathematical model structures (i.e. variables and mathematical notations, and understand their meanings) and the assumptions of the model, and in turn, the elicitation answers are represented as agent contexts (i.e. as roles, tasks and rules). The real world conceptual domain modeling layer (or CIM) models the real world problem into goal, role, organization and domain. Modeling is done by mapping the elicited answers into goal model, role model, organization model and domain model. The agent simulation world – platform independent design modeling layer (or PIM) involves design of simulation artifacts in agent system. Here, agents are modeled to mimic the roles described in CIM layer to solve a problem. These agents are artificial representation of real entities (i.e. human or creatures) designed to be situated in a simulation environment. In the simulation world, these agents will behave according to the behavior or task performed by the real entities they represent (the roles). They will be modeled in scenario model, interaction model, knowledge model and behavior model. Finally, the agent simulation world – platform dependent modeling layer (or PSM) involves modeling of runtime aspect of agent simulation. In this paper, NetLogo is considered as a platform for developing agent oriented mathematical model and simulation. NetLogo is a multi-agent simulation platform for simulating complex phenomena.

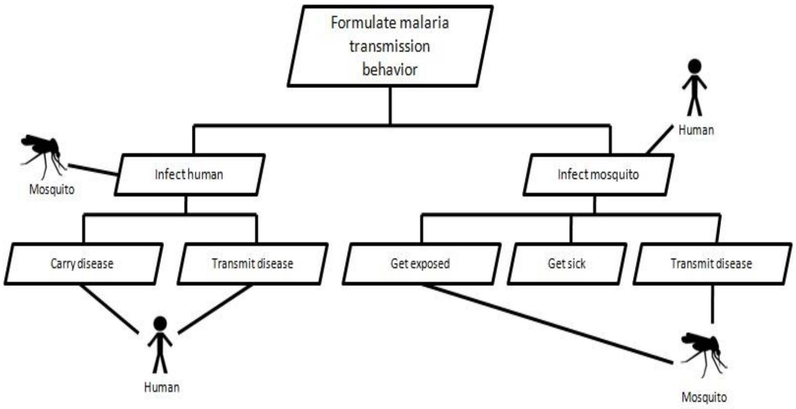

Figure 1. An overview goal model for malaria transmission study.

In order to validate the agent oriented methodology, a walkthrough example on how the malaria transmission study can be modelled as agent oriented model and simulate in netlogo is presented next. Due to the space limit, we only present goal model and domain model for malaria transmission study. The models are derived upon the elicitation phase as detailed in (Shiang et al., 2016). Figure 1 shows the overview goal model for malaria transmission study. The goal model in Figure 1 states that transmission of malaria happens when mosquito starts to infect human or vice versa. For mosquito, in order to achieve the goal of infecting human, it must first carry the disease from infectious human and then transmit disease to another susceptible human via bite and feed. For human, in order to achieve the goal of infecting mosquitoes, he/she must first get exposed to the disease via bites from infectious mosquito, get sick (i.e. fever) and then transmit disease to another susceptible mosquito that bit him/her.

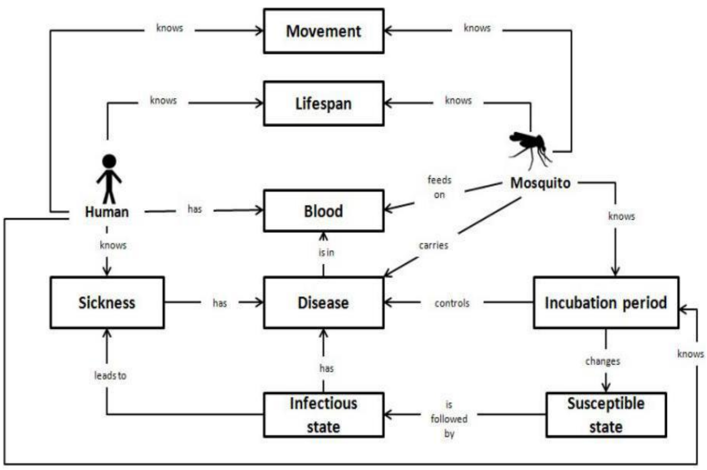

Figure 2. The domain model for malaria transmission behavior study.

The domain model for malaria transmission behavior study is represented in Figure 2. According to the malaria transmission behavior study learnt from the elicitation, the resources required for malaria transmission are Movement, Lifespan (derived from death rate), Blood, Disease, Sickness, Infectious state, Susceptible state and Incubation period. This domain model expresses that both human and mosquito knows about incubation period. The incubation period controls how disease comes to exist by first changing human or mosquito from being Susceptible to Infectious (and leads to human to become sick as well). Being Infectious means that human or mosquito now has the disease. In order to transmit this disease, it has to be contained in human blood where it will be ready to be carried by mosquito through bite and feed.

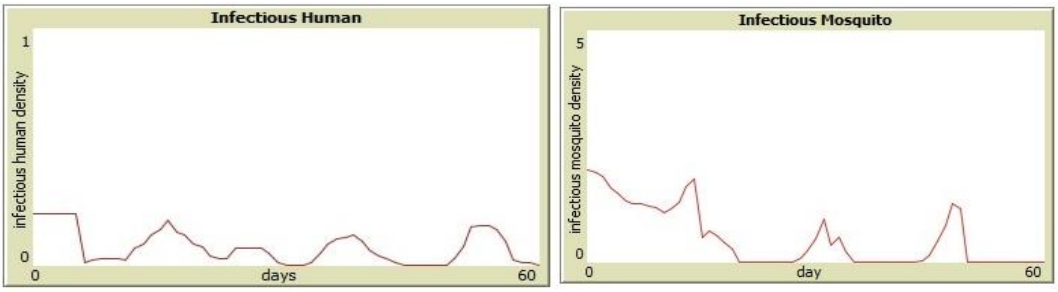

Figure 3. The spread of infection mosquito agents in 60 days.

From the goal model, domain model, the modeller will proceed with organization model, interaction model, scenario model, knowledge model, interaction model and behaviour model. Then the runtime model is developed through netlogo. Finally, the execution model is presented as shown in Figure 3. Figure 3 shows the behavior of spread of Infectious mosquitoes and humans agents in NetLogo after 60 days. The figures illustrate the spread of Infectious humans and mosquitoes in NetLogo when there are 200 initial Infectious mosquito agents). Results have shown that curves become higher and wider when number of Infectious mosquitoes is increased. For instance, in first 20 days of simulation, the curve of density population of Infectious mosquito in Panel-B appears to be larger.

FIELD STUDY

Work have been done to conduct an usability study of AOM for malaria transmission study. There were 30 undergraduate students who voluntarily participating in this usability test. These students are from Faculty of Computer Science and Information Technology in UNIMAS and have varied in study majors such as Software Engineering, Computational Science, Network Computing, Multimedia and Information System and have range of study year (from 1st year until 4th year students). These students have no prior knowledge or experience in ABMS and epidemiological study. Nevertheless, they do have familiarity or experience in basics of programming and knowledge of classical software development life cycle, obtained at some point of their past IT studies (i.e. from college or some training courses). In this research, two experiments are conducted. Due to the space issue, we present the first experiment in details. The experiment involved the study of requirement elicitation extension and the second experiment is to study the agent modelling and simulation. In the experiment 1, all students are required to answer a list of questions in related to malaria transmission differential equation model. These students were asked to complete Pre-Test within 1 hour. This is followed by a short tutorial session was conducted by the moderator on eHOMER. These students are instructed on how to use eHOMER to collect information about mathematical models. At the end of tutorial session, requirements elicitation session was conducted with these students. Upon completion of requirements elicitation session, students were asked to do Post-Test which consists of test questions regarding the malaria transmission study. The results of the experiment 1 is following. The mean and standard deviation of students' test scores and time in Pre-Test and Post-Test were first calculated. These values are used as proxies for measuring the usefulness of AOM in aiding students comprehending malaria transmission model. Mean measures the average of scores and time in Pre-Test and Post-Test. Standard deviation measures how spread out students' scores and time in Pre-Test and Post-Test is. Table 1 shows the mean and standard deviations from students' test scores.

Table 1. The mean and standard deviation from Pre-Test and Post-Test.

	Mean score (μ)	**Standard deviation of score (σ)**
Pre-Test	14	12
Post-Test	46	15

From Table 1, it can be concluded that a) students' scores in Post-Test (after using AOM) are larger than their Pre-Test score (not using AOM) and b) time taken to complete test questions by students in Post-Test is smaller than in Pre-Test. Hence, the use of extended AOM has led to improvement of test scores and reduction of time taken to complete test questions. Mean and standard deviation values from Table 1 are then translated into normal distribution graph to illustrate how spread out these Pre-Test and Post-Test scores is. Figure 4 presents the plots of normal distributions (the bell curves) based on means and standard deviations of Pre-Test and Post-Test scores. Red graph describes the curve for Pre-Test that has the mean of scores, $\mu = 14$ and standard deviation, $\sigma = 12$ whereas green graph describes the curve for Post-Test that has $\mu = 46$ and $\sigma = 15$. Mean value show where the peak is at (x- axis) whereas standard deviation value shows the width of the curve – the bigger the standard deviation value, the wider it becomes (data become spread out over wider range of values). According to the distributions shown in Figure 4, it appears that nearly all students in Pre-Test have same low scores. On the other hand, Post-Test shows sign of improvement in students' test scores where test scores are much diverse. Meanwhile, some of these students have achieved high scores.

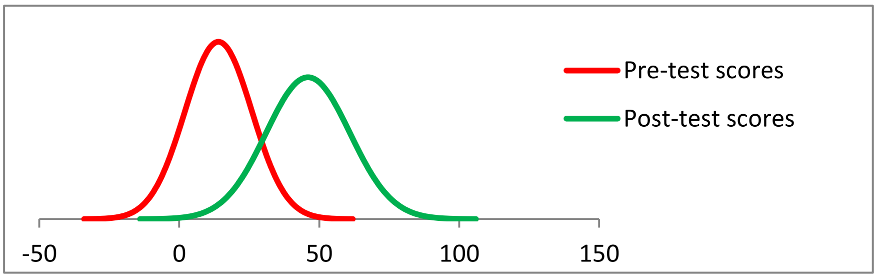

Figure 4. Normal distributions of Pre-Test and Post-Test scores.

CONCLUSION

This paper presents a systematic approach to model and simulate a malaria transmission study through agent oriented approach. The benefits of the systematical approach are following. With the methodology, we are able to replicate the malaria transmission differential equation model into individual based modelling. The agent models able to mediate the communication between technical person and non-technical person. The agent modelling is able to support a rapid prototyping of the malaria model. In future, an empirical study on the extended AOM among a wider sample is needed in order to produce better and accurate results. Meanwhile, the adoption of the AOM in other simulation platforms like GAMA, repast and exploring the AOM in other epidemiology study are worth to explore.

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