A Spatial Agent-Based Model of Malaria: Model Verification and Effects of Spatial Heterogeneity

S. M. Niaz Arifin, University of Notre Dame, USA
Gregory J. Davis, University of Notre Dame, USA
Ying Zhou, University of Notre Dame, USA

ABSTRACT

In agent-based modeling (ABM), an explicit spatial representation may be required for certain aspects of the system to be modeled realistically. A spatial ABM includes landscapes in which agents seek resources necessary for their survival. The spatial heterogeneity of the underlying landscape plays a crucial role in the resource-seeking process. This study describes a previous agent-based model of malaria, and the modeling of its spatial extension. In both models, all mosquito agents are represented individually. In the new spatial model, the agents also possess explicit spatial information. Within a landscape, adult female mosquito agents search for two types of resources: aquatic habitats (AHs) and bloodmeal locations (BMLs). These resources are specified within different spatial patterns, or landscapes. Model verification between the non-spatial and spatial models by means of docking is examined. Using different landscapes, the authors show that mosquito abundance remains unchanged. With the same overall system capacity, varying the density of resources in a landscape does not affect abundance. When the density of resources is constant, the overall capacity drives the system. For the spatial model, using landscapes with different resource densities of both resource-types, the authors show that spatial heterogeneity influences the mosquito population.

Keywords: Agent-Based Modeling (ABM), Computer Science, Landscape, Malaria, Spatial ABM, Verification & Validation

INTRODUCTION

Agent-based modeling (ABM) can be applied to a domain with or without an explicit representation of space. In some cases, however, an explicit spatial representation may be required for certain aspects of the ABM to be modeled more realistically. For example, in a spatial ABM of malaria, events like obtaining a successful bloodmeal (host-seeking) or finding an aquatic habitat to lay eggs (oviposition) can be modeled by utilizing the distribution of corresponding resources in the landscape.

Malaria is one of the top three pathogen-specific causes of global mortality, causing an...
estimated one million deaths per year, mainly in children (WHO, 2011). Only female mosquitoes of the genus Anopheles transmit human malaria, and as such are known as malaria vectors. The species Anopheles gambiae is the most important malaria vector in Sub-Saharan Africa, and one of the most efficient vectors (in terms of malaria transmission) in the world. Earlier, we developed an agent-based model derived from a conceptual entomological model of the A. gambiae lifecycle (Zhou et al., 2010; Arifin et al., 2010a; Gentile, Davis, StLaurent, & Kurtz, 2010). The model, however, was non-spatial: none of the agents and/or environments possessed any spatial attributes.

In this study, we describe a spatial extension of the previous model. Though in both models, all mosquito agents are represented individually, in the new spatial model, the agents also possess explicit spatial information. We show how the previous model and the current spatial model yield consistent results with identical parameter settings (whenever applicable), and hence are docked. We also show how spatial heterogeneity affects some results in the spatial model.

Spatial heterogeneity is considered as one of the most important factors for an effective representation of the environment being modeled. In the discipline of spatial epidemiology (also known as landscape epidemiology), in most cases, the probability of disease transmission significantly declines with distance from an infected host. Thus, the spatial locations of pathogens, hosts and vectors are fundamentally important to disease dynamics (Ostfeld, 2005).

In modeling malaria with ABMs, representation of space may be crucial (Gu, 2009a, 2009b; Menach, 2005). The dynamics of malaria can be subject to substantial local variations that result from various spatial differences (Vriess, 2001). Examples of local variations may include locations of aquatic habitats and bloodmeal events, characteristics of mosquitoes, etc. For malaria models, space can be represented as mosquito world, aquatic habitats, etc. for the mosquito agents; and as houses, huts, etc. for the human agents.

In our malaria simulation, some events (e.g., host-seeking, oviposition) by nature require spatial attributes. The underlying spatial heterogeneity defines the spatial distribution of resources, and controls how easily adult female mosquitoes may find resources that are necessary to complete their gonotrophic cycle (the cycle of obtaining bloodmeals and ovipositing eggs). This, in turn, directly affects the mosquito population in the ABM (Arifin, Davis, & Zhou, 2011).

In the previous non-spatial model, the resource-seeking events were modeled with separate probability distributions (to account for travel and search times incurred by adult female mosquitoes), simply because it did not have any explicit space (Zhou et al., 2010; Arifin et al., 2010a; Gentile, Davis, StLaurent, & Kurtz, 2010). For example, host-seeking and oviposition events were modeled with 25% probability of success in each hour of searching (the value of 25% was chosen as a baseline and not meant to be absolute). The spatial model, however, provides opportunities to spatially model these events by coupling them with the corresponding locations of resources in the landscape. This concept can be generalized whenever an agent needs to seek for a resource.

One of the primary goals of this study is model verification, which is achieved in part by docking of the non-spatial and spatial models. Docking, also known as alignment, replication, cross-model validation, or model-to-model comparison, is a form of verification & validation (V&V) that tries to align multiple models (Kennedy et al., 2006; Xiang, Kennedy, Madey, & Cabaniss, 2005). In the past, we showed how to obtain a successful dock between separate implementations of our malaria ABMs (Arifin, Davis, Zhou, & Madey, 2010b; Arifin et al., 2010a). In this study, we show that docking significantly helps in model verification.

In spatial ABMs, space can be represented in a variety of ways. For example, Bian (2003) categorized grid and patch as the two fundamentally different data models to represent space. A grid consists of a finite number of regular
Adaptive Congestion Controlled Multipath Routing in VANET: A Multiagent Based Approach
www.igi-global.com/article/adaptive-congestion-controlled-multipath-routing-in-vanet/201444?camid=4v1a

Simulating Tax Evasion with Utilitarian Agents and Social Feedback
www.igi-global.com/article/simulating-tax-evasion-utilitarian-agents/39030?camid=4v1a