# MASON AfriLand: A Regional Multi-Country Agent-Based Model with Cultural and Environmental Dynamics

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***Abstract*—Agent-based models of regions of the international system composed of several countries are few and not as advanced as other classes of spatial computational models on a comparable scale. Most relevant extant models are of a single country or polity, or they model an entire international system putatively comprising all countries as in a world system. Here we present AfriLand, a new agent-based model for developing a large-scale and more detailed model of the geographic region of contemporary Eastern Africa. AfriLand is part of the Mason-HRAF Joint Project on Eastern Africa funded by a multi-year ONR-MURI grant. We present the motivation and challenges behind the AfriLand agent-based model design and a description of the model architecture and dynamics. AfriLand offers a useful scale for analyzing socio-cultural and environmental dynamics that transcend national boundaries, such as refugee flows, transnational conflict and crime (narcotics, trafficking in persons, smuggling) and natural hazards across national frontiers. AfriLand also presents visualization challenges that call for a range of solutions from software to hardware.**

***Index Terms*—Conflict modeling, agent-based modeling, social simulation, civil war, insurgency, regional conflict, simulation, international relations, Eastern Africa, refugee flows, border disputes**

## I. Introduction

Every country is situated in one or more ecological zones and most countries have neighbors that jointly comprise regional systems. How does conflict propagate in a region consisting of several countries subject to various levels of societal stress and diverse ecological zones subject to change? What is the relationship between domestic (internal) and foreign (international) conflict dynamics? How do trans-border or transnational issues, such as refugees, affect regional political and ecological dynamics? Research questions such as these and others have challenged investigators for decades. Related research puzzles regard the nexus between human dynamics and environmental dynamics within a coupled socio-natural ecology. Eastern Africa is an example of a region where research questions like these have both scientific and policy relevance.

Agent-based models of entire regions of an international system composed of several countries are few and not as advanced as other classes of spatial computational models on a comparable scale. Most relevant extant models refer to a single country or polity. The Iruba model (Doran 2005), MASON RebeLand (Cioffi-Revilla & Rouleau 2009), Bhavnani et al.'s (2008) authoritarian regime model, and Bennett's (2009) polity model are all examples of single-country (monadic) models. Models of an entire international system putatively comprise all countries, as in a world system. Examples of world system models include the pioneering Realpolitik "chicken wire" model (Cusack & Stoll 1990), GeoSim and its sucessors (Cederman 2003; Cederman & Girardin 2007), the MASON InterHex model (Cioffi-Revilla & Balan 2006), and the AWorld system (Min et al. 2009), among others. None of the extant models in this area includes *both* a variety of countries *and* a diversity of ecological regions distributed across the set of countries. Formally, there is a mapping between countries and biomes, or

$$\exists f \ni \mathbb{C} \mapsto \mathbb{E},$$

where $\mathbb{C}$ is the set of countries and $\mathbb{E}$ is the set of biomes.

MASON AfriLand is a new agent-based model toward developing a large-scale and more detailed model of the geographic region of contemporary Eastern Africa (target system), which comprises ten countries: Sudan, Ethiopia, Somalia, Djoubuti, Eritrea, Rwanda, Burundi, Kenya, Tanzania, and Uganda. The AfriLand model is part of the Mason-HRAF Joint Project on Eastern Africa funded by a multi-year ONR-MURI grant.

AfriLand is written in the MASON computational system (Luke et al. 2005) and builds on our earlier RebeLand model (Cioffi & Rouleau 2009), which modeled a single country with several provinces.[1] In the next sections we present the motivation, challenges, and design requirements behind AfriLand, as well as a description of the model architecture (main agent classes and relations supported by UML diagrams) and dynamics (sample runs of emergent phenomena, including patterns of political stability and instability induced by societal and environmental stresses).

Unlike earlier models, AfriLand offers a more useful scale and computational approach for analyzing socio-cultural and environmental dynamics that transcend national country boundaries ("coupled socio-natural systems"), such as refugee flows, transnational conflict and crime (narcotics, trafficking in persons, other forms of smuggling) and a broad variety of natural hazards that disregard national frontiers (e.g., earthquakes, drought, epidemics, floods).

The multi-country scale of AfriLand also presents some visualization challenges that call for a range of solutions in software and hardware (Thomas & Cook 2005). .

## II. The MASON AfriLand Model

There are three basic types of research questions addressed by the AfriLand model:

1) How does a regional polity system respond to levels of societal stress (anthropogenic or natural) and governmental capacity or performance?
2) How does insurgency, domestic political instability, or (in extreme cases) state failure emerge and propagate across borders?
3) How do heterogenous border conditions (e.g., contentiousness, permeability, stability) affect regional dynamics on a multi-country scale?

Building on RebeLand (see Cioffi & Rouleau 2009) and other geographically situated models, the AfriLand regional simulation model must be spatially situated, because geography and heterogeneous ecologies are defining features of every world regions. In addition, the simulated model must posses a system of government that is based on basic principles of political science. Following a complexity perspective, we also want emergent regional phenomena to be generated by the interaction of agents and ecologies in a "bottom-up" way and not hardwired. Finally, we want the model (simulated system) to capture some of the key dynamics shown by real-world international boundaries (Cioffi & Zinnes 1985; Starr & Most 1983).

### A. *Model structure*

Figure 1 shows a "map" view of AfriLand as a region consisting of ten polities or countries. Each country has provinces (not shown on the region-scale map) and is situated in a natural environment with both topography and climate.[2]

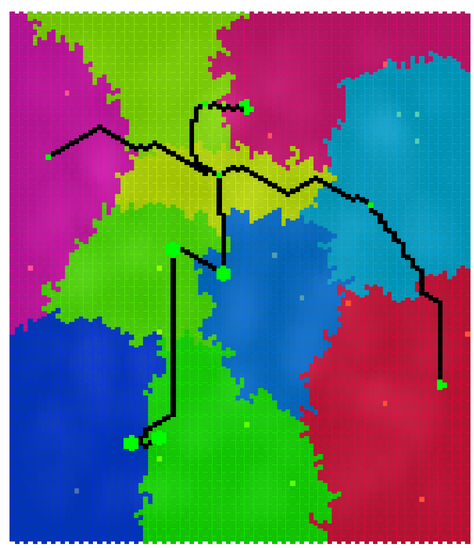


Fig. 1. Map of the AfriLand Region showing its main natural and social features, including countries, borders, cities (green), roads (black), and resources (dots). Physical topography is shown on a greentone scale. *Source:* Prepared by the authors.

The basic ontology of AfriLand is that of a "coupled socio-natural system" or "socio-ecological system" (Kohler & van der Leeuw 2007).

*Environments.* The AfriLand environment consists of terrain and a simple weather system comprising a variety of ecological zones or biomes (desert, savannah, forest,

[1] See http://cs.gmu.edu/ eclab/projects/mason/

[2] Climate dynamics are not implemented in the initial version.

mountain). Generic natural resources (oil, diamonds, gold, or similar; dots in Fig. 1) are distributed over the terrain. Additional features (e.g., hydrology) can also be added.

Topography affects two things. First, elevation determines the distance that an agent will travel. Elevation is computed by the A* algorithm for determining the shortest path between two points in this model. Second, topography determines the probability that a rebel agent will be spotted by the military. In other words, the rougher the terrain, the easier it is for rebels to hide.

*Polities.* Each of the ten polities in AfriLand has the same canonical structure and dynamics as in the one-country RebeLand model (Cioffi & Rouleau 2009), namely as a society and a system of government for dealing with public issues through public policies (Fig. 2), based on the SimPol model (Cioffi-Revilla 2009). Initially each government in every country formulates policies to address public issues that affect the respective society. Later in the simulation, under some conditions, the society can also generate insurgents that interact with government forces.

Rebels can hide within the population if support for rebels is high versus support for government.

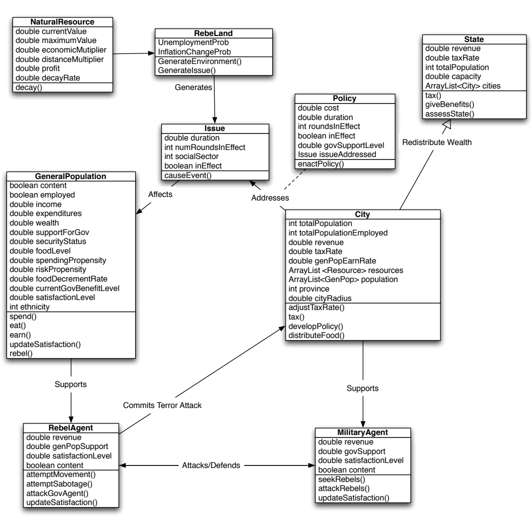



Fig. 2. UML class diagram of the RebeLand-type polity model representing each of the ten countries in AfriLand. *Source*: Cioffi-Revilla & Rouleau (2009).

*Boundaries.* Unlike earlier models (including RebeLand), AfriLand models each 2-country border as a separate association class that encapsulates essential features of an international boundary, such as the *stability* of the border (level of violence or cooperation experienced), its *permeability* (open or closed), and its legal status or *contentiousness* (how contested is a given border). Additional border attributes and dynamic operations (methods) will be added in subsequent versions.

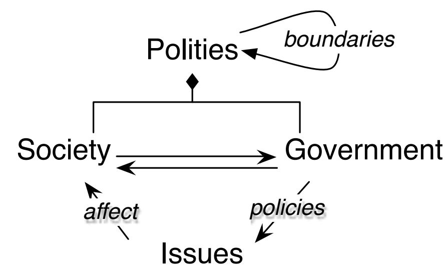



Fig. 3. High-level UML class diagram of a set of RebeLand-type polities such as that represented in RebeLand. Government manages public issues through policies, as detailed in Figure 2. Source: Cioffi-Revilla, 2008.

## B. Dynamics

AfriLand models domestic (internal) and cross-border (international) dynamics. Domestically, each of the polities in AfriLand operates as the SimPol model implemented in RebeLand: At any given time, a public issue affects the population, which causes societal stress. In response, government formulates and implements policies that aim to eliminate or mitigate stress on the population. Government operates with capacity derived from revenues produced by taxes (public finance), and taxes are paid by the population based on disposable income derived from labor. Normally, state capacity is sufficient to deal with public issues, but various factors can contribute to instability and even political change—just like in real-world polities (Cioffi-Revilla & Rouleau 2009).

Internationally, agents (population, insurgents, military) cross borders depending on the state of a border (stability, permeability, contentiousness). Activity in the border regions is thus a major innovation in AfriLand, since previous multi-country ABMs (regional or global) model border regions without actual agents flowing or transiting through.

# III. Computational Demonstration Results

Compared to other multi-country models, AfriLand displays a range of human and social dynamics, including troop movements, insurgency activity, conflict regions, refugee flows, and other phenomena, in addition to the full range of domestic or internal dynamics in RebeLand. Figure 4 shows the emergence of urban and rural conflict on a regional map of AfriLand.

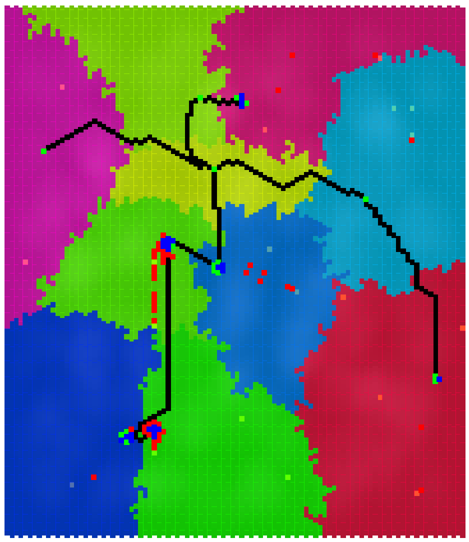
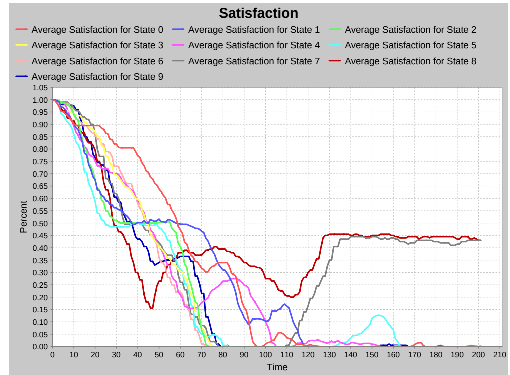


Fig. 4. Conflict zones (red dots) in the AfriLand regional map. Both urban and rural conflicts are represented. Source: Prepared by the authors.

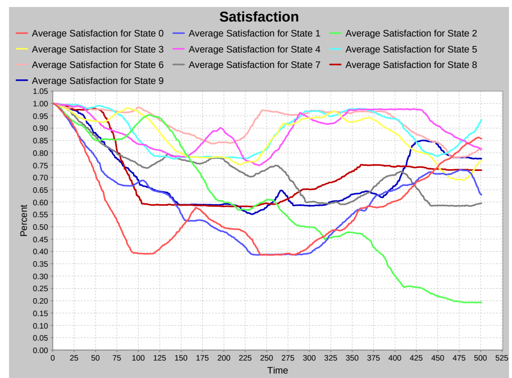
Several areas are affected by conflict in Figure 4. Interestingly, the regional map shows how insurgent rebels in the DarkGreen country have established a stronghold in the border zone with neighboring DarkBlue. From the border zone base camp insurgents carry out attacks on the capital of DarkGreen.

The following time series plots exemplify some of the data collection facilities available in AfriLand.

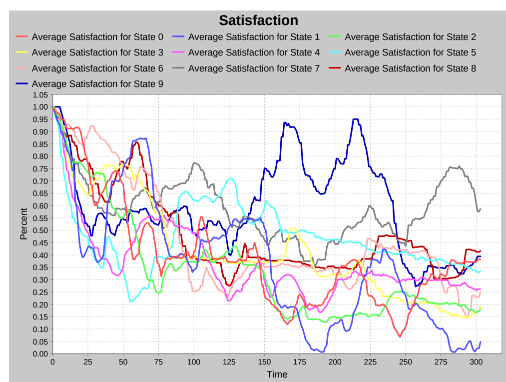
Figure 5 illustrated trends in societal satisfaction across countries in the region, resembling a socio-cognitive seismograph. While the initial cycles portray the burn-in epoch, subsequent cycles portray the long-term dynamics. As conflict increases, satisfaction levels become de-coupled and uncorrelated.




(a) General population satisfaction under a stable scenario.




(b) Population satisfaction under an unstable scenario.

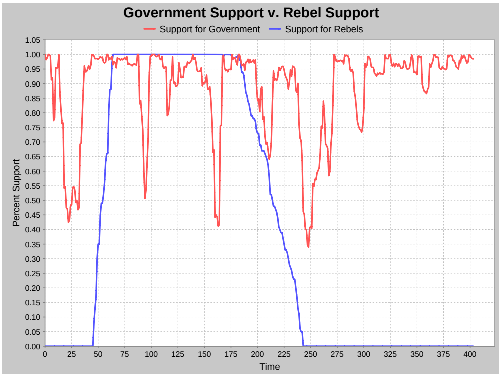



(c) Popular satisfaction in a conflict scenario.

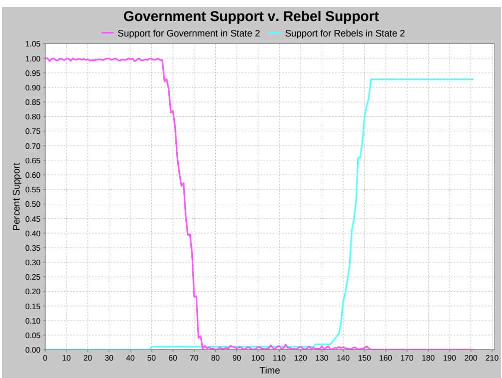
Fig. 5. Sample AfriLand simulation runs for regional scenarios where governments have varying capacities for managing public issues.

Other dynamics pertaining to support for government vs. rebels are also noteworthy. The graphs in Figure 6 illustrate regional support dynamics for government and rebels, in three variations. The first shows initially unstable support for government but eventually strong pro-government support following a major challenge by rebels. This scenario is symptomatic of a stable polity with sufficient capacity to withstand insurgency.

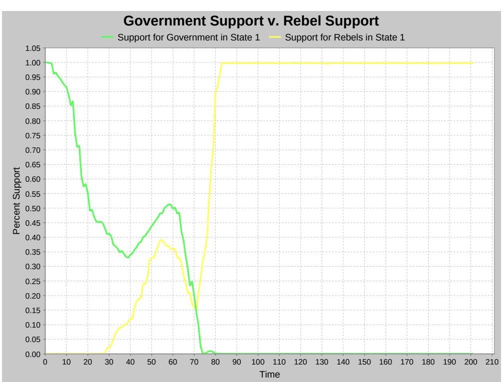
The second scenario (Fig. 6b), in State 2, shows support for government collapsing and support for rebels rising after a hiatus of anarchy lasting approximately 70 time units.




(a) General population support under a stable scenario.




(b) Population satisfaction under an unstable scenario.




(c) Popular satisfaction in a conflict scenario.

Fig. 6. Sample AfriLand simulation runs for regional scenarios where governments have varying capacities for managing public issues.

The third scenario (Fig. 6c) , in State 1, shows a more complex dynamic. In this case support for government undergoes a significant but not complete decline while support for rebels rises significantly. While the two are competing for popular support, after about 10 time units the tide turns against both government and rebels. However, at t = 70 support for government collapses and rebels wins out.

## IV. Conclusions and Summary

Agent-based models of regions of the international system composed of several countries are few and not as advanced as other classes of spatial computational models on a comparable scale. Most relevant extant models are of a single country or polity, or they model an entire international system putatively comprising all countries as in a world system.

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