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Under the Hood: Modeling Pastoralist Movement in a Multi-Scale Spatial Agent-Based Model in East Africa

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Abstract:	A team of computational social scientists at George Mason University in collaboration with anthropologists from the Human Relations Area Files at Yale University are developing a multi-scale spatial agent-based model to better understand the environmental, social, and cultural dimensions of conflicts in the Rift Valley region of eastern Africa. In this paper we experiment with a section of the model concerned with pastoral movement in savanna environment simulating day-to-day grazing and seasonal migrations of herds. We describe the agent units, rules and environment, and discuss the place and future of agent-based modeling in anthropology.

Under the Hood: Modeling Pastoralist Movement in a Multi-Scale Spatial Agent-Based Model in East Africa

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Abstract
A team of computational social scientists at George Mason University in collaboration with anthropologists from the Human Relations Area Files at Yale University are developing a multi-scale spatial agent-based model to better understand the environmental, social, and cultural dimensions of conflicts in the Rift Valley region of eastern Africa. In this paper we experiment with a section of the model concerned with pastoral movement in savanna environment simulating day-to-day grazing and seasonal migrations of herds. We describe the agent units, rules and environment, and discuss the place and future of modeling in anthropology.

KEYWORDS: agent-based modeling, pastoralism, East Africa, computational social science

Introduction
Modeling fits a new social science understanding of social phenomena as complex nonlinear, multi-factor, multi-scalar, open systems (Henrickson & McKelvey 2002). Models are able to incorporate these various components and dimensions in a sophisticated rendering of both social theory and phenomena (Read 1990). A model-centered approach allows investigators to examine the interrelationship between at least several causal variables and the effects they produce, which would not be possible in the real world for many practical and ethical reasons. This is a step forward in examining social complexity and comes at a time when social scientists are less satisfied with simple one answer explanations of observed social phenomenon. While it might be understood that an effect had more than one cause it was difficult to show how multiple causes might interact with each other to produce an effect. Furthermore, it was also difficult to assess feedback processes wherein an effect might impact on the original causal variable altering it and with it subsequent effects. Finally, causal factors on one level can produce effects on another level creating patterns or structures, which are attributes of social phenomenon of interest to researchers in and of themselves. Because modeling is isomorphic with social complexity, it is a means well suited to conceptualize and explain that complexity (Epstein 2008).

In this paper, we discuss an agent-based model (ABM) of pastoralism in East Africa, which offers one way to study human mobility across spatiotemporal scales. In an agent-based computer model it is possible to build up a representation of both natural and man-made environments based on data from remote sensing and other sources, drop in rule-governed agents, and then observe their behavior, in this case movement, across space and time. The emergent patterns validate theory or observed phenomenon. In an experiment-like situation, variables can be isolated and controlled to verify causal effects or patterns observed in the archaeological, historical, or ethnographic record. ABM allows us to see the scalar effects in space and time of decisions made by individual households at the local level. ABM is a bottom-up study of social processes in which social organization and structure are the consequence of the actions and interactions between multiple, autonomous and heterogeneous agents. ABM is able to reveal in a unique way the global patterns that emerge from the interaction of individual agents (Macy & Willer 2002).

Agent-based computer modeling simulates conscious agents operating in the world by combining an objective environment with a subjective decision-making processes. The computer models both mind and nature. The computer can mimic decision-making thought processes in a way more sophisticated than simple stimulus-response behavior and perfect-knowledge rationality. A model can incorporate *limited* information, *limited* cognitive abilities, and *limited* time to make decisions, thus replicating more truthfully real-life situations and experience (Kennedy & Bassett 2011). Memory and emotions can be included as well (ibid.).

Background

To date, ABM has had limited use in archaeology. One study used agent-based computational modeling to try and reproduce settlement patterns and population fluctuations of an Anasazi community (Axtell et al. 2002). The researchers were able to use the rich paleoenvironmental record in one 96-sq. km topographically discrete area to reconstruct the environmental conditions for a period from 200 to 1500 AD. The size and nutritional requirements of the household agents were based on the ethnographic studies of historic Pueblo groups. The simulated population and settlement patterns followed the archaeological record. Interestingly the data and model differed in the final period when historically the valley was abandoned, whereas the model showed a small community lingering on. The authors suggest the difference is attributable to social and cultural dynamics not accounted for in the model.

In cultural anthropology, researchers have modeled contemporary pastoral groups by combining the Savanna ecosystem model with a household simulation model, PHEWS (Pastoral Household and Economic Welfare Simulator.) Originally developed for the Turkana District in Kenya, Savanna simulates plant and animal population growth and nutrient recycling. PHEWS tracks cash flow and calories in agro-pastoral households. One study using the integrated model examined the effect of cultivation on wildlife, livestock, and people in a conservation area in Tanzania (Boone et al. 2006). Another study examined the effects of land fragmentation and ranching on pastoral communities in Kenya (Thornton et al. 2006). Using another ABM model called NOMAD, researchers examined conflict between pastoral and farming households in Darfur, Sudan (Kuznar & Sedlmeyer 2005). Specifically, this study focused on the effect of drought on trading and raiding behavior.

Modelers at George Mason developed a model of pastoralist and agriculturalist interaction in the Mandera Triangle area in the border area of Kenya, Somalia, and Ethiopia. The model used a multiagent simulation environment and visualization library (MASON) written in the Java programming language (see Luke et al. 2005). The model called HerderLand has an area approximately 150 sq. km. with no towns, cities, rivers, lakes, or varied geographic feature. Several scenarios were run examining the effect of environmental stress on herding behavior (see Hailegiorgis, et al, 2010; Kennedy, et al, 2010a; Kennedy, et al, 2010b). Based on this model a larger more ambitious model was built called RiftLand, a 1600 sq. km. area around Lake Victoria (the red outlined square in Figure 1.) The purpose of this model is to study conflict, natural disasters, and humanitarian relief in a region with a wide variety of natural and man-made environmental factors. In the original model, we established a basic modeling scale of 1km by 1km parcels of land, agents at the household level, and a time step of one day. The RiftLand model continues this lowest level of modeling but develops larger and more diverse behaviors in a much more varied environment.

Figure 1. HerderLand (small, solid square) and RiftLand (large, open square) model areas of East Africa.

Model Description

The RiftLand model includes a variety of biomes, weather features, and human agents. In addition to the grazable area of the HerderLand model, RiftLand includes freshwater lakes and rivers, urban areas, forests (not grazable unless cleared), and protected reserves. These areas were determined by GIS data as well as politically defined regions. Pastoralists were prohibited, in the model, from movement outside non-grazable areas. In the HerderLand model, due to its small size, the weather was modeled uniformly across the entire area based on nearly 10 years of rainfall data. For the RiftLand model, we identified approximately 2,500 weather cells of correlated data covering the approximately 2.5 million 1km by 1km parcels. The modeling of the weather was varied based on an analysis of 12 years of approximately bi-weekly weather data representing the various biomes of the Rift Valley region. Into this environment, we placed a variety of agents representing households and individuals.

In the HerderLand model, we explicitly modeled farmers who were stationary and herders who daily decided where to move their herd. For the rural agents of RiftLand, we represented households using a combination of three different subsistence activities: farming, herding, and wage labor. (Urban agents are modeled differently and are not addressed here.) The subsistence profiles were mostly based on the code for subsistence economy found in George P. Murdock's Ethnographic Atlas (Murdock 1967) supplemented by the ethnographic literature. Altogether there are 134 different cultures in RiftLand as identified in Murdock's ethnographic map of Africa (Murdock 1959). As a household, the agent decided whether and how much effort to put into each subsistence activity. The farming activity is involved with deciding when to plant and when to harvest based primarily on the observed local weather. The agents must also decide how many hectares to plant and consider the labor involved and labor available within the household. The farming activity results in a food store which the household consumes throughout the year.

The herding activity operates very much like the dedicated herders of the HerderLand model. When herding, the herders decide daily where to move the herd based on four factors. These factors represent the herd's level of hunger, level of thirst, whether there is conflict in the area, and how far away the herd may have to move. The rules are implemented as a hierarchy of if-then questions based on the importance of the factors modeled after Gigerenzer's "Fast and Frugal" decision making architecture described in Kennedy and Bassett (2011). The decision tree is shown in Figure 2.

Figure 2. Herding Decision-Making Tree

These movement decisions are made relative to the current source of water. If the water source becomes unserviceable, for example dries up, the herding agent selects the closest watering source that is not known to be serviceable and moves toward it. We are using a memory for a fixed small number of previously used watering holes. Depending on the spatial distribution of the watering holes, different macro-level behavior can develop.

Experiment Description

The purpose of our first set of informal experiments was to ensure reasonable movement patterns would emerge from our modeling of the herders' decision making. Because the focus was on herder movement, rather than run millions of agents (there are over 100 million people living in the area), we focused on a smaller area, specifically the original area modeled for HerderLand. We could then compare the results to the previous HerderLand experiments. A major enhancement in the RiftLand model over the HerderLand model was the use of more flexible rural agents. In RiftlLand, the rural households start with plans to survive based on farming, and when not farming, herding, rather than purely farming or herding as in the HerderLand model. However, we have not yet modeled conflict within RiftLand, that portion of herder movement is not exercised.

The first experiment focused on the herding activity when the water source was adequate for a season. In this case, the first two questions in the decision tree would not determine movement, only the third would. Therefore, we expected to see movement confined around the watering hole with the herd returning to the water supply every few days and on other days moving between good pasture areas.

The second experiment focused on the herding activity when the water source becomes inadequate for the herds' needs, i.e., when the first question in the decision tree becomes operative. Consistent with the movement rules, we expect to see herds move toward a nearby water supply. Interestingly, how these water sources are spatially arranged in the environment would cause some form of overall pattern. In the HerderLand model, watering holes were placed randomly causing a variety of patterns. In RiftLand, watering sources are around lakes, along rivers, and where GIS data on the land's elevation shows local lowlands, i.e., potential river beds. The patterns that would be observed in RiftLand would be the result of the actual environment rather those resulting from the random placement of watering holes.

Experiment Results

The two experiments produced the expected results with some interesting characteristics. Figure 3 shows daily movement around a watering hole and Figure 4 shows the migratory behavior. In Figure 3, the herds are shown as filled-in dark circles with open circles showing the five previous locations. Each possible location is a 1km by 1km. sq. parcel. Figure 3 covers a total area of 15 km by 15 km surrounding one watering hole shown as a solid blue square. The image shows that three herds left the watering hole and went to good grazing parcels. In the daily movement, the herd is moved to a good grazing area and grazes there until watering needs overcome the grazing needs and the herd returns to the watering hole.

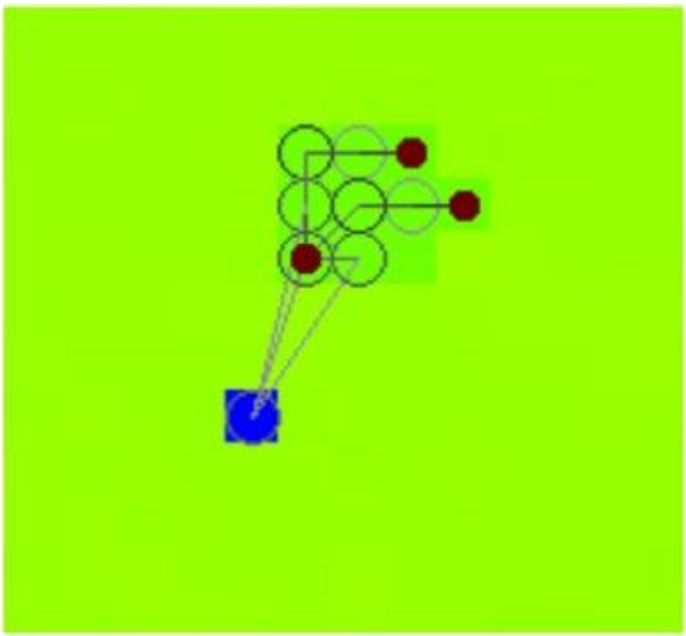

Figure 3. Herders (in black) daily movement around a

watering hole (dark blue).

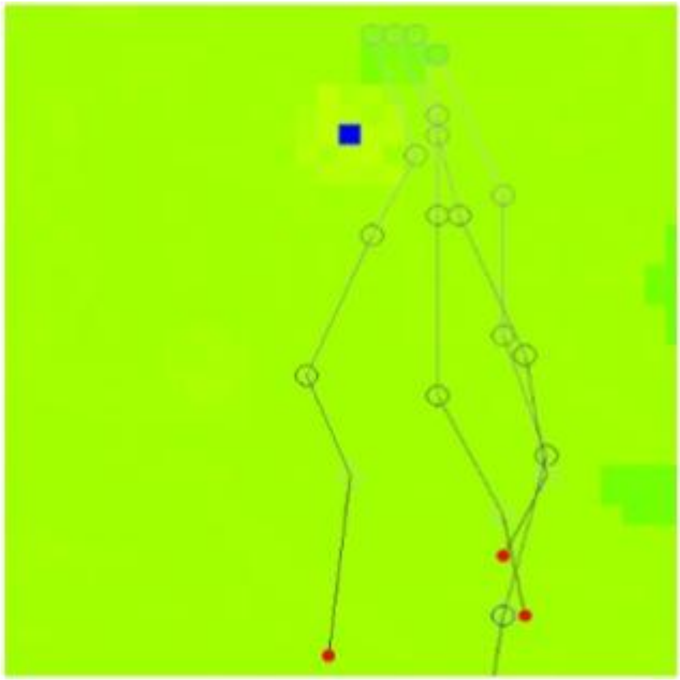

Figure 4. Migration of herds (red circles) from one watering hole (blue square) to another (off screen).

Figure 4 shows four herds in an image approximately 40 km by 40 km around their watering hole. The image shows the herds having left their grazing area and migrating southward for five days as indicated by the open circles of previous positions. Note that the four herds did not follow exactly the same path as they individually decided where to move at each step.

Discussion

Our model successfully simulated the behavior of herders in an East African savanna environment. Using only a few rules governing behavior around water holes and pasturage, we were able to generate migration patterns. A macro spatial-temporal effect was achieved from decisions made on the household level. A better fit between the model and observed phenomenon would require a more sophisticated set of rules governing agent behavior and a model environment more closely resembling the real environment and ecology. Of course there are limitations to both and that is the challenge to modeling where exact verisimilitude is impossible. The challenge then becomes what environment and what rules can be abstracted to make as close a fit as possible between the model and observed phenomenon. This approach requires theoretical assumptions about which aspects of behavior and environment are most important, or which best serve the research interests of the study. In the case of finding evidence in the archaeological record of human movement across space and time, a model would best serve research interests by generating possible migration patterns that would point fieldworkers to where they might most likely find the evidence they are looking for.

The challenge remains how best to model the agents and the environment. A more precise modeling of the environment would entail incorporating data on weather patterns, soil types, and vegetation, all of which are available and being used in the RiftLand model. A better model of agent behavior would have to incorporate cultural practices that are not direct responses to short-term environmental cues. While cultural practices have their own internal logic, it is not a logic entirely divorced from the environment as a whole. We need only look at the crisis we face today of climate change and the societal failure to recognize and respond to the larger ecological cycles in which our society is embedded. Our present-day climatic crisis is a hard reminder that culture and the environment are more closely linked than many dare imagine. Global warming and its fallout could well be a case of environmental determinism in the last instance! This is all to say that herders know their weather. They are keen observers of it and act accordingly. Their life events and cycles are closely attuned to short and long-term weather cycles and events. We explore this more fully below.

The new ecological anthropology shares with the new social science the complex view of social phenomena. It recognizes that communities are embedded in multiple systems of different scale, including local, regional, national and global (Kottak 1999). It also recognizes the political, historical and symbolic dimensions that mediate the human-nature relationship (Biersack 1999). The RiftLand model addresses some of this complexity by including the built-up, man-made, artefactual environment such as towns, cities, markets, nongovernmental organizations, refugee and famine relief camps, etc. East African herders have learned to include many of these in their coping strategies (Sørbe 2003).

The new ecology also has a more sophisticated, less functionalist understanding of culture. Although Roy Rappaport's (1968) classic work on New Guinea pig rituals was a serious attempt to posit a direct relationship between human ecology and symbolic behavior, he was criticized for his reductionist view of ritual behavior as purely an instrument of adaptation.[1] In a later work, he answered his critics with a more complex view of the relationship between culture and the environment, arguing that ritual sanctioned truth and trust, both essential to a society's long-term sustainability (Rappaport 1979). This basic insight to the integral relationship between symbolic behavior, the social group, and the environment remains relevant. We would argue that symbolic behavior is in fact a response to large-scale ecological cycles, or long-term environmental cues, which lie beyond the immediate experience and concerns of the group, but have a significant impact on a group's long-term survival. Such behavior is based on the collective memory of the group and the ability of the group to forecast and plan ahead. A discussion of an East African pastoral society, the Turkana, will serve to illustrate this point.

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[1] More specifically, Rappaport argued that the pig feast signaled the initiation of hostilities between villages and occurred when the pig population had grown beyond a manageable size thus acting as a surrogate for human population growing beyond the carrying capacity of the environment. Ember and Ember offered one critique in which they did not find any regular cycles of periodic warfare that might correlate with herd growth and overpopulation. This lead to a follow up study in which they instead found a correlation between resource unpredictability and violent conflict (Ember and Ember 1992). A recent study has focused on East African societies and found a correlation between increased intensity of violent conflict and either of two kinds of environmental crises, famine or natural disaster (Ember et al. n.d.).

The Turkana are egalitarian nomadic pastoralists who live in the savanna of northwest Kenya. They subsist on milk, blood and meat from their livestock of cattle, camel, sheep, goats, and donkeys, and grain obtained in trade. Numbering close to a half million, they are divided into twenty territorial sections which vary in size and population. The territorial sections are regions in which herding groups of several households called *adakar* migrate in a normal season. Territorial sections encompass several different ecological zones which can be exploited at different times of the year, by different kinds of livestock. An *adakar* usually migrates 10 to 50 km every 15 to 40 days in search of water and fresh pasture (Mathew & Boyd 2011, 11376). This movement inscribes a large circle from lowlands to high lands and back again in the course of a year. In drought years the herding groups are forced to travel even further, often far outside their own territorial section (McCabe 2004).

The Turkana live in one of the most inhospitable environments on earth with average annual rainfall below 600 mm a year (Ellis & Galvin 1994). Furthermore, the rainfall pattern is highly irregular varying between regions and from year to year, sometimes dropping below 300 mm a year. There is also a seasonal bimodal annual rainfall pattern as the intertropical convergence zone moves north then south over the equator in concert with seasonal declination of the earth (ibid.). The interannual variability is influenced by the El Niño southern oscillation. In places such as the northwestern Kenya it can result in a drought once every three to four years and a severe drought once every ten years (McCabe 1990, 96). The Turkana have coped with regional, seasonal, and interannual weather patterns for centuries (McCabe 1987, 371). One adaptive response is mobility, the ability to move into different ecological zones at different times of the year (ibid.). This mobility is dependent in part on alliances made between groups that permit a group to trespass into territories not their own. However under more extreme drought conditions herders might find themselves in tribal border regions where the potential for conflict with tribal enemies is high.[2]

The movement across sectional territories requires a second kind of livestock movement as a prerequisite: the exchange of cattle. Anthropologists have long recognized the key role cattle play in the construction, maintenance and reproduction of social relationships (Abbink 2003). Cattle are more than food on the hoof. They are also gifts, status-markers, bridewealth, and objects of great affection, all components of pastoral social structure and processes. The anthropologist Vigdis Broch-Due writes about the web of relationships and transactions that constitute the Turkana social landscape: "The more livestock that have moved between partners, the more solid the relationship and the more likely those resources will flow from that relationship in times of scarcity (Broch-Due 1999, 52)." In times of surplus, livestock is used to establish these social relationships, which are insurance in times of scarcity (ibid. 63). Cattle are considered inalienable possessions which "constitute a shared resource, subject to more or less overlapping and inclusive claims, rights, and interests (ibid. 80)." These multiple, overlapping claims constitute social and symbolic capital which are vital in an environment in which a herding family can lose up to 90 percent of its animals in a severe drought (McCabe 1987). The social landscape of clans, alliances, and partnerships cut across territorial sections and thereby provide friendly, uncontested pathways out of drought-stricken areas, as well as, opportunities for restocking. In an alternative restocking strategy, the same social relationships can be the basis for forming raiding parties to capture livestock from more distant groups. Exchange and raiding are two arms of an economy of reciprocity

[2] A study of rainfall patterns and interethnic conflict in the Turkana district shows increased intensity of livestock raids during drier months and drought years (Ember et al. *in press*). This suggests that resource scarcity can intensify violent conflict. The authors also suggest, following ethnographic reports (McCabe 2004), that scarcity forces herders into contested and potentially violent border areas. The implication here is that movement is perhaps a key intervening variable mediating between drought and violent conflict.

practiced in non-market societies and represent two choices agents have to augment herd size beyond natural reproduction.

Conclusion

Agent-based modeling is developing as a powerful tool in the social sciences to explore social behavior and its relationship to the environment and social processes. Modeling allows for a more sophisticated rendering of decision-making and environmental variables, both man-made and natural. The challenge for any interdisciplinary project is one of translation. In this case, how can cultural behavior be translated into agent-based rules? In this paper, we have shown that even the simple rule-governed behavior produces interesting patterns and results. We have also tried to theorize a more complicated nature-culture interaction that sees the establishment and maintenance of social networks as a hedge against extreme climatic events. Here symbolic behavior, i.e., rituals associated with cattle exchange, is seen as a pro-active response to long-term environmental cycles. The economy of reciprocity which includes cattle exchange and cattle raiding, the latter as an example of negative reciprocity, is vital to the social reproduction of pastoral groups in inhospitable climates. Agent-based modeling that can tract cattle exchanges, the social networks they produce, and the level of trust, all across different spatiotemporal scales has a future in anthropology.

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