AN AGENT BASED MODELING APPROACH FOR REPRESENTING CAPUCHIN (*Sapajus spp.*) BEHAVIOR IN BRAZIL

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ABSTRACT

An agent-based model was implemented to represent biological and physical environmental factors associated with the ranging behavior of bearded capuchin monkeys (*Sapajus libidinosus*) in Brazil. The model incorporates GIS features and data (e.g., coordinate system and multiple data layers), and represents the interaction of capuchins with their environment. Environmental factors and capuchin behavior were modeled for the interface between Caatinga woodlands and savanna, in Northeastern Brazil. The main physiographic features considered include topography and land cover/use related layers, such as vegetation density, resource availability and natural landmarks or barriers to movement. Slope and derived costs associated with moving across the landscape were also considered during implementation. Behavioral elements observed during field campaigns were used in the modeling of interactions between monkeys and their environment, particularly when foraging. Behavioral contingencies of the elements, such as group cohesion and positional behavior of individuals as a function of social status, were defined by theories of primate behavior and by direct field observation. Verification of the model involved multiple runs based on simulation of resource elements and their associated attributes (i.e., food type preference value and patch size value). Behavioral correlates of monkey agents are detection distance at which agents are attracted to the resource site and time necessary for monkey agents to deplete the site. Fieldwork for data gathering and to support model validation has been conducted and the validation effort involves comparing field data describing the behavior of monkeys interacting with their environment while foraging and the statistics derived from several runs of the implemented model.

KEYWORDS: agent based model, capuchin, *Sapajus*, *Cebus*, spatial cognition, animal behavior

INTRODUCTION

Advanced geospatial simulation methods provide insights to complex systems, particularly when applied to social systems (Galán et al., 2009). For instance, animal behavior studies can benefit from the use of a set of modeling tools, linking individual and group behavior with geographic features in novel ways. One such tool, agent-based modeling (ABM), enhances the understanding of macro-level behaviors through the investigation of their micro-level components. Being a form of automata computational models, ABMs simulate the actions of autonomous individuals or "agents" in an attempt to recreate and predict the actions of complex phenomena (Gilbert & Troitzsch, 2005). Sets of behavioral rules and constraints within environments determine the actions of the autonomous agent(s) in a simulated landscape. The sum of individual decisions/actions for each time step considered allows the representation of processes (Johnston, 2009). For example, agents act to maximize processes such as reproduction, health, biomass, and social status. They also may act to minimize costs such as energy expenditure or competition (e.g., Emlen, 1966; Altmann, 1974). A single agent may move and perform actions in a simulated 2D or 3D environment, and/or the agent can interact with other autonomous agents to simulate competition, aggression, attraction and other social interactions. Although agent-based models have been used since the 1990s for applications in social sciences, urban growth, transportation, consumer behavior and spread of diseases, their use in wildlife studies is more recent (Kohler & Gumerman 2000; Fa et al., 2001; Topping et al., 2003; DeAngelis & Mooij, 2005; Li et al., 2005). Johnston (2009) used agent-based modeling to simulate cougar actions including movement to prey, kills, feeding, resting and attraction to other cougars with decisions made according to energetic state, time since last feeding, strength of attraction and security. The study of animal movement is particularly well suited to simulation using ABM techniques (Tang & Bennett, 2010). Spatial memory of animal agents has been simulated in numerous previous ABMs (e.g., Bennett & Tang, 2006; Dumont & Hill, 2004; Arrignon et al., 2007) and the navigation abilities of animals have been simulated using machine learning algorithms such as evolutionary algorithms, artificial neural networks, reinforcement learning, and Hebbian learning (e.g., Morales et al., 2005; Bennett & Tang, 2006).

The chosen model system for this investigation is bearded capuchin monkeys (*Sapajus libidinosus*, until recently *Cebus libidinosus*) in a savanna habitat (Portuguese name: Cerrado) of northeastern Brazil. These monkeys are especially interesting to geographers and primatologists due to their use of stones to crack open nuts, a form of percussive tool use. Tool use of any kind is of inherent interest as a rare form of behavior in nonhuman animals (Beck, 1980; Bentley-Condit & Smith, 2010). Percussive tool use is of particular interest given its importance in the paleoarcheological record of early humans (e.g., Roux & Bril, 2005).

The main goal of this work was to design, implement and verify an agent-based model of capuchin monkey's simulated foraging behavior to be compared with observational data and validate conceptual models of the monkeys' use of resources in time and space. These validated models should provide insights into the use of resources by capuchins, including those directly associated with percussive tool use and affecting the frequency of the behavior, and where in their home range the behavior occurs.

CAPUCHIN NUT-CRACKING BEHAVIOR AND THE STUDY SITE

In the study site (Boa Vista research site, in the state of Piauí, Brazil), the capuchins crack palm nuts throughout the year (Spagnoletti, 2009; Verderane, 2010) using stones that weigh on average about 1 kg (Visalberghi et al., 2007) half the weight of an adult female. They use stones as hammers which consist primarily of harder sandstone and quartzite cobbles. As these stones are relatively rare in the landscape as hammer stones, they transport these stones to anvils (Visalberghi et al., 2009). Sandstone and siltstone boulders serve as anvils for nut-cracking. Anvils are distinctively pitted from repetitive use and typically a hammer stone and nut shells are on or near the working surface. Anvils are numerous and widely distributed across the monkeys' home range (Visalberghi et al., 2007); we have located more than two hundred anvil sites in the home range of the two groups of monkeys we have followed in Boa Vista (unpublished data).

Figure 1. A capuchin monkey (*Sapajus libidinosus*) cracking a nut.

The Boa Vista research site is a sandy plain at approximately 420 m above sea level, interspersed by ridges and mesas composed of sedimentary rock ascending steeply to heights of 20 to 100 m above the plain. The climate of the region is seasonally dry from April to September. Total annual rainfall averages 1,112 mm and dry season rainfall averages 203 mm (data source: Brazilian National Water Agency-ANA). The extended dry periods, in combination with well-drained sandy and sometimes rocky soil, are associated with a specific community of drought-tolerant (largely deciduous) vegetation. The most common vegetation type in this area is savanna like (Cerrado) varying in density and structure from tall, dense-canopy woodland to nearly treeless open savanna grasslands (Oliveira & Marquis, 2002). The understory is made up of a mixture of grasses, small shrubs, and ground palms. The ground palm species which provide the nuts cracked by the capuchin monkeys belong to *Attalea*, *Orbignya*, and *Astrocaryum*, common genera in the region. In addition to palm nuts, the capuchins at the study site use stone tools to process a variety of smaller seeds, tough fruits, and cactus.

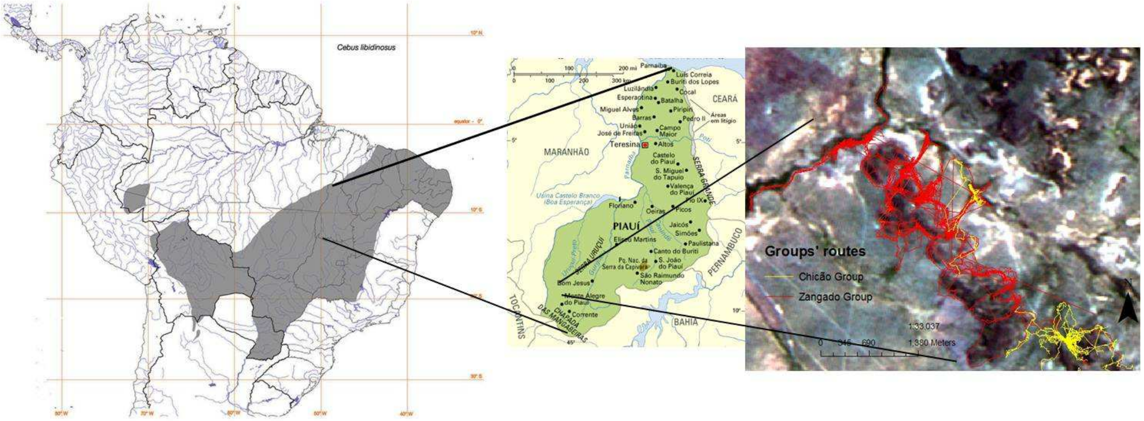
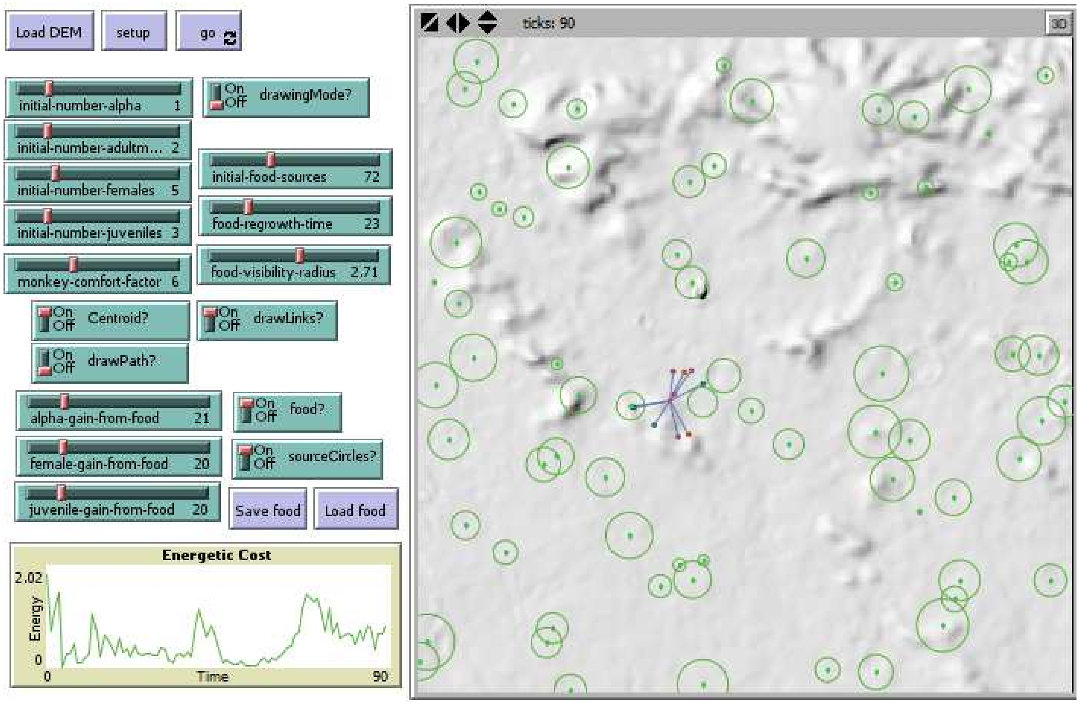


Figure 2. Range of *Sapajus libidinosus*, the bearded capuchin. Reproduced from Fragaszy et al. (2004b), Piauí State and *S. libidinosus* daily routes (Presotto et al. 2010), at the Boa Vista research site.

AGENT BASED MODEL DEVELOPMENT

The agent-based model was implemented using the Recursive Porous Agent Simulation Toolkit (Repast, North et al., 2007), a widely used advanced agent-based modeling and simulation platform. This complex adaptive system is currently being augmented to incorporate learning and extend our prototype effort (in NetLogo and Repast), which incorporates proto-models, individual monkeys (alpha males, adult males, adult females and juveniles), and relevant elements of their environment (e.g. food resources, anvil sites) as agents. Individual behavior and social interactions among members of a group were addressed using an object-oriented approach, which characterizes agents using attributes and methods/actions (including decision rules) as well as perceptual capabilities to sense and respond to the surroundings (e.g. proximity to food). The analysis of complex spatial processes thus allows the study of behavior as constrained by space. The environment where the capuchin monkeys occur is represented by field and imagery derived data (e.g., natural barriers, vegetation type and density, topography), stored in vector and raster formats. The implementation contemplates capuchin observed behavior at the Boa Vista research site, incorporating rules governing an individual's movement in that environment and life process rates reported in Fragaszy et al. (2004a). The movement rules of the agent-based model include behavioral ecology data from the capuchins at the study site (Verderane et al., in review), habitat suitability for percussive tool use, habitat preference and suitability for capuchin feeding, water and shelter resources, life process rates (e.g., growth and death rates), and information on travel costs and route preferences. With respect to tool use in particular, as that is a unique focus of our work, the model will allow us to simulate frequency and timing of tool use by different individuals, where tool use occurs, and routes taken to visit tool-using sites using available data. Learning and spatio-temporal knowledge will be incorporated into our proto-model by using reinforcement learning (RL) through the customization of the Intelligent Agent Model heuristic algorithm proposed by Bone & Dragicevic (2010). The method implements a self-learning mechanism and is particularly efficient in exploring detailed datasets associated with temporally dynamic models. Our implementation considers multiple drivers for learning, including the success or failure of monkeys in finding food resources, nut-cracking sites and shelter. The implementation allows for the parametrization of the learning process and the simulation of different learning scenarios. Details regarding the incorporation of learning and implementation of RL (e.g., reward structure and parameter definition) are currently under investigation, as part of a prototyping effort.

NetLogo, a programmable modeling environment for simulating natural and social phenomena, was chosen for the development of a pilot agent-based model representing the movement of a group of monkeys foraging at the Boa Vista site. The prototype uses NetLogo's GIS extension and incorporates physical characteristics of the landscape, such as elevation (ASTER GDEM, a product of METI and NASA) and resources. The availability of food resources results from the random positioning of food sources over the landscape (a food location layer can also be loaded into the model). Aspects such as the number of resources, regrowth time after the resource is consumed by the monkeys and resource radius (or attractiveness of the resource) were incorporated into the model and can be modified by using the model's interface (Figure 3). Behavioral aspects, including those resulting from the hierarchical stratification of the group and role associated behavior were incorporated considering the DomWorld model (e.g., Hemelrijk, 1999; Hemelrijk & Wantia, 2005) and field observational data from our team. This NetLogo model is currently being ported to Repast Simphony, using Java and Relogo. Among the improvements in modeling, the Repast model will incorporate learning by using an Intelligent Agent Model heuristic algorithm.



initial-number-alpha 1
initial-number-adultm... 2
initial-number-females 5
initial-number-juveniles 3
monkey-comfort-factor 6
initial-food-sources 72
food-regrowth-time 23
food-visibility-radius 2.71
alpha-gain-from-food 21
female-gain-from-food 20
juvenile-gain-from-food 20

Figure 3. Interface of the capuchin agent-based model, implemented in NetLogo. On the left panel: model controls. On the right: a representation of the terrain in Boa Vista, foraging monkeys (close to the center), food resources distributed over the landscape (green dots), resource radius as a function of amount and type of resource (green circles), and energy spent by the monkey group while traveling over the terrain (graph on the bottom left).

Using the model's interface we can control several parameters of the model, as well as get feedback regarding model progress, exemplified in Figure 3 by the calculation and graphic representation of the energetic cost of traveling over a particular terrain. Model background can be set to multiple raster layers, including a digital elevation model, a vegetation index image, a layer representing cost, and others. Figure 3 shows a hillshade image derived from an ASTER/GDEM loaded into the model. At the same time, real elevation values are read and used for calculations. Vector layers can also be loaded, displayed and used during modeling.

We can size our group of monkeys, by defining the number of alpha-males, adult males, adult females and juveniles. Using an object-oriented approach, a monkey group has a series of attributes, including its unique identification, which allows for the consideration of more than one group of monkeys competing for resources at the study site. Individual monkeys are also characterized by a set of attributes and methods, including hierarchical status inside the group, the identification of the group the monkeys belongs to, energy level and others. Methods include those associated with the creation and destruction of monkey agents, movement, resource consumption and interaction with other monkeys. Monkeys are uniquely represented according to their status by colored circles and their change of behavior related attributes can be observed and recorded. Field work associated with monkey behavior collection is often performed using the center of a group of monkeys as a reference. Our model incorporates a centroid agent, which is continuously repositioned as the monkeys move over the landscape. Monkey route analysis is supported by the drawing and recording of the path of this centroid. As the monkeys travel over the terrain, a measure of energetic cost considering both horizontal and vertical distances is calculated and graphically displayed.

The distribution of resources over the landscape can be controlled using the model's interface, including the number of resources to be randomly created and distributed over the area. The implementation also allows for the input of resouces using a GIS layer representing data collected in the field. Several attributes are associated with food resources, contributing to define the interaction between these resources and monkeys. Food attributes include amount, energy, preference, aspect and regrowth time. Some of these attributes contribute to the definition of regions around resources, which are related to visibility and attractivenness of the resource. When monkeys are foraging and enter one of these regions, they move towards the food source and start consuming it. This model considers that when the resource is depleted the monkeys leave the site, looking for another food resource. To account for seasonalities or regrowth, food resources have a regrowth time, which can be adjusted using the interface.

Our Repast implementation, which uses elements of the NetLogo model, introduces modifications and improvements, increasing model complexity. Additional landscape elements are considered, exemplified in Figure 4 by nut-cracking sites (anvil sites, represented by orange triangles).

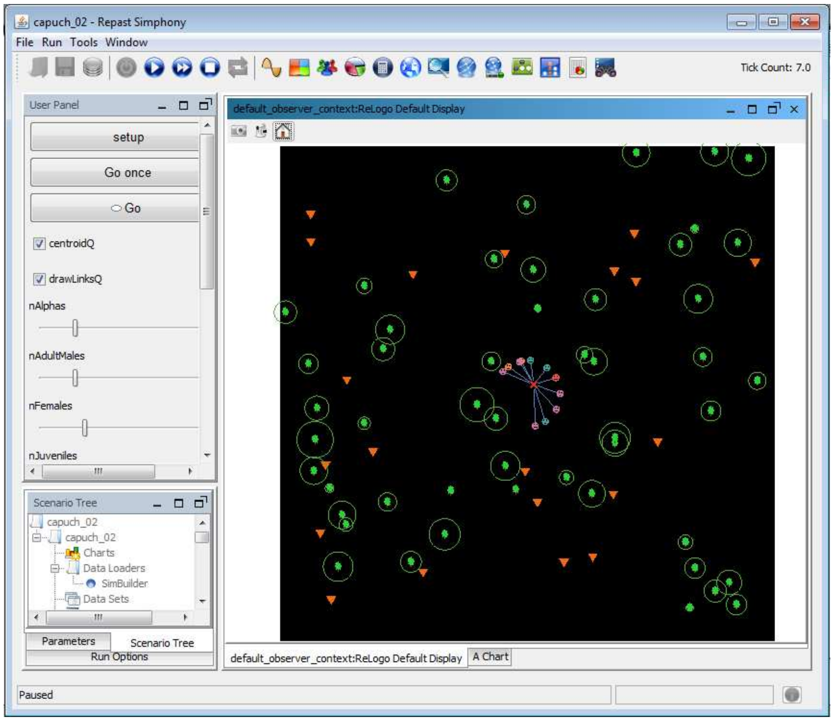


Figure 4. Interface of the capuchin agent-based model, implemented in Repast Simphony, showing (on the left panel) model controls, (on the right) foraging monkeys (close to the center), food resources distributed over the landscape (green dots), resource radius as a function of amount and type of resource (green circles), nut-cracking anvils (triangles). Energy spent by the monkey group while traveling over the terrain is also calculated (not shown).

CONCLUSION

The study of animal movement is particularly well suited to simulation using agent-based modeling techniques. Advancing the use of these methods in animal behavior investigations will enhance the methodological toolkit available to researchers in this area.

We designed, implemented and verified an agent-based model using two model development platforms, NetLogo and Repast Simphony. The proto-model implementation incorporates elements of behavior of capuchin monkeys living in the northeastern part of Brazil, considering interactions between members of one or more groups of monkeys. Aspects related to the monkey's environment were represented in the model, either by adding these aspects as features of the landscape (e.g., a digital elevation model representing the topography of the region) or by considering the incorporation of agents with unique sets of attributes and methods (e.g., each of the food resources distributed over the region investigated). Verification of the model using multiple runs has shown consistency in individual and group behavior, as monkeys travel over the area of study and forage. Further implementation is underway, including the incorporation of learning and memory to the proto-model. Model validation will use field data collected at the research site and follow the learning algorithm implementation.

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