OVERVIEW, DESIGN CONCEPTS, AND DETAILS FOR FMODEL

The following description of FMODEL the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2006, Grimm et al. 2010). This ODD is associated with a forthcoming publication:

Davies, B., S. J. Holdaway, and P. C. Fanning. *In press.* Modeling relationships between space, movement, and lithic geometric attributes. Accepted to *American Antiquity*.

1. Purpose

The purpose of the model is to:

1. Explore the formation of time-averaged surface stone artefact assemblages by modelling the manufacture, transport, and discard of lithic artefacts.
2. Evaluate the relationships between movement tortuosity, curation, and ratio of observed cortical surface area to expected cortical surface area (the Cortex Ratio) in surface assemblages (see Douglass et al. 2008).

Additional configurations, discussed in section 7, are used to examine the effects of raw material availability and spatial differences in movement patterns.

2. Entities, state variables, and scales

To model the effects of artefact manufacture, transport, and discard on the composition of lithic assemblages, two primary entities are used: a single mobile agent and patches representing a known space. The agent operates as a transport vehicle for stone artefacts, moving in an uncorrelated random walk, discard artefacts between moves, and manufacturing artefacts on an 'as needed' basis. A patch is a discrete unit of space within a gridded toroidal space (referred to using the more generic term 'cells' in the text but using the NetLogo specific term 'patches' here).

Artefacts are modelled as two discrete types: cores and flakes. Cores are modelled as icosahedra (20-sided polyhedral solids), while flakes are modelled as triangular prisms. The triangular cortical surface of the dorsal side of each flake corresponds to 1/20th of the surface area of a cortical surface area of a core. The relationship between the amount of cortical surface area present in a local assemblage

The spatial relationships in the model are abstract and could be taken to represent any number of scales that reflect an archaeologically meaningful 'window of observation' such as a surface exposure. Time advances between agent movements but is not explicitly represented here.

3. Process overview and scheduling

In the model, agents manufacture artefacts to a set reduction level determined by the `reduction` parameter. That value is a fraction of the total surface area of a core rounded to the nearest 1/20th, and this fraction is divided into equal parts to represent flakes. Both cores and flakes are added to a list variable called `assemblage` in the patch immediately beneath the agent. Each core is added to the list as a 0, while each flake is added as a 1.

Following a reduction event, the agent will select the core, or a portion of the flakes produced by the reduction based on the `selection` parameter. The model is designed to evaluate strategies that target either flakes or cores, so the targeted artefact type in the model is determined by the `target` parameter. These are tabulated and stored in a variable called `carry_count`. The agent then moves in a random direction with step lengths to model different degrees of tortuosity in movement, established with the `levy_mu` parameter. Between each step, agents will discard an artefact by subtracting one from their `carry_count` and, depending on what kind of element is being targeted in the model, adding a flake or core to the patch's `assemblage`. This is repeated until either a) the agent runs out of artefacts (`carry_count` = 0), prompting the agent to manufacture more artefacts, or b) the agent leaves the window of observation, in which case that agent is removed and a new agent is added to the model. Agents may start off carrying a set number of artefacts, determined using the parameter `carry_in`. Simulations are run until a set number of agents, determined using the parameter `walkers`, is reached.

4. Design concepts

4.1 Basic Principles

FMODEL is based on basic concepts of forager technological organisation, viewing the discard and procurement of stone artefacts as embedded within the movement routines of the forager. The forager moves with a degree of tortuosity of movement across a space given the intensity of the foraging activity. Greater tortuosity movement results in greater redundancy in place use, producing more opportunity for local discard and potentially limiting the amount of stone material that might be taken away from a place.

4.2 Emergence

Regularities in the ratio of cortical surface area to expected cortical surface area occur through the additional and removal of flakes and cores to patches within the window of observation.

4.3 Interaction

Agents within the model interact with patches by adding artefacts to the local assemblage, and obtaining artefacts from generated assemblages.

4.4 Stochasticity

Agent movement directions were determined randomly to assume no directional bias in movement. Movement lengths were drawn randomly from a Lévy distribution (see section 6) to model different degrees of tortuosity in movement.

4.6 Observation

Data was primarily collected at the end of a simulation run. Cortex ratios were calculated from accumulated assemblages by multiplying the number of cores (0s) in patch `assemblage` lists by 20, multiplying that value by the `reduction` parameter setting, and then adding the total number of flakes (1s) to get the observed cortical surface area, and then dividing this by the number of cores (0s) multiplied by 20 (taken to be the expected cortical surface area).

5. Initialization

At the start of the model, there are no agents, and all patches contain no artefacts. When the first agent moves into the world following the movement submodel, it will either begin by discarding an artefact or making new artefacts, depending on the value of the `carry_in` parameter.

Table 1 Parameter settings used in FMODEL

Parameter	Setting
`world_size`	32 × 32
`Walkers`	10, 100
`Reduction`	0.1 – 1 (0.1 intervals)
`Selection`	0.1 – 1 (0.1 intervals)
`levy_mu`	$1 < \mu \leq 3$

6. Submodels

6.1 Movement submodel

The probability of the agent taking a step of length is determined using the parameter `levy_mu`, which is the μ variable in a heavy-tailed probability distribution using the equation:

$$P(l) = l^{-\mu}$$

where μ is a value equal to $1<\mu\leq3$. At the start of the model, the agent draws a value from the above distribution, and a random fraction of that value is obtained. The agent then moves into the world by that fraction from a random point at the edge of the world. All subsequent moves are taken using the full value of the draw until a move carries the agent out of the world.

7. Alternative configurations

7.1 RAW MATERIAL MODEL

FMODEL was reconfigured to examine the effects of differences raw material distribution on a forager whose stone procurement was embedded in foraging movements, as well as the influence of imbalances in the intensity of place use between 'stone-rich' versus 'stone-poor' region. In this model variant, the world is split evenly into two sides, right and left. In each side, raw material is identified by the agent based on patch colour; red patches have raw material which black patches do not. The number of patches in a side that contain raw material is determined as a proportion of the total number of patches on the side using the parameters `left_abundance` and `right_abundance`, respectively. While agents continue to discard between steps, they are constrained in their ability to manufacture new artefacts by the presence of raw material in the patch at which they are located.

In addition, instead of moving to a single level of tortuosity, movement tortuosity is governed depending on what side of the world the agent is located on, using the parameters `left_mu` and `right_mu` as the μ parameter in the movement submodel above. This was used to model the differences between a residential mobility pattern where there was no substantial difference in the redundancy of place use, and a logistic mobility pattern where the redundancy of place use was higher in some places and lower in others.

Table 2 Parameter settings used in FMODEL_A

Parameter	**Setting**
`world_size`	32 × 32
`walkers`	100
`reduction`	0.1 – 1 (0.1 intervals)
`selection`	0.1 – 1 (0.1 intervals)
`left_abundance, right_abundance`	0 – 1 (0.1 intervals)
`left_mu, right_mu`	$1 < \mu \leq 3$

8. References

Douglass, M.J., S.J. Holdaway, P.C. Fanning, and J.I. Shiner. 2008. An Assessment and Archaeological Application of Cortex Measurement in Lithic Assemblages. *American Antiquity* 73: 513–526.