OVERVIEW, DESIGN CONCEPTS, AND DETAILS FOR FMODEL_OccupationVsAccumulation

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

Davies, B., M. Douglass, S. J. Holdaway, and P. C. Fanning. Resilience and reversibility: engaging with archaeological record formation to inform on past resilience. Submitted to *Archaeological Review from Cambridge*.

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).

This model is based on an earlier simulation, FMODEL, which is reported elsewhere (Davies et al. 2018; Holdaway and Davies 2019).

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 or site. Time advances between agent movements but is not explicitly represented here.

3. Process overview and scheduling

In the model, agents manufacture artefacts (see Submodels 6.1) to a set reduction level determined by the `reduction` parameter. Cores and flakes are added to a list variable called `assemblage` in the patch immediately beneath the agent. Following a reduction event, the agent will select a portion of the flakes produced by the reduction based on the `selection` parameter and are stored in an agent variable called `flake_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 (see Submodels 6.2).

Between each step, agents will discard an flake by subtracting one from their `flake_count` and adding a flake (1) to the patch's `assemblage`. This is repeated until either a) the agent runs out of flakes (`flake_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 flakes, up to the total produced by a single reduction event (20), which is determined using the parameter `carry_in`. Simulations are run until a set number of agents, determined using the parameter `walkers`, is reached.

At the conclusion of the simulation, the Cortex Ratio (`cortex_ratio`) is calculated from the assemblage remaining in the window of observation (see Design Concepts 4.5).

4. Design concepts

4.1 Basic Principles

FMODEL_OccupationVsAccumulation 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 addition and removal of flakes and cores to patches within the window of observation, an outcome determined through the stochastic pattern of movements.

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.

4.5 Observation

At the conclusion of the simulation, the Cortex Ratio (`cortex_ratio`) is calculated from the assemblage remaining in the window of observation. This calculation uses arbitrary but constant values for average nodule volume (`nod_vol`, hard coded here as 100000), and surface area (`nod_csa`, hard coded here as 10418.8). Three values are then generated from the `assemblage` lists on each patch:

- `assem_cores`: the number of cores (0) in the assemblage, given as the sum of each patch's `assemblage` list minus any flakes (1)
- `assem_flakes_on_cores`: the number of flakes remaining on cores, given as `assem_cores` multiplied by the degree of `reduction` times 20
- `assem_flakes`: the number of flakes (1) in the assemblage, given as the sum of each patch's `assemblage` list minus any cores (0)

The 20 flakes on a nodule are considered to have volume equal to a proportion of the `nod_vol` (given as the tunable parameter `flake_vol_prop`). Total assemblage volume (`assem_vol`) is then calculated by adding the volume of all flakes to the volume of all cores. This is divided by the `nod_vol` parameter to give the number of nodules (`mod_num_cobs`) that should be represented given the volume of material present. The expected cortical surface area (`exp_csa`) is then calculated by multiplying this value by the `nod_csa` variable.

Finally, the cortical surface area observed for the assemblage (`obs_csa`) is calculated, which comes from adding `assem_flakes` and `assem_flakes_on_cores`, and multiplying this by 1/20th of the `nod_vol` value. Dividing `obs_csa` by `exp_csa` gives the `cortex_ratio`.

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_OccupationVsAccumulation

Parameter	Setting
`world_size`	32 × 32
`walkers`	100 - 500
`reduction`	0.1 – 1 (0.1 intervals)
`selection`	0.1 – 1 (0.1 intervals)
`levy_mu`	$1 \leq \mu \leq 3$
`flake_vol_prop`	0.2
`carry_in`	0 -1

6. Submodels

6.1 Manufacture submodel

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 a portion of the flakes produced by the reduction based on the selection parameter, given as a fraction of the total number of flakes produced in a reduction event rounded to the nearest 1/20th. The number of flakes are removed from the assemblage list and are stored in an agent variable called flake_count.

6.2 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 $1 \leq \mu \leq 3$. 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.

Steps in the simulation are drawn as lines trailing the agents movements. Movements are capped at a step length of 500000; this would certainly carry the agent outside the window of observation (which is 32x32), but the cap eliminates the possibility (however remote) of drawing an extraordinarily long step that could crash the program.

7. Alternative configurations

Alternative configurations within the model can be chosen using the models parameter.

7.1 OCCUPATION MODEL

In the "Occupation Model", all parameters are held constant except for levy_mu, which is determined by a random float draw between 1 and 3. This is used to model the effects of different use of space in an otherwise neutral model of lithic manufacture and distribution.

Parameter	Setting
`world_size`	32 × 32
`walkers`	100, 200, 300, 400, 500
`reduction`	1
`selection`	1
`levy_mu`	Random value $1 \leq \mu \leq 3$
`flake_vol_prop`	0.2
`carry_in`	0, 1

7.2 ACCUMULATION MODEL

In the "Accumulation Model", all parameters are held constant except for levy_mu, which is determined by a random float draw between 100 and 500. This is used to model the effects of different degrees of accumulation in an otherwise neutral model of lithic manufacture and distribution.

Parameter	Setting
`world_size`	32 × 32
`walkers`	Random value $100 \leq w \leq 500$
`reduction`	1
`selection`	1
`levy_mu`	1, 1.5, 2, 2.5, 3
`flake_vol_prop`	0.2
`carry_in`	0, 1

8. References

Davies, B., Holdaway, S.J., and Fanning, P.C. 2018. Modeling relationships between space, movement, and lithic geometric attributes. *American Antiquity* 83 (3): 444–61.

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.

Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., and Railsback, S.F. 2010. The ODD protocol: A review and first update. *Ecological Modelling* 221 (23): 2760–68.

Holdaway, S.J., and Davies, B. 2019. Surface Stone Artifact Scatters, Settlement Patterns, and New Methods for Stone Artifact Analysis. *Journal of Paleolithic Archaeology* 2019.