

SEAcross ABM v1.0

ODD + D Protocol

Christine Hertler^{1,2}, Jan-Olaf Reschke^{1,2,3}, Ericson Hölzchen^{4,5}, Iwan Pramesti Anwar⁶, Mika Puspaningrum⁶, Nicolas Büscher³, Emmanuel Kipruto Ngetich^{1,2,3}

¹ ROCEEH Research Center, Senckenberg Research Institute, Frankfurt am Main, Germany

² ROCEEH Research Center, Heidelberg Academy of Sciences and Humanities, Heidelberg, Germany

³ Paleobiology and Environment Group, Institute of Ecology, Evolution, and Diversity, Dept. of Biosciences, Goethe University, Frankfurt am Main, Germany

⁴ Trier Lab for Social Simulation (TRILAB), Trier University, Trier, Germany

⁵ German Center for Artificial Intelligence (DFKI), Cognitive Social Simulation, Trier University, Trier, Germany

⁶ Bandung Institute of Technology, Faculty of Earth Sciences and Technology, Bandung, Indonesia

We provide a technical description of the model by applying the ODD + D protocol, which was originally developed by Grimm et al. (2010) and later extended by Müller et al. (2013) for models of human decision making.

The model is a modified version of the HomininWaterCrossingABM introduced by Hölzchen et al. (2021, 2022).

Overview

Purpose

The model simulates the crossing of a water barrier by agents representing terrestrial mammals.

It is designed for researchers and students in (paleo-)biogeography to quantitatively test the chances of agents crossing a water barrier on an artificial map. The agents represent individuals of certain species with specific swimming performances.

Entities, state variables and scales

On the one hand, the environment of the model consists of a grid of cells, which we refer to as “patches”. These patches belong either to the source area, to the water barrier, or to the target area. On the other hand, we refer to the mobile entities as “agents”. The agents represent individuals of terrestrial mammal species. All parameters of the environment are listed and described in Table 1, all parameters of the agents are described in Table 2.

Visualization parameters are listed in Table 3. They determine what is visible in the simulation view and have no effect on the simulation results. The functions of the buttons in the interface are listed in Table 4.

Table 1. Environment and patch parameters

Name	Type of parameter	Description
<i>coast-base-range</i>	global factor	extent of terrestrial patches on both sides of the water barrier; default = 25
<i>current-direction</i>	global factor	direction of the water current in degrees; default level = 90
<i>current-speed</i>	global factor	speed of the water current; default level = 0.1 km/h
<i>is-source-area?</i>	patch factor	True = patch belongs to source area; False = patch does not belong to source area
<i>is-target-area?</i>	patch factor	True = patch belongs to target area; False = patch does not belong to target area
<i>max-simulation-duration</i>	global factor	model run duration in ticks; default level = 2160
<i>patch-type</i>	patch factor	type of the patch (e.g., “land”, “water”)
<i>pcolor</i>	patch response	built-in NetLogo variable which holds the color of the patch which is determined by the map coloring factor (<i>map-coloring</i>)
<i>plabel</i>	patch factor	built-in NetLogo variable which holds the label text of the patch; not used in the present model

Name	Type of parameter	Description
<i>plabel-color</i>	patch factor	built-in NetLogo variable which holds the color of the label of the patch; not used in the present model
<i>pxcor</i>	patch factor	built-in NetLogo variable which holds the x-position of the patch on the map
<i>pycor</i>	patch factor	built-in NetLogo variable which holds the y-position of the patch on the map
<i>resources</i>	patch factor	Resource qualities of the patch
<i>slope</i>	patch factor	slope of the patch in percent rise
<i>time-occupied</i>	patch response	cumulative number of ticks in which the patch was occupied by agents
<i>water-barrier-size</i>	global factor	extent of the water barrier

Table 2. Agent parameters

Name	Type of parameter	Description
<i>action</i>	agent response	Action of the agent, e.g., “water-movement” or “land-movement”
<i>actual-patch</i>	agent response	holds whether the current patch of the agent is in the source area, water or target area; required for counting the crossing attempts
<i>breed</i>	agent constant	built-in NetLogo variable which holds the breed of the agent; breed = animals
<i>color</i>	agent constant	built-in NetLogo variable which holds the color of the agent; color = red
<i>constant-population-size</i>	global factor	switch on for agents who disappear being replaced by new agents in the source area, off for no replacement; default level = On; This factor is not varied in the previous experiments and is intended for future applications.
<i>decision-randomness</i>	global factor	randomness of decision; default level = 0.1
<i>effective-walking-distance</i>	agent response	effective movement distance calculated from slope
<i>energy</i>	agent response	current energy in kcal
<i>energy-loss-water-movement</i>	global factor	loss of energy when paddling quadrupedally, calculated from body mass and swimming

Name	Type of parameter	Description
		speed (see section "Submodels")
<i>heading</i>	agent response	built-in NetLogo variable which holds the direction of movement of the agent
<i>hidden?</i>	agent constant	built-in NetLogo variable which allows switching the visualization of agents on or off; hidden? = False (agents are visible)
<i>hours-spent-in-water</i>	agent response	duration in hours the agent spent in water; is reset to zero, if the agent returns onto a land patch
<i>hours-water-crossing</i>	agent response	duration in hours the agent needed to cross the water barrier
<i>hydrophobia-coefficient</i>	global factor	likeliness of the agent to move into water (see section "Submodels")
<i>label</i>	agent constant	built-in NetLogo variable which holds the label text of the agent; label = "" (no label)
<i>label-color</i>	agent constant	built-in NetLogo variable which holds the color of the label: label-color = black; labels are not used in the model
<i>max-animals</i>	global response	maximum number of agents which is calculated from the density of agents (<i>population-density</i>)
<i>max-energy</i>	global factor	maximum energy, calculated from body mass (see section "Submodels")
<i>new-founder?</i>	agent response	True = member of a founder group; False = not a member of any founder group
<i>number-founder-agents</i>	global factor	required number for a founder group; default level = 20
<i>optimal-swimming-speed</i>	agent factor	speed of movement in water which is calculated from Head-body-length (see section "Submodels")
<i>optimal-walking-speed</i>	global factor	maximum speed of movement on land; default level = 5 km/h
<i>pen-mode</i>	agent constant	built-in NetLogo variable which holds the mode of the mark of the agent; not used in the present model
<i>pen-size</i>	agent constant	built-in NetLogo variable which holds the size of the mark of

Name	Type of parameter	Description
		the agent, when <i>pen-down</i> is activated; not used in the present model
<i>perception-radius</i>	global constant	radius of perception; default level = 50 km
<i>population-density</i>	global factor	density of agents on the map; default level = 0.1 individuals/km ²
<i>previous-patch</i>	agent response	holds whether the previous patch of the agent was in the source area, water or target area; required for counting the crossing attempts
<i>reached-target-area?</i>	Agent response	True = reached the target area; False = not reached the target area
<i>shape</i>	global constant	built-in NetLogo variable which holds the shape of the agent; shape = "dot"
<i>size</i>	global constant	built-in NetLogo variable which holds the size of the agent visualization; size = 2
<i>target-patch</i>	agent response	patch towards which the agent heads
<i>vision-range?</i>	global factor	switch on for agents to have a reduced vision-range
<i>who</i>	agent response	built-in NetLogo variable which holds the ID of the agent
<i>xcor</i>	agent response	built-in NetLogo variable which holds the x-position of the agent on the map
<i>ycor</i>	agent response	built-in NetLogo variable which holds the y-position of the agent on the map

Table 3. Visualization parameters

Name	Type of parameter	Description
<i>map-coloring</i>	global factor	Holds which terrestrial map type is visualized, e.g., slope, resources or source-target-area

Name	Description
<i>go</i>	runs the simulation until <i>max-simulation-duration</i> is reached
<i>setup</i>	calls the <i>setup</i> procedure
<i>update-visual</i>	updates map visualization if <i>map-coloring</i> has been changed

A patch represents 1 km² of real space and 1 time step, which we refer to as „tick“, represents 1 hour of real time.

Process overview and scheduling

At the beginning of each *tick*, the number of agents is maintained, when *constant-population-size* is enabled. During a simulation run, agents may die if they move in the water (see section “Submodels”) or leave the map at the border, either on land or in the water. In the case of disappearance, new agents will be placed randomly in the source area of the map until the set density of the agents (*population-density*) is met. Then, the agents move across the landscape (see section “Individual Decision-Making”).

The speed of the movement on land is controlled by the factor of optimal speed of movement on land (*optimal-walking-speed*), which is 5 km/h by default. Moreover, the speed of movement is modulated by the topography, which is represented by slope, whereas the maximum speed of movement is applied when the slope level is 0%, and the slowest speed of movement is applied at a slope level of 100%. To prevent agents from getting stuck on the map in the case of slope values close to 100%, we limit the slowest speed to 1% of the optimal speed, which results in a minimum speed of movement of 0.05 km/h. As a result, the agents are substantially obstructed in movement at slope angles beyond 45°.

Design Concepts

Theoretical and Empirical Background

The environment of the model is a simplified representation of a landscape being divided by a water barrier. Here, we define a crossing as a movement from a source area towards a target area on the opposite shore across the water barrier. The movement on land of the agents is controlled by the range of perception (*perception-radius*) of resource qualities of surrounding patches within this radius. This includes resource qualities of the opposite shore, if these are within the range of perception. Furthermore, the movement is controlled by a degree of randomness (*decision-randomness*) of decision (see “Individual Decision-Making” section). The movement in water represents quadrupedal paddling and is controlled by factors of physiology (see section “Submodels”) and factors of the water barrier (see section “Environment” in “Submodels”).

Individual Decision-Making

The movement on land is determined by the resource qualities of the patches and the randomness of decision (*decision-randomness*) of the agents. The agents move on land by selecting a target patch within their range of perception (*perception-radius*) and heading towards it. The degree to which an agent selects the patch with the highest resource qualities within its range of perception, is defined by the randomness of decision (*decision-*

randomness). This prevents the agent from getting stuck in local maxima of resource qualities.

When starting a crossing attempt, before moving onto the first water cell, the agents are tested for their likeliness to move into open water (*hydrophobia-coefficient*). Depending on the hydrophobia value (see section “Hydrophobia” in “Submodels”) the agents are less or more likely to move into the water and start a crossing attempt or abort and search for a new cell in the starting area. A crossing attempt stopped due to hydrophobia is counted as a failed crossing attempt.

The movement in water depends on whether the agents can perceive the target area. If the target-area is within the perception radius, they target the nearest cell and swim towards it. In the case of a broader water barrier, the agents perform random swimming until they can perceive a cell in the target area. The swimming performance depends on the set physiological scenario (see sections in “Submodels”) and the occurring currents (see section “Environment” in “Submodels”).

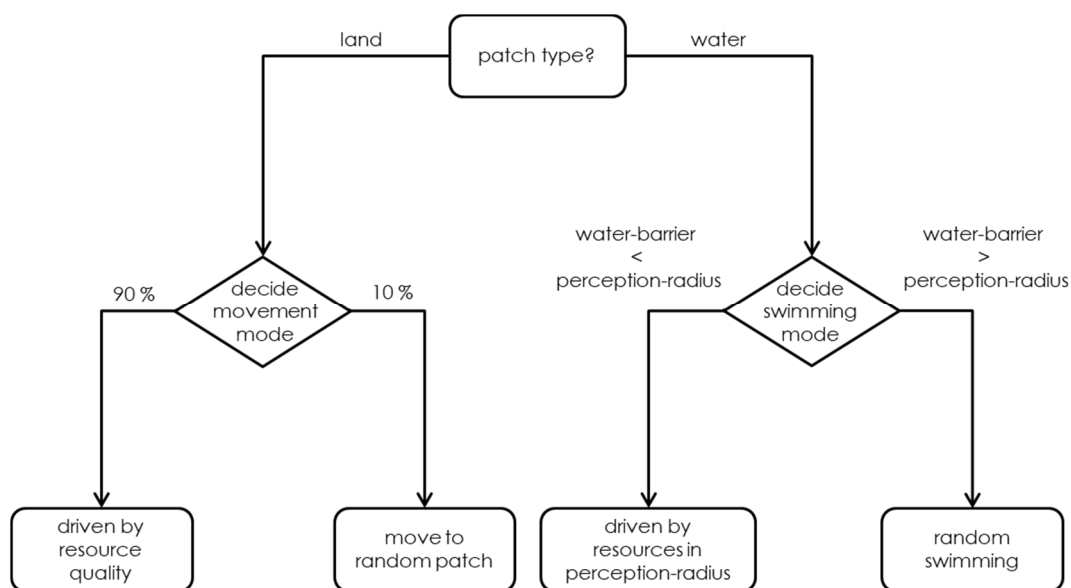


Fig 1. Behavioral decision tree of the agents.

Learning

In the present version of the models, the agents do not learn or communicate.

Individual Sensing

The agents perceive resource qualities of the patches within the set radius of perception (*perception-radius*), 50 km by default. To allow for erroneous assessments of resource qualities, we introduced a factor of randomness (*decision-randomness*) in the model, which determines the percentage of incorrectly assessed resource qualities. In this case, the agent selects any patch within its radius of perception, instead of targeting the patch with the highest resource quality.

Stochasticity

The distribution of environmental patch values (resource qualities and slope) is random across the land patches. Moreover, initial agents and new agents appear across the source area randomly. Target patch selection by the agents is probabilistic, with a higher probability for patches with higher resource qualities. Failing the check for hydrophobia and aborting a crossing attempt before moving into the water is probabilistic, with the chance to increase with a higher hydrophobia (*hydrophobia-coefficient*).

Observation

The model allows for various analyses of responses (Table 6). These responses can either be measured at each tick, or at the end of a simulation run.

Table 6 Model responses

Name	Description
<i>attempts-source-water</i>	total number of crossing attempts by individual agents
<i>attempts-source-water-founder</i>	total number of crossing attempts by groups of individuals of the size of a founder group (<i>number-founder-agents</i>)
<i>crossing-success-rate-founder-population (CSR)</i>	crossing success rate of founder groups which is calculated from the crossing attempts by founder groups (<i>attempts-source-water-founder</i>) divided by the total number of successful crossings (<i>sum-of-founder-population-size-reached</i>)
<i>crossing-success-rate-individuals</i>	crossing success rate when assuming each individual agent to be a sufficient founder group (<i>number-of-founder-agents</i>) = 1
<i>death-exhaustion</i>	total number of agents who died from exhaustion
<i>death-left_map_land</i>	total number of agents who left the map via a land border
<i>death-left_map_water</i>	total number of agents who left the map via a water border
<i>founder-population-size-reached</i>	Boolean response which is 0, when no founder group is establishing in the present tick, and is 1, when a founder group is establishing
<i>hydrophobia-aborted-attempts</i>	total number of aborted attempts
<i>mean-individual-hours-water-crossing</i>	mean number of hours required for successful crossings of the water in the present tick
<i>sum-mean-hours-water-crossing</i>	cumulative number of mean hours required for a successful crossing of the water
<i>sum-of-death</i>	sum of deaths by all death causes and map exits
<i>sum-of-founder-population-size-reached</i>	cumulative number of successful establishing of founder groups
<i>sum-of-target-area-animals</i>	cumulative number of agents in the target area
<i>target-area-animals</i>	number of agents in the target area in the present tick

Details

Implementation Details

The model has been implemented in NetLogo 6.2.2 (Wilensky, 1999).

The model proper as well as documentary data (ODD+D protocol, replication assessment, sensitivity studies) is available for download at zenodo.org: [10.5281/zenodo.6833780](https://zenodo.org/doi/10.5281/zenodo.6833780).

The SEAcross model is a spinoff of the Hominin SeacrossingABM described in Hölzchen et al. (2021).

Initialization

The configuration of the terrestrial environment is determined by the selected size of the coast (*coast-base-range*). The sea strait is generated from the selected size of the water barrier (*water-barrier-size*), and the properties of the current (*current-speed* & *current-direction*). Moreover, the color visualization of the patches is set by the factor *map-coloring*, the duration of the simulation by the factor *max-simulation-duration* and the random seed by the factor *seed*. The default levels of the aforementioned factors are shown in Table 7.

Table 7. Default levels of factors for initialization

Name	Description
<i>map-coloring</i>	coloring of the map = “resources” (green color scale)
<i>max-simulation-duration</i>	duration of a single run of the simulation = 2160 hours (90 days)
<i>seed</i>	seed number for built-in NetLogo procedure <i>random-seed</i> ; default-level = 1000

Submodels

Hydrophobia

The probability of an agent to enter the water and start swimming ranges between 0 and 1 (*hydrophobia-coefficient*). A high value results in a higher number of aborted attempts, while an agent with hydrophobia coefficient = 0 always decides to move into the water.

The used value is derived from observable behavior of living reference taxa. Animals in our model are assigned a hydrophobia coefficient of 0, if they are semiaquatic or frequently interact with water. Animals interacting regularly with large bodies of water without depending on it, are assigned to a hydrophobia coefficient of 0.25. If an animal only swims sporadically it can be rated as having a hydrophobia coefficient of 0.5, while animals who avoid getting into contact with water altogether, are classified as having a hydrophobia value of 0.75.

Swimming performance

In water, the agents move by quadrupedal paddling. Swimming performance is calculated on the basis of a physiological swimming model (Meijaard, 2001) as the ratio between energy available as fat and energy consumption when swimming.

Energy storage

Each agent has a certain maximum amount of available energy (*max-energy*) in [kJ], which is estimated from fat in body mass of the species in question.

For animals between 4 g and 21.5 kg:

$$\log(F) = \log(W) - 1.207$$

For animals between 21.5 kg and 10,000 kg: $\log(F) = \log(W) - 1.146$

with F = fat weight [kg] and W = body mass [kg]

Fat weight is converted into available energy with an energy density for fat of 39 MJ per kg and a conversion efficiency of 0.23 (Pennycuick 1998).

Available energy = $(F \cdot 39,000,000) \cdot 0.23$

Swimming speed

In water, the agents move by quadrupedal paddling with a specific speed (*optimal-swimming-speed*) in m/s calculated from head body length (HBL). Optimal swimming speed corresponds to c. 16.5 % of the theoretical maximum, here represented by hull speed V_h .

Maximum swimming speed V_h [m/s]: $V_h = \sqrt{HBL \cdot \frac{g}{2\pi}}$

with HBL = head body length [m], g = gravitational force 9.81 m/s, and $\pi = 3.14159$

Optimum swimming speed V_o [m/s]: $V_o = V_h \cdot 0.165$

In order to convert units and express optimum swimming speed in km per hours, the value is multiplied by 3.6.

Energy consumption

Energetic requirements for quadrupedal paddling of terrestrial mammals (*energy-loss-water-movement*) depend on the costs of transportation, body mass and swimming speed (*optimal-swimming-speed*).

Energy-loss-water-movement in Watts $\left[\frac{J}{s}\right] =$

costs of transportation $COT_{tot} \cdot W \cdot \text{optimum swimming speed}$

With $W = \text{body mass [kg]}$ and

costs of transportation $COT_{tot} \left[\frac{J}{kg \cdot m}\right]: COT_{tot} = 39.73 \cdot W^{-0.29}$ with $w = \text{body mass in [kg]}$

An agent dies of exhaustion when its energy deposits are depleted. If an agent survives the movement in the water and reaches a land patch, its energy deposit is restored to its maximum level (*max-energy*).

Environment

The environment of the model is a dynamic grid, where one patch represents 1 km². Patches are either water patches or land patches. The land patches consist of layers of resource qualities and topography represented by slope. The levels of resource qualities range between 0 and <1, whereas a low value (closer to 0) refers to an unfavorable patch and a high value (closer to 1) to a favorable patch. Consequently, the resource qualities of patches perceived by the agents affect their direction of movement on land (see section “Individual Decision-Making” and “Individual Sensing”). Additionally, the slope affects the speed of movement (see “Individual Decision-Making”).

The speed and direction of currents affect the speed and direction of the movement across the water by adding the speed and direction to the movement of the agent, which results in a deflection of the original movement.

The model generates a map with random values of resource qualities and slope of the patches and uniform water temperature and uniform dynamic current properties. The size

of the map depends on the chosen width of the sea strait (*water-barrier-size*) and the size of the coast on both sides of the water barrier (*coast-base-range*). The water barrier runs horizontally across the center of the map.

References

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