Overview, Design Concepts, and Details (ODD) Protocol for the MobileForager Agent Based Model

The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al., 2010, 2006).

This protocol is for MobileForagerB X-06-2.

Purpose

“MobileForager” is a spatial agent-based computer simulation of hunter-gatherer mobility behavior build in NetLogo[1]. To be used as an laboratory, the model simulates the behavior of agents representing some kind of ideal-typical human forager. The model has been developed by Martin Solich in the course of his PhD-project in the 1st phase of the Collaborative Research Centre 806 “our way to europe”[2].

The hypothetical model behind MobileForager is based mainly on the work of Robert Kelly (Kelly, 2007). Kelly uses the theory of human behavioral ecology (HBE) and optimal foraging theory (OFT) and refines them to explain differences between foraging groups. The individual-focused perspective of both theories fits very well with the method of agent-based modeling (ABM). Additionally, social factors are taken into account (i.e. different modes of sharing, building and maintaining friendship ties).

Purpose of the model is to generate emergent mobility patterns that can be found among hunter-gatherers and by this means helps to explain these. It is used in the project context primarily as a deductive approach to test existing hypotheses and to get a better understanding of the inter-play of different factors and goals by changing parameters affecting environmental conditions and forager-agents' goals and abilities.

Also, with the development of a simulation it should be possible to better assess the explanatory power of existing HBE and OFT hypotheses concerning hunter gatherer mobility and help to improve and integrate them.

Since the model tries to be a high-level framework, many variables can be set by the user to accomodate with his research needs. Also the submodels could be changed to implement other goals, strategies or resources.

Questions that can be asked are, for example:

[1] NetLogo is a free programming languange and environment especially for agent based modeling. For more info see http://ccl.northwestern.edu/netlogo/.

[2] See http://www.sfb806.uni-koeln.de/

To which extend do different types of resources change the movement patterns?

How will different sharing rules affect fission processes?

How will the wish for socialization change the results?

With scarce resources, how does residential movement takes place? Do camps move together?

Despite the vast theoretical body of OFT and HBE, building a model with these assumptions shows many uncharted terrain. So in some modeling decisions guestimations have been used. If any assumption seems to be unrealistic or downright implausible you are most welcome to tell us. Also, despite trying to build a model as broad as possible, decisions have been made which don't hold for specific groups. These should, however, be easy to change in the source code.

Entities, state variables, and scales

The model distinguishes between two kinds of agents and cells. Cells make up the landscape but are not further differentiated but for their use as a camp site. Each cell represents a square of 3*3 kilometers. The total landscape consists of 41*41 cells (summed up to a total of 1681 cells). The number of patches suitable for a camp can be changed. Their distribution on the landscape is random.

Agents are used for the human foragers as well as for the resources. Resources supply the human agents with energy, which is calories. These energy is used for living and movements [3]. It is assumed, that all the agent needs to survive - besides water and shelter - is contained in this energy. Water and shelter is assumed to be there sufficient at the places suitable for a camp.

Time is modeled in steps of one hour. Following OFT a forager agent can in this time move 3km at a cost of 300 calories (Kelly, 2007)[4]. 24 hours make up a day. Each day at 9 am the human agents decide which action to take from 9 am to 4 pm. At 5 pm the energy gathered by the human agents is consumed and the resource agents are updated. The temporal extend of the model depends on the question posed by the experiment.

Resources can be of two types. Resources of type 1 are harvested partially whenever an agent forages on the cell it inhabits. Their current energy value is then reduced accordingly. They regenerate a bit every day up to their maximum energy level. The rate of regeneration also can be set. These resources don't move. They can be imagined as representing plant resources or smaller animals with fixed housing.

[3] The amounts of energy consumed by the agents doing different tasks are estimated values taken from Kelly (). These values vary highly for different ages and cultural groups. In the model the costs of living per day is calculated using an estimated base value and then modifying it according to the age of the agent.

[4] This is the default value of the parameter human-MovCost. This parameter can be changed like many others however to suit the research needs.

Resources of the second type can only be aquired completely. If a forager agent chooses to go for such a resource, he has a certain chance to aquire it If the forager agent succeeds the respective resource agent is removed.
A simple population dynamic is used, causing some type-2 resources to die and new ones to be created. Resources of this type can be imagined as representing deer or other big mammals.

Besides its type property each resource agent has a maximum energy value and a current energy value. The individual maximum energy of a resource can vary in amount according to the model settings.

Human agents are first of all differentiated by age, sex and kinship network. These don't change in the model run - except that agents may die if their energy need gets to high. Other values that change during the model run include their energy need, which they try to get down to zero, their camp-site (a patch), the actions they perform (go to resource, return home, forage, move camp, select a new action), their social-network (a list of other agents), sometimes a target they go to (a certain resource agent) or a new camp site to move to (a patch).

There are either 5 or 25 human agents, comprising 1 or 8 households of different composition. This should resemble a rough representation of different kinds of households found in hunter-gatherer societies.

Agents share their food at least within their household group. There are active and dependent forager agents. The last are below a certain age and don't go foraging. Thus they do not contribute to the households energy income.

The model allows to restrict the foraging activities to an 8 hour day, or enable so called "logistical mobility" (Binford, 1980). Under the first condition, the selection of resources is limited to such that can be exploited within 8 hours. Under the latter conditions the time is extended to 16 hours, allowing for resources further away. In this case the agent stays outside the camp in the night. This is to simulate hunting camps. These setting will affect all male human agents.

Besides long foraging trips there is also the possibility of families or whole camps to move when resources get scarce, and settle at a new place a distance away.

The kind of food sharing can be set to range from household only to whole camp. A complete list of the available conditions can be found in table 4. More details can be found in the submodels section. These setting also will affect all human agents alike.

It is possible to set up two seasons of variable duration that control the growth of type2-resources: Only in one of the seasons is the resource available then.

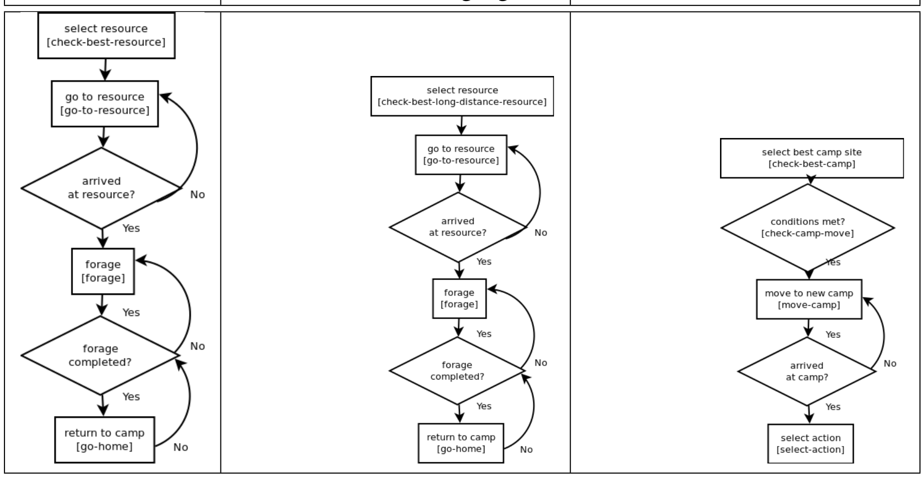
Process overview and scheduling

In our simple version of the forager life, the agents perform their daily tasks according to a fixed shedule. At 9 the daily tasks (foraging strategies or camp move) are decided on. Crucial for this is the calculation of the energy needed by the reference group (the family household). These group is composed of the foragers, their spouses and dependant children. Elder children are supposed to care for themselves (Kelly, 2007).

These activities are then take on from 9 to 16 in steps of one hour (represented by one *tick*). At each timestep all agents in random order execute the actions belonging to the selected task.

Possible tasks and their related actions (Program procedures are written in square brackets):

foraging	long distance foraging	move camp



Tab. 1: possible agent tasks

Each agent hunts or gathers individually. If configured so in the settings, agents with different gender go for different resource types.

At the end of the day, if the agents are back at their camp, the collected resources are shared and consumed and the energy-need is calculated. Else only the energy-need of the agents is calculated.

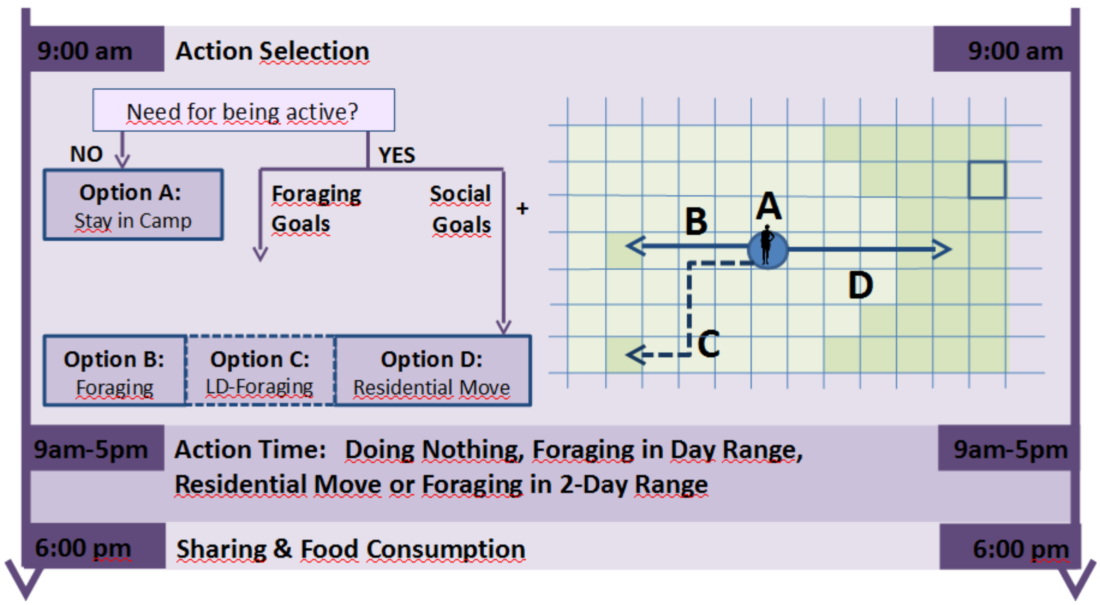
Resources are updated once per day in random order, after the foragers have finished their actions. Resources of type 1 regenerate following a simple growth model. Resources of type 2 are computed by a simple population dynamic. For details about both sub-models see below.

According to the settings, a male agent can follow up to two strategies with corresponding actions:

Tab. 2: foraging strategies

action number	near-distance foraging	long-distance foraging (settings: human-dis=true, human-2D=true)
-	select best near-distance resource	select best near-distance resource
-		select best long-distance resource
2	go-to-resource	go-to-resource
4	forage	forage
-	if time left: repeat	
1	go-home	go-home

The sequence of activities is depicted in the following diagram:



Design concepts

Basic principles

The model uses Human Behavioral Ecology (HBE) and Optimal Foraging Theory (OFT), especially as used by Kelly (Kelly, 2007), for the subsistence dimension of mobility. According to these theory, foragers are optimal adapted to their environment. Thus, no better way of exploiting the resources is possible. This is modeled by giving the actors near perfect knowledge of the resources to allow them to choose their foraging strategy based on the ratio of the expected return and the time and energy it will cost to exploit it.

The social dimension of mobility is modeled for once by giving the agents a need for socializing with others. The agents satisfy this need by prefering camps with a higher number of other agents when choosing their residence. The amount of this need can be changed.

Also agents can bet set to use different sharing rules.

The model is not based on any actual foraging group or uses resource data from an actual landscape. Instead, the model is intended to be used as a reference (or Null Model) to compare the predicted behavior with actual foraging groups. Especially in comparing outcomes of models with and without a social dimension the model should assist in assessing the explanatory power of HBE and OFT and inspiring future the research.

Emergence

Depending on the settings we can observe varying mobility patterns, characterized by different

- relative frequencies of foraging trips, long foraging trips and residential changes
- ranges of foraging trips
- landscape use
- fission and fusion dynamics
- settlement patterns
- distances of camps
- forager network characteristics

Adaptation

Forager agents adapt to their environment by choosing the optimal foraging strategy. The range of available strategies depend on the objectives of the agents and the model settings and are respectively:

1. to look for the best patch in day reach from the camp
2. to look the for best patch away more then a day
3. to move the camp

The agent evaluates the outcomes of these strategies and choose the one with the highest net gain according to their objectives.

*Objective*s

ForagerAgents can optimize on an energy dimension (*human-goal*) and on a social dimension (*social-goal*).

The model can handle three different objectives *for human-goal*:

- maximize food (settings value = 1)
- maximize foraging return (settings value = 2)
- minimize foraging time (settings value = 3)

In the first scenario the agent tries to gather as much resources as possible, independent of his current energy need. In the second case the agent only goes out hunting and gathering if he or his reference group are in need of food, and then tries to gather as much as possible. In the third case he only goes hunting or gathering if he or his reference group are in need of food and only until the food needed is collected.

On the social dimension forager agents can

- ignore other agents (settings value = 0)
- try to keep contact with a minimum number of other agents (which is a parameter to be set) (settings value = 1)
- try to keep contact with as many other agents as possible (settings value = 2)

See below under *Interaction*and Forager Agent Settings.

Prediction

Agents have near total knowledge of the resource distribution. They have total knowledge of the energy gained at a specific location concerning resource type 1 and estimate an expected return concerning resource type 2.

To evaluate the best resource available the forager agent first determins the best resource of type 1 reachable within his available time frame. This is done by selecting the resource with the best energy to moving costs ratio from all type 1 resources reachable in half the time left - assuming that the agent is in the camp when evaluating the resources[5] (r=expected return value, e = current energy of resource, p=percentage of energy that can be exploited at a time, t=time-limit ($\frac{timelLeft}{2}$) , d=distance to resource and back to camp, c=movement costs):

$$r = \frac{e - e \times (1-p)^{t-d} - d \times (c + \frac{c}{6})}{t}$$

Then the nearest type-2 resource reachable in the time left is choosen (if any), thereby maximizing the time to successfully aquire a type-2 resource.

[5] Since this is only an abstract model, we can ignore the fact that diagonal movements take more time than straight movements in this world of square patches.

The resource of type 2 has a probability of being successfully hunted which is known to the forager agent and constant to all resources of this type. The expected return r is calculated as (e = energy of he resource, p = success rate, t = time to search):

$$r = e \times p \times t$$

For comparison the costs of getting there and back to the camp are also taken into account. An return rate rr is thus calculated as (d = distance to the resource and back to camp, c= costs of moving, t = time to search:

$$rr = \frac{r - d \times c}{t + d}$$

Both outcomes are then compared to select the best available resource.

Sensing

Agents are able to sense the existence and energy of resource agents throughout the model environment. Also they sense the patches that can be used as campsites. They take into account however only these resources who are in one or two days reach - depending on the setting[6].

Agents sense the current energy of their household members to calculate the energy need. Depending on the setting they also know the decisions of other household or camp members for deciding when to move the camp. When maximizing a social goal they also sense the number of other agents in different camps.

Interaction

Forager Agents interact in numerous direct and indirect ways. Direct ways include the sharing of food, the coordinated movement of camps and the establishing of networks by joining other agents in a camp. An indirect way is the consumption of resources.

According to the model settings food is shared either in the family alone, with the family first and then the camp, with the family first and members of the camp who are in need or with the whole camp. There is, so far however, no explicit idea of reciprocity involved: All agents act on all other agents indiscriminately.

Camp movement can be undertaken for different reasons and including a different range of people. In the extreme case the decision of one agent to move can lead to the whole camp moving (see below Residential Change).

Agents establish networks of aquaintancy by creating links to other agents based on cohabitation of a camp. These links influence the movement of agents according to the *social-goal* model settings: Agents can be motivated to maintain a minimum amount of links or to maximise their degree in the network. The

[6] You can set human-2D to true to extend the sensing to two days reach.

first time agents share a camp, a link is build and gets a value of 1. Then for each day they share a camp the links value is raised by 1. On the other hand, each day agents don't share a camp their link's value is diminished by 1 and is deleted if it's value drops to zero.

Stochasticity

Stochasticity is used to create a variability in the environmental conditions and to model the varying success of foragers going for type-2 resources.

Type-1 resources in the model are assumed to have different fertility and usefulness, randomly distributed in the virtual world. For this we supply each patch with a resource of type 1. Each of these resources has its specific maximum energy level. These levels can be controlled by setting the mean and the variance for the maximum energy.

Type-2 resources also randomly vary in the amount of energy they contain. They also have a percentage rate to be successfully hunted. So the foraging success has a stochastic outcome. Both values can be determined in the model settings. Also the distribution and - if activated - the movement of type-2 resources use a random procedure.

Also, when the human population is setup to number 100 agents, the age distribution and the family structure is computed with a random function (see page 11).

Collectives

Two kinds of collectives can be identified in the model. The first is the household, who's members are prescribed in the source code and don't change. In some settings it's the summed up energy-needs of it's members that let the forager agent take action.

The second is the camp. If residential movements are concerned, depending on the parameters the opinion of the other active agents are taken into account. Also either all families who will move go together or even the whole camp moves. This has been described in detail under Residential Change. Also food sharing can be among the members of a camp (see under *Interaction*).

Observation

There exist different counters, plots and histograms that are updated hourly, daily, monthly or once every year.

- hour, day, month and year counters are updated everytime their value changes.

- Nr of Humans: The plot showing the number of humans is updated every hour.

- energy_current_need Status: Every day at 9 am a plot showing the energy need of each family in the last 30 days is plotted.

Every 1st day in a month at 9 am the plots for the distances moved, on foraging trips or on residential changes, are updated. The plot (Distances) shows:

- forage-mean: the development of the mean length of the foraging movements of the active agents.
  Every agents has a list containing the length of all foraging trips in the last month. The function first calculates the mean of this value. Then the mean of all the active agents mean foraging distance is calculated and plotted.

- forage-min: the development of the shortest foraging movements. Here the mean value of the shortest foraging trip of every active agent is used.

- forage-max: the development of the longest foraging movements. Here the mean value of the longest foraging trip of every active agent is used.

- camp-mean: the development of the mean of all agents mean of camp movement lengths.
  Every agents has a list containing the length of all camp movements in the last month. The function first calculates the mean of this value. Then the mean of all the active agents mean camp movements length is calculated and plotted.

- camp-min: the development of the shortest camp movements. Here the mean value of the shortest camp movement of every agent is used.

- camp-max: the development of the longest camp movements. Here the mean value of the longest camp movement of every agent is used.

Also the frequency and range of movements per month is calculated an plotted:

- forage-mean: the development of the mean of all agents foraging movements. Therefore the mean of all the active agents foraging trips in the last month is taken and plotted.

- forage-min: the development of the shortest foraging movements. Here the value of the smallest mean of an agents foraging trips in the last month is used.

- forage-max: the development of the longest foraging movements. Here the value of the biggest mean of an agents foraging trips in the last month is used.

- camp-mean: the development of the mean camp movement lengths. Here the mean of all agents camp movements in the last month is used.

- camp-min: the development of the shortest camp movements. Here the value of the smallest mean of an agents camp movements in the last month is used.

- camp-max: the development of the longest camp movements. Here the value of the biggest mean of an agents camp movements in the last month is used.

After the plots are updated, the list of every agent is cleared.

- Camps: the number of camps is plotted every day.

- Social Network: the mean number of members of an agents network (network degree) is plotted every day.

Since there are no real data to be compared with, this statistics until now only serve to identify different movement patterns when running the model with different paremeters.

Initialization

Since this is a very general model, there are a lot of parameters that can be manipulated related to the agents and the virtual landscape with it's resources.

Forager Agent Settings

How many agents and in which relationship It can be choosen between either

- 1 household with two parents each 25 years and 3 children age 4, 7 and 10

- 25 human agents (comprising 14 grownups), divided into 8 households of different composition

- a random population of 100 human agents

  In this last case a empirically based age distribution is used as a basis for the generation of agents. After the agents are created, they are grouped to families. First it is tried to link the female agents above a certain age each with a male agent at least as old as the female agent but not more than 10 years older. Then dependent agents (agents below a certain age) are associated as children to active female agents and their partners (if any). Elder female agents are privileged, since it is assumed that they potentially had more time to reproduce.
  At last the agents belonging together are randomly located in one of four primary camps.

Human goals Agents choose their actions to accomplish certain goals. In our case there are two dimension where agents can follow goals: the foraging dimension (modeled according to HBE and OFT) and the social dimension.

On the forager dimension agents can have the goal to

- go out and gather as much energy as possible
- go out if needed and try to maximize the return
- go out if needed and minimize their time out of camp (thus maximizing their recreation time)

On the social dimension agents can be set to

- don't care about contact with other agents
- try to maintain a minimum social network
  The minimum of social contacts to be maintained can be set by the *social-min* parameter.
- try to maximize one's social network

These settings influence the choice of a new camp in the way that - if necessary - new camps with more other agents there will be preferred. The weight these goals will have when evaluating a camp site can be set by the *social-value* parameter.

When Foragers change their camp Although at least household groups move together, it is the individual calculation of an active forager agent which give rise to such an action: If an active forager agent expects a better return rate when moving to a new camp, or when he needs to maintain his social network, he has the incentive to move. Then, depending on the settings, the calculations of other agents are taken into account to compute if there is a residential move and who will move. The parameter *human-MovStrat* combines the aspect of when a group moves and who this group will consist of:

Tab. 3: human-MovStrat

		when to move?			
		at least one agent	agent and partner	majority of camp	whole camp
who moves?	household		1		
	group of households		2		
	whole camp	5		3	4

Another parameter important in this context is the time needed to move the camp (i.e. pack the belongings, build a new shelter, ...) This can be set with the *human-Camp* variable.
Also, agents can be set to prefer a residential move even if it will not yield a higher return-rate. This is the case if there are no resources at all to cover the calculated demand for food. If the parameter *human-Esc* is true, agents then choose the nearest camp site with an average energy of surrounding resources (in a radius of 4.5 km) higher than the average energy of all type 1 resources.

With whom agents_share Different sharing rules can be applied by the parameter *human-Share* to determine with whom foragers share at the and of the day when they return to the camp. At the least, the energy gained is shared among the members of the household (human-Share = 0). Other rules allow the surplus - the energy which is not needed by the household members - to be shared either equally among all other camp mates (*human-Share* = 1), or just among the ones who have a need for food (*human-Share* = 2).
Also the whole food gained by a forager agent can be shared with all the camp members, without preferencing ones own household (*human-Share* = 3).

How far agents will roam Agents can look for food either in day range or in two days range. For the latter foraging trip agents will stay out of the camp over night. This option is called logistic move (Binford, 1980)and can be activated by the *human-Dis* parameter. For this to work, the parameter *human-2D* also has to be set to true. This parameter allows the agents to calculate return rates for resources within two days range. It also determines the knowledge agents have when evaluating a new camp site.

If there is a differentiation of labour If the parameter *human-Div* is true, male and female agents prefer different resources. Female agents will only look for type-1 resources and male agents will only look for type-2 resources if available. If set to false, both kinds of agents will select which ever resource has the best expected return-rate.

These and some more parameters are outlined in table 4 below.

parameter	values	description
human-PopSize	[1,2,3]	1: 1 household (5 human agents) 2: 8 households (25 human agents) 3: random population of 100 human agents
human-goal	[1,2,3]	1: Maximize Food 2: Maximize Foraging Return, 3: Minimize Foraging Time
social-goal	[0,1,2]	0: No goal 1: Maintain a minimum (social-Min) of contacts 2: Maximize contacts
social-min	[0-20]	Minimum number of others an agent wants to be connected to. Only used when social-goal is 1
social-value	[0-10]	Weight of the social goal when comparing possible camp sites
human-MovStrat	[1,2,3,4,5]	0: No residential moves 1: (1) Residential moves if partner wants to move as well (2) Only the family moves together 2: (1) Residential moves if partner wants to move as well (2) All families who want to move move together 3: Residential moves if the majority of the camp wants to move (2) The whole camp moves 4: only residential moves if all in the camp want to move (2) the whole camp moves 5: residential move if at least one human wants to move (2) the whole camp moves
human-Camp	[0,1,2,3,4]	Time (hours) used to build a camp. Is added to cost for moving a camp.
human-esc	On, Off	If no forage strategy delivers enough food, move anyway to the nearest camp-site with above average resources in the near
human-Share	[0,1,2,3]	0: Only household-sharing 1: Household-sharing (remainder camp-sharing) 2: Household-sharing (remainder donation for hungry camp members) 3: Campsharing
human-Dis	On, Off	Possible logistical moves (of men) human-2D needs also be set to true
human-2D	On, Off	Sensing is extended to resources 2 days away Used for evaluating a new camp site and - in conjunction with *human-Dis* - to allow for logistic moves
human-Div	On, Off	Division of labour: a distinction between “male” and “female” is made. Each looks for a different kind of resource type
human-Die	On, Off	Agents are removed, if their energy needed is bigger then ten times their daily energy-need
human-InDep	[10-20] increment 1	Age below an agent is in dependence (= not active)
human-Stor	On, Off	If no storage food is reduced by 10% each day (simulates degredation) - else food is not reduced.

Tab. 4: forager settings

Environment Settings

The environment also can be set up very differently. You can controll

- if there are resources of type 2 and their initial (and maximum) number
- if there are two seasons and how long they last
- how many possible camp sites there will be
- what mean quality (energy) and variance type-2 resources will have
- if type-2 resources move
- what mean quality resources of type 1 will have
- how fast the resources of type 1 will regenerate
- if the return rate (of resource type 1) is constant (like paid labour)
- how much the resource quality of all resources will vary

The variance and quality (energy) of the resources can be controlled by setting the *environ-resource1-qual* (or *environ-resource2-qual*) and the *environ-Variance* parameter. For each resource a maximum energy value is determined with the following formular (e = maximum energy, q = resource quality, v = setting of *environ-Variance parameter*):

$$e = q - (q * 0.01 * v) + random(q * 0.01 * v) * 2$$

All parameters are listed in the table below (table).

Submodels

Here we describe various algorithms that inform foraging behaviour, residential change, networks and resource dynamics.

Foraging

If the hunter reaches his target resource the hunting or gathering is executed, according to the selected resources. In the case of resources of type 1 the agent gathers as long is there is enough time left to return to the camp and the gain per hour is more than his energy need per hour. In the case of resources of type 2 the agent tries to get it as long as there is time left and returns to the camp on success.

If the resource is of type 1 the agent can harvest a percentage of the resource. That percentage can be controlled by the model settings in a range up to 100 percent. By using such a computation, the energy that can be gained from plant resources in an amount of time is diminished after each gathering (diminishing returns).

parameter	values	description
environ-Distri	On,Off	If On, resources of type 2 are only created in half of the virtual landscape. If *environ-resource2-mob* is On, however, they can move into the other half as well.
environ-AltType	On,Off	If Off the return-rate is constant (like paid labour). If On the return is diminshed with each harvest.
environ-CampSites	[0-1680] increment 20	The number of possible camp sites in the virtual landscape. Since the landscape has a total of 1681 patches, 1680 would mean that all but one patch are suitable.
environ-Grow	[0-100]	Growth rate for resources of type1. The exact formula can be found under on page 18.
environ-Season	[0-6]	Length of a second season. If greater than 1, only in this number of consecutive month resources of type 2 are able to recreate. Also in the other number of month of the year these resources have a higher mortality.
environ-resource2	[0-300]	Maximum number of resources of type 2 in the virtual landscape.
environ-Variance	[0-100]	variance of the maximum energy level among type-1 and type-2 resources
environ-resource1-qual	[0-300000] increment 1000	mean energy level of type 1 resources
environ-resource2-qual	[0-150000] increment 1000	mean energy level of type-2 resources
environ-resource2-mob	On, Off	If type-2 resources are able to move randomly.
human-resource1-ret	[0-100] increment 1	percentage of energy that can be exploited at a time
human-resource2-Enc	[0-100] increment 1	encounter rate (percentage)
human-MovCost	[0-1000] increment 50	energy cost of moving one patch (3 km)
human-Camp	[0-4] increment 1	energy cost of moving a camp

Tab. 5: environment settings

If a resource of type 2 is selected, the success is computed by random. The percentage of success can be set from 1 to 100 percent (*human-resource2-Enc*). As long as there is enough time left, each time step the success is computed anew. If a type-2 resource is successfully hunted, the specific energy of the resource is added to the hunters food supply.

If a resource is taken and enough time is left, another resource is targeted as described above. If not enough time is left, the agent returns to the camp.

Residential Change

Depending on the available resources and the social goals of the agents, households can move to a new camp site. Since not all places are considered as suited for a camp, only a number of the patches can be used. The number of suitable patches can be set initially.

Normally, and If there is no social need to change the camp, only the foraging return rate counts. In case agents can sense only resources in day reach, to evaluate the return rate of a new camp first the best type-1 resource within reach after the new camp has been moved will be calculated. Then the return rate of the resource of type 2 closest to the camp will be calculated. The highest return rate of both will then be compared to the return rate of the last foraging trip[7]. If the expected return rate of the new camp is higher, then the agent decides to move.

In case agents can sense resources reachable within 2 days, first the best type1 resource is selected within an extended radius, then the nearest type 2 resource (with the extended foraging time). Again the expected return rate is compared to the last foraging return rate and the agents decision set appropriatly.

Because other agents decisions will be also taken into account, the decision to move will not by itself lead to a camp change, but depends on the settings and the kind of agent (see on page 12).

Since different types of camps are possible, which accordingly afford different time and energy to move, the energy needed to move the camp is taken into account (can be set from 0 to 1000 in steps of 50) and the time needed (can be set from 0 to 4 hours). The time needed is substracted from the time left for hunting when arrived at the new camp.

Social goals can influence residential change. So even if there is no need for food an agent can decide to change to a new camp if his social links drop below a threshold value or if he wants to maximize them.

If social goals play a role in determining a new camp, only camps that are inhabited by humans are evaluated in the first place. Then the number of humans in each camp is counted and multiplied with the return rate *potential-camp-rr* for weighting:

social-advantage = 1 + humans-in-potential-camp * *social-Value* * 0.1
best-camp-social = *potential-camp-rr* * *social-advantage*

Social Networks

Social networks play an important role for the forager agents. The need for food will be calculated for the household. A household in this case is constituted of the partner of the forager agent and any dependent children. Then the food gained is shared according to the active food sharing rules

- with the household (rule 0)
- with the household first and the remainder with people of the camp who have a need for food (rule 1)

[7] According to Kelly camp choice depends on resources of type 1 which can be gathered by all group members and is more predictable then that of type 2 (Kelly, 2007). Also to work this way the resources have to be distributed homogeneously.

- with the household first and the remainder with the whole camp (rule 2)
- with the whole camp (rule 3)[8]

Beside this food-sharing network, the selection of a camp can be influenced by the presence or absence of other agents. According the social goal settings an agent can try to

- maintain a minimum (*social-NetMin*) of contacts
- maximize contacts

In case an agent seeks to maintain a minimum of contacts with other agents (not belonging to the household) and that mimimum is not met, he will lookout for a new camp which is inhabited by forager agents. Also if one of these cases is selected, the possible camps will also be compared by the number of forager agents dwelling there.

More to the actual creation of the network under *Interaction*.

Resource Dynamics

Type-1 resources recover every day a bit up to their maximum energy value. The formula for the growth is (e = current energy of the resource, g = growth rate as defined by the *environ-Grow* parameter):

$$e_{t+1} = e_t + round(e_t * 0.01 * (g/30))$$

where *environ-Grow* can be set from 0 to 100 and is the same for every patch of type-1 resource. This value defines the percentage of growth per month[9].

Resources of type 2 on the other hand are harvested per capita and the resource agents are removed from the environment. Each day the model checks if the set number of type-2 agents is reached. If not, new type-2 agents are created. The number of new agents depends on their maximum number, which can be set in the model's interface. The higher the maximum number of agents, the more can be created (n=number of type-2 agents):

$$n_{t+1} = n_t + floor(n_{max} * 0.05)$$

The total number of type-2 agents, however, can never exceed the maximum value[10].

Besides being aquired by a forager agent type-2 resources can also die if they are seasonal resources and their season is over. The duration of seasons can be from 1 to 6 month of the year. If out of season there will be no new type-2 resources created.

[8] This is a hypothetical variant for explorative purposes.

[9] This is no exact calculation, but should be sufficient here

[10] We use this formula instead of a one relating offspring to the number of existing animals because this one comes closer to an open population where the landscape offers some capacity for a certain number of animals.

If set so, type-2 resources are able to move according to a simple rule: each day they move - if possible - to a random adjacent place with no other agent (human or resource) on it.

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