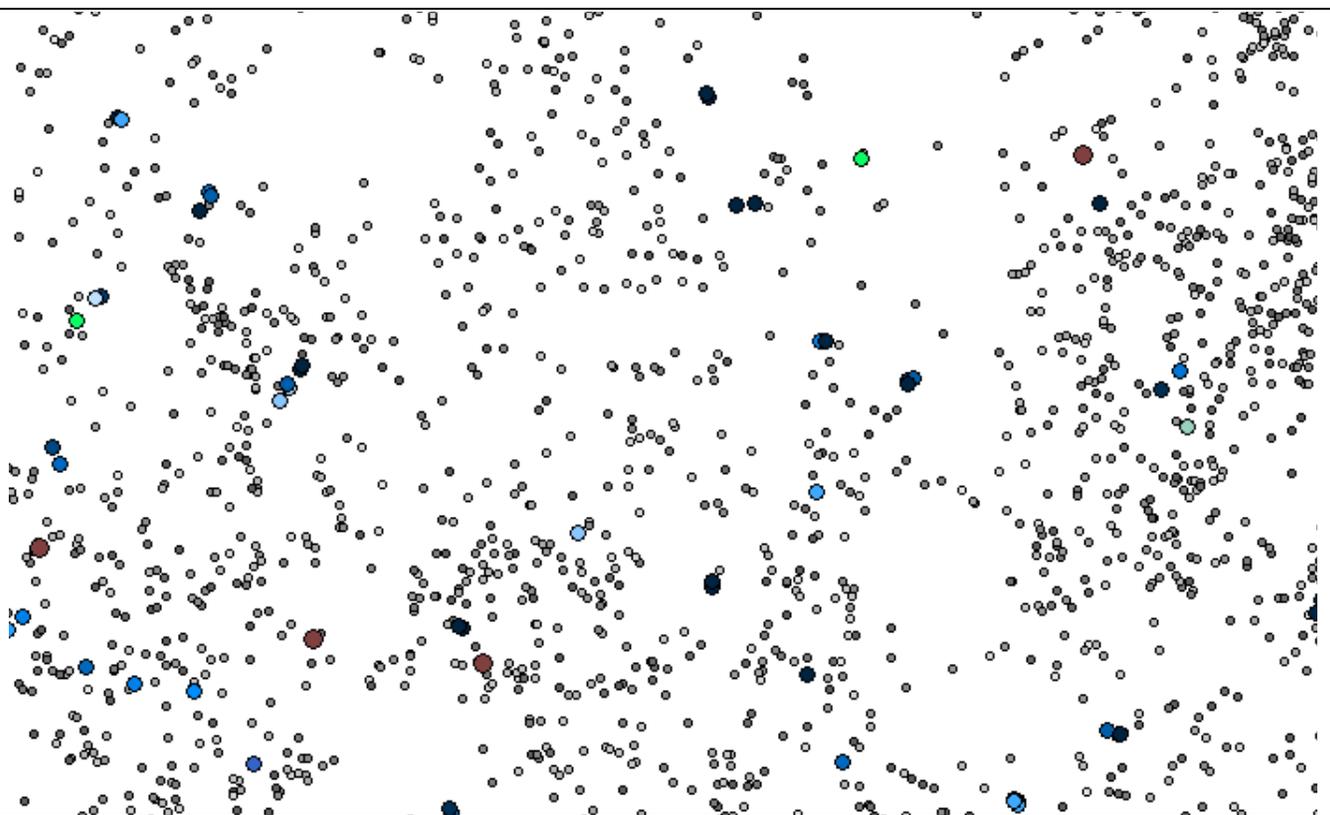


AffectSim 4.0 Manual

Martin Baatz & Luc Ciompi
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2 Introduction

2.1 What is AffectSim?

AffectSim is a software program that allows to simulate the evolution of affect-like patterns in autonomous agents through a strict energetic selection regime.

In the concept of affect-logic, emotions are understood as evolutionary advantageous functions that support energetic effectiveness and meaningful behaviour under changing life situations. Cognitions are inseparably connected to emotions like fear, pleasure, aggression, cooperation or flight. Each emotion is characterized by a specific pattern of energy consumption. In our approach, this is related to the direction of movement towards or away from the object in the focus of attention, velocity of the movement and a smaller or larger cognitive horizon.

AffectSim allows exploring how such emotion-like patterns of function evolve under various frame conditions. It contains all tools (graphical user interfaces) and steering options that are needed to configure simulation runs, to monitor simulations visually and to efficiently export statistics and results.

AffectSim is the outcome and the central tool of a privately financed research project performed by Luc Ciompi, Lausanne, Switzerland and Martin Baatz, Munich, Germany. AffectSim is a non-commercial freeware; there is no guaranteed functionality, no support and no maintenance.

2.2 Who are the users of AffectSim?

AffectSim is made public in order to inspire scientists and other people interested in fields like emotions research, psychology, psychiatry, sociology, artificial intelligence or evolutionary biology to further explore an energy-based evolutionary understanding of emotions.

2.3 System Requirements

Since AffectSim allows you to run simulations of global evolutionary processes it is computationally demanding. Therefore the recommendations are:

- Processor: 1 GHz minimum, faster CPU advantageous
- Memory: 1 GB RAM
- Operating system: Windows XP

The needed disk space is small. Since the statistical results come in comma separated format (csv), correspondent software is needed to read them.

2.4 Installing and Uninstalling

AffectSim does not come with a specific installation routine. Download the program from <http://www.affect-logic.com/3.html>. Choose the zipped version (*.zip) in order to avoid problems with your firewall. In this case you have to unzip the downloaded file. Simply copy the program into an appropriate folder on your computer. Create a shortcut on your desktop for convenience. No changes in the registry are needed or done. For uninstalling, simply delete the affectsim.exe file and the shortcuts.

2.5 Support and Contact

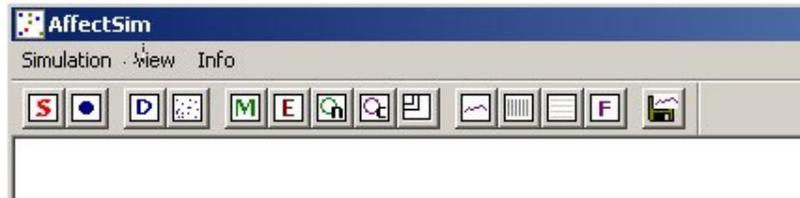
There is no official support for AffectSim. Nevertheless, if you have any questions or comments mail to info@affect-logic.com. You will be contacted as soon as possible.

3 Getting Started

3.1 Starting AffectSim

Start AffectSim by selecting the *affectsim.exe* file or the respective shortcut.

The main window of AffectSim appears and you see the menu and the toolbar (see explanation below).



The user interface of AffectSim was developed such that all major functionality is accessible through toolbar buttons.

3.2 Take the plunge: perform your first simulation run

Please first read through this chapter before you do it yourself in AffectSim.

The simulation parameter dialog box

Select the  (simulate) button to open the *Simulation Parameter* dialog box. It contains a number of parameters which appear with default settings if you open it the first time or it will contain the settings that you edited for your last simulation run. For this first run, leave everything as is.

Starting a simulation run

Press the button *Start New Run*. Typically, the program needs some seconds to initialize the simulation. After that, you will see the living space in the main window with agents and grey food units. The agents are moving around in different colours – yellow for *food mode* (when having a food unit in the focus of attention), green for *fellow mode* (when perceiving fellow agents) and blue for *exploratory mode* (no specific object in the focus of attention). Additionally, two dialog boxes are popping up: *Statistics of Simulation Dynamics* and *Statistics of Gene Values*. Whereas the first one allows monitoring the rather phenotypic dynamics of the evolution, the second provides actual information concerning the genetic values of the population, which basically program the patterns of function in different cognitive modes.

The energetic selection regime

Directly after the run has started, you see a large number of agents – namely 2500 (this number was defined in the so-called *Standard Simulation Parameters*). Some few action steps later this number is strongly reduced. The reason is that the genotype values for the initial population are chosen randomly and therefore most agents are equipped with a non-functional (lethal) genetic program for functioning adequately to the given environmental situation. They soon have consumed the package of energy that each agent is initially equipped with and die. Only those agents will survive that are equipped with a genetic program that causes them to take food units into their focus of attention with a certain priority, and that provides them with an appropriate motor and cognitive behaviour for the *food mode* - namely running towards food units, eating them and thus, intaking the energy which is contained in each food unit. Agents compete for the limited food resources and only a certain part of the initial population will survive until the end of each generation.

Generations and action steps

For reasons of simplicity, this simulation uses a distinct-generation-model, i.e. there is no overlap of generations, parents produce offspring at the same action step and die after that. At the beginning of each new generation you therefore see a cloud of offspring in the local vicinity of the parent's position.

The number of generations can be pre-defined for each simulation run as well as the life time within each generation. The life time is defined as the number of action steps per generation.

Note that for a representative evolutionary process the number of generations must be considerable as well as the number of action steps: the selective advantage or disadvantage of a specific pattern of behaviour is realized only through a significant number of action steps.

Within each action step an agent performs following three steps (see chapter 3.2 for more details):

1. Cognition: The agent screens its vicinity in order to detect the nearest object (food, predator or fellow agents) and to take one of these objects into its focus of attention. The radius of the screen in each mode as well as the priority of the attention focus regarding different object types are determined by the genetic program and can freely evolve. The energy consumption of the cognition grows with the square of the screen radius.

2. Resetting the mode: Depending on the type of the new object in the focus of attention, the agent switches the mode of function. If there is no object in the focus of attention, the agent switches into exploratory mode.

3. Motion: Determined by its genetic step size value (*STS*) for the new mode, the agent moves towards (positive value) or away from (negative value) of the object in the focus of attention. In the exploratory mode, the direction of the motion is randomly altered. The energy consumption of the motion grows with the square of the step size.

The affective modes

An important principle is the fact that the type of the object in the focus of attention –food, predator, fellow agent or no object at all - – defines the mode that basically activates the mode-specific genetically coded program of functions: Direction of movement towards or away from the object in the focus of attention, velocity of this movement, and range of the cognitive horizon. During each simulation run, these genetically coded pattern of functions can freely evolve.

Genotype and phenotype

The genome of each agent is haploid (asexual) and consists of a series of gene loci. Each gene locus contains a real number which represents the genotype value. At the beginning of each simulation run, these genotype values are initialised randomly. See here how the different types of genotype values translate into correspondent phenotypes:

Motion	Cognitive radius	Priority of attention focus
Motion is determined by the genotype value <i>STS</i> (step size) in pixels and the direction is related to the object in the focus of attention.	The genotype value <i>CRF</i> (cognition range factor) times the <i>cognition range unit (pixels)</i> which is defined under <i>Simulation Parameters</i>	The genotype values <i>FFP</i> (fellow agent/food priority) or <i>PPF</i> (predator/food priority) are compared to the ratio of the distances to the respective different objects. If <i>FFP</i> is larger than the measured ratio of the distances, than the perceived fellow agent (and not the food unit) will be taken into the focus of attention..

Offspring and mutation

At the end of each generation, the remaining agents are producing offspring. The number of offspring linearly depends on the energy that the parent has accumulated during his life time (~ number of action steps per generation). Parents with particularly successful behaviour therefore will produce more offspring than others. By producing offspring the parent is transmitting its genetic program to the next generation. This process includes mutation, too. The mutation rate and the strength of mutation effects that works on the individual genotype values can be defined in the *Simulation Parameters*.

Restarting and rendering

In order to restart a simulation run, simply open the *Simulation Parameter* dialog box again with the  button and press the button *Start New Run*. When the simulation is running, you can pause and

continue it with the  (pause) button. If you are not interested to see each single action step in the living space but rather only each new generation, then you can toggle between these two visualization modes with the  button. The rendering of the agents in the living space of course takes time. You can toggle with the  (show hide) button between rendering the living space and only displaying elementary information concerning the simulation progress.

Energy intake through food units

Switch (back) to the living space rendering mode, activate the rendering in each action step (and not only each generation) and continue the run. You can now observe the agents moving around and eating food units. In each action step, a defined number of new food units (15 in the default setting of the *Simulation Parameters*) are distributed over the living space, thus providing a continuous stream of available energy into the living space. You might wonder about the different grey scales of the food units. The scale stands for the energy content of the individual food unit: light grey for low energy and dark grey for high energy. You can define the energy distribution of the food units under *Simulation Parameters*. What is it good for? First of all, the distribution of energy into the living space via food units allows creating different scenarios: few food units with high energy content will favour different behaviours of the agents than many food units with low energy content. Additionally, this tool allows defining frame conditions that favour competition between agents or that favour cooperation. The mechanism is that a certain portion of the energy content of a food unit (% can be defined in *Simulation Parameters*) defines a “resistance against agents”, that is the amount of energy needed for overpowering the food. Agents have a fixed energy of 10 for overpowering food units. If the resistance energy of a food unit is larger than the 10 energy units of an agent, the agent cannot eat it. However, he can cooperate with other agents to overpower the resistance of a food unit. If two or more agents together approach a food unit, they can join their overpower energy and crack the food unit. In that case, the energy content of the food unit will be equally distributed to the agents involved.

Grouping

Under specific frame conditions agents can form groups. This is a purely self-organizing effect that results from genetically coded attraction between agents plus analogous patterns of function at a similar position in the living space which means similar local context.

In order to measure aspects of group-formation like group size and duration of groups, you have to activate the *track groups* checkbox in *Simulation Parameters* under Group statistics. There are two criteria which define from which moment on a cluster of agents is internally considered as a group. It is the *minimum time* (~minimum number of action steps) that an agent has to be close to a specific cluster of agents, and the *maximum distance* parameter that defines this distance. The group definition mainly serves statistical purposes. There is no major functional effect resulting from it (for more

details see chapter 3.1, the grouping option). Agents can join and leave at any time by only following their individual genetically programmed pattern of function.

Introducing big (high-energy) food units favours group formation. From about generation 20 on, you can see the first grouping effects. See in the next section how you can visualize groups.

Visualization of agents

Agents can be rendered in different ways, depending on the information you are interested in. When starting a simulation run or by pressing the  button, individual agents will be rendered according to their current mode of functioning (focus of attention). They appear yellow in the food-mode, green in the fellow-agent-mode, red in the predator-mode and blue in the exploratory mode (when they perceive no object at all). The  button renders agents according to their currently accumulated energy: Agents appear dark blue if the accumulated energy is high and light blue if the accumulated energy is low. If you are interested to observe the group formation, select the  (group size) button. Agents will be rendered beige if they are not grouped, light blue if the group is small and dark blue when they are members of a large group. Sometimes it is interesting to observe one specific group. The  (group identification) button renders each group with an individual colour.

Getting the right information

Getting the right information at any time is essential for performing and understanding the simulation dynamics. Much effort was done in AffectSim in order to measure and collect data concerning a multitude of effects.

Here is a short overview about the different information panels; for a more detailed description see Chapter 5:

If you want to get information concerning an individual agent during a simulation run, simply left click near to it in the living space. The agent is rendered red and the dialog box *Agent Information* will pop up. It contains statistical information about this agent, especially concerning its energy intake and energy consumption and its individual genomic values. The current object in the focus of attention of the agent is rendered yellow. If you press the *Observe* button, you can observe the individual agent moving around; the statistics are continually updated.

With the  button you can open and close the dialog box *Statistics of Gene Values*. As the name says it contains an overview and a statistic concerning the genome values of the population. For each locus, the mean value, the standard deviation, the minimum and the maximum value are displayed.

The  button opens the dialog box *Statistics of Simulation Dynamics*. It displays a lot of valuable information that is tracked over the course of a generation and it is recommended to leave it always open.

A very helpful interface is the dialog box *Time Series* . It allows plotting 3, or if you enlarge it even 6 different time series of parameters. Here you can observe how evolution acts over generations on the population and changes specific aspects. Main parameters are average genome values, or most of the information that you also find in *Statistics of Simulation Dynamics*. Select the parameters that you are interested in. You can leave this dialog box open while continuing the simulation run.

If you are interested you can export any times series at any point in time with the  button.

4 Interesting to know

4.1 The main simulation scenarios

The basic configuration

The most basic configuration is one where agents simply act on food resources. Agents do not perceive other agents and there is no grouping (*activate fellow cognition* is off, *track groups* is off and *number of predators* is 0): Agents are only capable to perceive food units. The evolving behaviour of the agents is basically a match to the size, number and distribution of food units. Many small food units will cause different behaviour than few and/or large food units.

Selective pressure through predators

A further selective pressure on the agents can be added through predators (*number of predators* is > 0). Agents will now additionally perceive and react on predators. Together with the whole section of gene loci that code for the pattern of function in predator mode, a further gene locus is activated that codes for the priority of predators vs. food in the focus of attention. The number of predators can be fix or it can grow and shrink in each generation with the collected energy of the predator parents (*with population dynamics of predators* off or on). The advantage then is that the number of predators will grow when the population of agents grow, thus maintaining the selective pressure on the population. Be aware that the population dynamics of agents and of predators are not necessarily synchronal. They are rather swinging in an acyclical prey-predator dynamics as described by Lotka and Volterra.

Perceiving and reacting on fellow-agents

An interesting affective-cognitive component is introduced with the perception and reaction on fellow agents (*activate fellow cognition* is on). Agents will now additionally perceive and react on fellow agents. Together with the whole section of gene loci that code for the pattern of function in fellow

mode, a further gene locus is activated that codes for the priority of the perception of fellow agents vs. the simultaneous perception of food.

The evolving behaviour can be different: Both cooperation (attraction to fellow agents) or competition (repulsion) is possible and depends basically on the size of food units. Energy-rich food units can only be overpowered by a number of agents; cooperation therefore is needed for survival.

Tracking groups

The grouping option (*track groups* is on) is closely related to the perception of fellow agents. It is basically a statistical function that allows to track and measure group numbers, group size and group duration. With appropriate frame conditions, group formation will evolve also when *track groups* is off. In this latter case, groups however can not be visualized and there are no statistics provided. There is one minor functional change related to the *track groups* option: If it is activated, there are two instead of one gene loci that code for the priority of the focus of attention on fellow agents vs. food. One locus is used when the perceiving agent is grouped and the other when it is ungrouped. The reason for this is that in selective frame conditions in which a single agent cannot survive, the importance of perceiving fellow agents is completely different if an agent is acting alone or if it is already grouped. Note that although gene loci are activated or inactivated with such functions by definition, still the genomic values on these loci can and will freely evolve.

4.2 What are agents exactly doing within each action step?

In each action step an individual agent performs a sequence of the following three actions:

1. Cognition

Depending on its current mode of functioning (food mode, predator mode, fellow agent mode or exploratory mode), an agent will read the respective genomic value for the range of cognition. . The resulting radius of cognition is the cognitive range factor times the *cognition radius unit* defined in the *Simulation Parameters*. It will scan this range in its local vicinity and detect the closest object of each type: food, predator and fellow agent . Only one of these objects can be taken into the focus of attention, the question is: which one? During the development of the model it soon turned out that simply taking the closest of these three objects into the focus of attention is inappropriate. It might well be that the detection of a specific object type (e.g. a predator) is very relevant for survival even if it is more distant than another object. Therefore, the genome contains loci that code for the cognitive priority of a perceived predator respectively a perceived fellow agent in relation to a perceived food unit. If the predator/food priority is 2, for instance, a perceived predator can be up to twice more distant than a perceived food unit in order to still focus the attention on the predator. A value of 1 means predator and food have the same priority, the closer of both will be taken into the focus of attention. See chapter 3.3. for more information.

2. Resetting the mode

Depending on the object in the focus of attention, the agents keep or switch the mode. In most cases, the new focus of attention is the same as in the last action step and the mode of function therefore remains the same.

3. Motion

Depending on the new mode, the agent will read the respective genomic value for the motion. A negative sign of this value will cause the agent to move away from the object in the focus of attention, a positive sign will make it to move towards the object. The step size (~velocity) in pixels is given by the genomic value. In the exploratory mode (when no object is perceived) the agent will perform a walk with a step size defined by the respective genetic motion value, with a random change of direction. When an agent hunts food and the food is located within the range of a step, the agent will move to the position of the food and “eat” it.

Eating food is the only way for energy intake. This happens when an agent has moved to the position of a food unit and when it can overpower the resistance of it. Then it will intake the full amount of energy in the food unit minus the amount necessary for overpowering it. The food unit is removed. In case that it cannot crack the unit individually, it will wait during the action step if further ‘bodies’ are joining him. This happens especially when agents form groups. When there are enough fellow agents to overpower the food unit, the energy contained in the food unit is equally distributed to all agents involved. In case that an agent cannot overpower a food unit it will memorize it and will not again take it into its focus of attention before it has approached another food unit (in order to support agents not to stick on food units that they are unable to crack).

Energy consumption At the end of each action step with a motion step size d (respective genome value) and a cognition range factor f (respective genome value), the consumed energy e of an agent is: $e = 1 + d^2 + f^2$.

4.3 Genphenotypes, behaviour and mutations

There are basically two different behavioural functions for each functional mode that the genome programs for:

- motion in relation to a perceived object, i.e. direction and step size
- range of perception

These functions are coded by rational numbers at specific gene loci. The genotypic value at a specific locus is a rational numbers. Whereas the genotype value for motion is directly translated in the pixel step size, the genotype value for the range of perception is multiplied with the *cognition radius unit* (*pixel*), defined in *Simulation Parameters*, in order to receive the perception range in pixels.

Since we want to see if these functions evolve differently for different affective-cognitive modes, we

need these two gene loci for each mode (food mode, predator mode, fellow agent mode and exploratory mode).-

The energy consumption that we are also interested to monitor follows implicitly from the motor and cognitive behaviour in each mode. It grows with the square of the step size and of the range of cognition.

Additionally, three further gene loci are implemented that code for the priority of predators $p_{pred/food}$ respectively of fellow agents $p_{fellow/food}$ in relation to food units in terms of an agent's focus of attention:

priority predator / food

priority fellow agent / food (agent is ungrouped)

priority fellow agent / food (agent is grouped).

The gene value is again a rational number and it is directly translated into the distances to the perceived objects. See also chapter 3.2.

Together with the distance to the closest fellow agent d_{fellow} , the distance to the closest food unit d_{food} , and the distance to the closest predator d_{pred} , these priority values are applied in the following way in order to decide for the object in the focus of attention:

Condition	perceived object
If there is no object within the cognitive range	\Rightarrow none
If $\frac{(d_{pred} / d_{food})}{p_{pred/food}} > 1$ and $\frac{(d_{fellow} / d_{food})}{p_{fellow/food}} > 1$	\Rightarrow food unit
If $\frac{(d_{pred} / d_{food})}{p_{pred/food}} > \frac{(d_{fellow} / d_{food})}{p_{fellow/food}}$	\Rightarrow fellow agent
If $\frac{(d_{pred} / d_{food})}{p_{pred/food}} \leq \frac{(d_{fellow} / d_{food})}{p_{fellow/food}}$	\Rightarrow predator

When setting up the initial population, each gene value is initialized with a number chosen randomly from a normal distribution. The initial mean value for the motion in the exploratory mode is 8, the mean values for the motion in all the other modes is 0. The standard deviation of the normal distribution in all cases is ~5. The initial mean gene value for the cognition range in all modes is 2, with a standard deviation of the normal distribution of 1.15. The initial mean genotype value for the

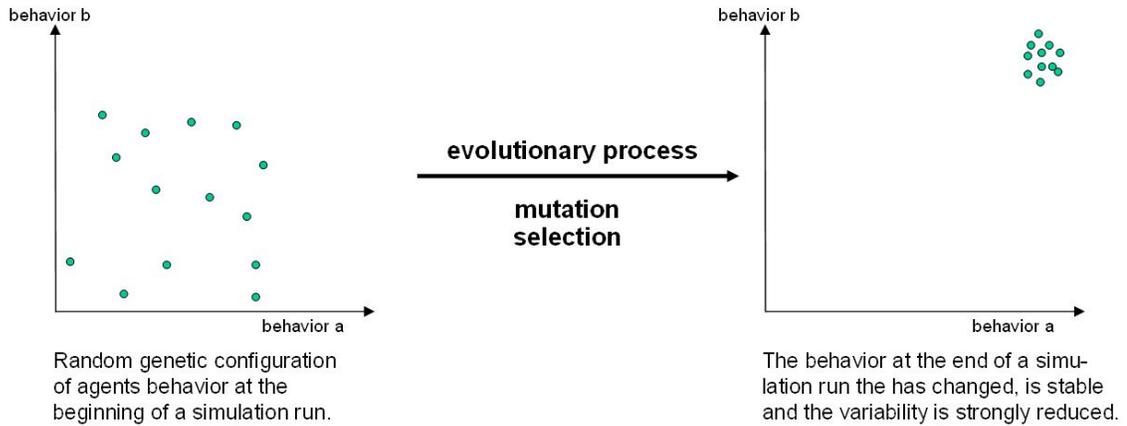
priorities of the attention focus in all modes is 1, with a standard deviation of the normal distribution of 0.57.

Mutation acts on the gene values every time when parents generate offspring. The rate and the strength can be defined in the *Simulation Parameters*. The strength of the mutational change is randomly chosen with a normally distributed probability. The value defines the standard deviation of the normal distribution.

Note that a high mutation rate makes the system adaptive and therefore is suitable for playing around, for exploring different simulation parameters and for achieving results with a lower number of generations. A lower mutation rate is favourable in order to get the maximum effect out of an adaptation process, since mutation doesn't smear the effects of selection. It however takes much more generations in order to reach the attractor, the final point of the evolutionary process. If the mutation rate is too high, any specific selection effect will be resolved through mutational noise. If the mutation rate is too low, the system will lack sufficient flexibility in order to deal with environmental changes.

4.4 Tips for planning and configuring simulations scenarios

- Don't worry, if the population gets extinct ahead of time under a specific set of parameters. This is normal in evolution. There are many constellations or parameter settings where only in a small fraction of all simulation runs the population adapts sufficiently to the frame conditions
- For trying out the software or investigating specific scenarios, a high mutation rate like 0.1 or 0.05 is recommended, in order to have sufficient adaptive flexibility of the population. Once you have found a scenario that you like to test in long simulation series then it is of advantage to choose a lower mutation rate like 0.001, since this will result in more significant and stable endpoints.
- For observing group dynamics: Grow food size slowly, so that the population can follow by adaptation
- Be aware of Lotka-Volterra (prey-predator) oscillations between agents and predators (when choosing *with population dynamics of predators*) as well as between food units and agents.
- The higher the number of agents and the lower the mutation rate, the less variation in the gene values occur.
- We speak about evolution of specific behavioural pattern when the initial random configuration with high variability is significantly reduced at the end by the "survival of the fittest", in a reproducible manner from one simulation run to the next one.



5 Configure and run simulations

5.1 Toolbar Overview



Configuring, starting, pausing and restarting simulations



Simulation **rendering** **options**
 (no rendering, render per life step, render per generation)



Agents **visualization** **options**
 (mode, energy, number per group, group, zoom)



Information **panels**
 (time series, gene values statistics, simulation statistics, 2-dimensional parameter distribution)



Export time series and results

5.2 Simulation Parameters

The central interface for the configuration of simulations is the *Simulation Parameters* dialog box, see fig 1. Here you define the selection frame conditions. Select the  simulate button to open it.

General settings

- (1) Configure the number of simulation runs. Choose 1 for exploring new settings. Choose an arbitrary higher number in order to run a series of simulation runs. Evolutionary processes are inherently non-linear and a number of internal functions like mutations or food distribution are using random numbers. Therefore only a series of runs gives a consistent idea and appropriate statistics concerning the systems dynamics. In this case, statistics will automatically be collected and also compiled over the series of runs (see chapter 4.8 for more information).
- (2) The number of generations per simulation runs. Note that the model is based on distinct and not on continuous generations, i.e. all agents will reproduce together at the end of a generation. The offspring will form the subsequent generation, the parent will die.
- (3) The number of action steps per generation defines the length of the life span of an agent.
- (4) The population size of agents at the beginning of a simulation run. Note that the genetic values are randomly chosen for each individual. Most of those genotypes will be lethal and about 90% of the agents therefore die soon during the first generations. Therefore, the population size must be big enough to contain sufficient individuals that are able to survive. The more demanding the frame conditions are set, the lower will be the proportion of surviving agents in the first generation, and the higher must hence be the initial population size.
- (5) The initial energy of an agent at the beginning of a generation and the initial energy of each offspring. Note that the number of offspring of a parent depends on this value, too, since the parent's collected energy will be distributed to its descendents.

Simulation Parameters

General

1 Number of simulation runs: 1

2 Number of generations: 500

3 Number of action steps per generation: 400

4 Initial population size: 2500

5 Initial energy per agent (valid for initialization as well as for the distribution of allocated energy to each offspring): 300

6 Screen update every action step (and not only every generation):

7 Side length of living space: 1000

8 Mutation rate: 0.01

9 Mutation effect (normal distributed): 0.5

10 Cognition radius unit (pixel): 15

Food

11 Number of new food units per action step: 15

12 Energy distribution of new food units

Min	100	150	250
start	generation	100	in generation 1000
Max	100	250	350

13 Portion of contained energy to resist agents (agents have a fixed energy to overpower food = 10): 8

Enemies

14 Number of Enemies: 0

15 With population dynamics of enemies:

16 Step size for catching agents: 3

17 Maximum agent energy that can be overpowered: 500

18 Portion energy intake when catching an agent: 100

Group Statistics

19 Track groups:

20 Criteria for being grouped

Maximum distance (pixel)	7
Minimum time (action steps)	15

Fellow Cognition

21 Activate fellow cognition:

22 Activate 'fellow agent in foreign group' mode:

Aggression damage factor: 0

23 New Run

The energy costs for movement are calculated as the square of the respective G Step Size. The energy costs for cognition are calculated as the square of the respective G Cognition Range Factor.

24 Continue with new parameters

Figure 1: The dialog box Simulation Parameters essentially allows defining the selective frame conditions for the evolutionary process. The displayed values are samples.

Important note: The above selected specific simulation parameter values are empirically useful, because they usually lead to a consistent long-term simulation over hundreds of generation. We therefore recommend that you start your simulation experiments with these values and modify them eventually.

- (6) Observe the simulation dynamics for each actions step or only for each generation. This checkbox has the same effect as the  button.
- (7) Defines the size of the living space. Note that the number of food units will randomly be distributed over the defined living space. Therefore, the food density which is an important frame condition for the evolutionary dynamics depend on this parameter, too.
- (8) The mutation rate defines the frequency in which changes to single genes are happening.
- (9) The strength of a mutational change, randomly chosen with a normally distributed probability. The value defines the standard deviation of the normal distribution.

- (10) The cognition radius unit defines the ratio of energy costs between the cognition radius and the step size for an agent.

Food settings

The number, the density distribution, the energy content and the energy distribution of food units are essential frame conditions for an evolutionary dynamic. The same amount of energy can be distributed using a few energy-rich units, or many low-energy units, resulting in different selection regimes. As a consequence, different rates of energy consumption and patterns of behaviour might evolve.

Food units which are not consumed in one action step will remain and can be consumed later. Under specific frame conditions, this sometimes can lead to significant counter-correlated agent-food oscillations that even can result in the extinction of the population.

An important feature is that each food unit resists the consumption by an agent with an energy that linearly grows with the energy content. Each agent is per definition equipped with an energy of 10 to overpower the resistance of food units

High-energy food units therefore can not be eaten by an individual agent. Only the combined strength of the agents within one group allows overbearing the strong resistance of a high-energy food unit.

High-energy food units are therefore useful to motivate the formation of groups.

Note that the distribution of nothing but high-energy food already at the beginning of the simulation will only result in a fast extinction of the population, since the agents of a new population first have to evolve basic survival patterns before more complex grouping patterns can be build on top of that. Therefore, the model permits to alter the energy content and the energy distribution of food units continually with the number of generations, thus allowing the population to gradually adapt to high energy food.

- (11) Number of food units randomly littered over the living space in each action step.
- (12) Energy distribution of food units in generation 0, in generation 100 and in an optional further generation. The minimum and maximum values for the energy content are linearly interpolated between the generations, in order to permit a gradual adaptation to changing frame conditions. The energy content for food units in a specific generation is randomly chosen between the minimum and the maximum value of this generation.
- (13) The strength with which a food unit resists consumption is defined as a percent proportion of the energy contained in the food unit. Mainly introduced to create a motivation for the formation of groups.

Predator settings

A further dimension of behavioural patterns is introduced through the selective pressure caused by predators.

- (14) The fixed or initial (in case of population dynamics) number of predators
- (15) Population dynamics of predators allows each single predator to reproduce according to the accumulated energy. The model is set up in a way that the predator population never dies out, i.e. at least one predator always survives. Population dynamics of predators can be used in order to significantly increase the selective pressure on agents through predators.
- (16) The step size defines the velocity for hunting agents.
- (17) The maximum energy of agents that can be overpowered supports a model in which agents can not only escape from predators through flight but also through their strength.
- (18) The portion of energy intake when catching an agent allows dampening strong predator/prey oscillations that can happen in case of population dynamics of predators and that might lead to early extinction of the population.

Group tracking settings

Cooperation through grouping is an interesting pattern of behaviour that can be observed. Energy-rich food units can create frame conditions to which agents adapt through evolutionary change, by adopting behavioural patterns for moving and overbearing food through collaboration in groups. Groups can reach considerable size like 20-50 agents per group. Note that the group tracking mechanism is only a statistical tool which allows to monitor group numbers and group sizes. The patterns of behaviour that result in building groups are inherently caused through mutation and selection.

- (19) Switches the tracking of groups on and off.
- (20) Criteria that define from which moment on a cluster of agents is considered to be a group, respectively from which moment on an agent is becoming a new member of an existing group. A group is defined through the maximum distance between participating agents which has to be maintained over a minimum number of action steps. Agents are tracked to be members of a group only if both criteria are fulfilled simultaneously. After reproduction, it therefore takes some time (some action steps) before the time criterion is fulfilled and groups in the defined sense appear.

Fellow agent cognition settings

- (21) The capacity to recognize fellow agents and to build patterns of behaviour accordingly can be switched on and off. Fellow agent cognition must be activated in order to allow group formation (moving towards a perceived fellow-agent) or competition (moving away from a perceived fellow-agent)
- (22) The last free fields in fellow-agent cognition have no implemented function in AffectSim 4.0.

Running simulations

- (23) The Start New Run button starts a new simulation or a new series of simulation with the chosen parameters.

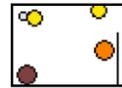
(24) The Simulation Parameters dialog box can be opened at any time during a simulation. The button “Continue” causes the system to continue the interrupted simulation run. The button “Continue with new Parameters” permits to continue the interrupted simulation run with changed parameters.

5.3 View Settings

By default, the simulation will render agents, food units and predators in the living space. Agents are visualized differently according to their mode of functioning and their energy content, see buttons M and E, below.. Food units appear as small bright grey dots when their energy content is low, and as small dark grey dots when their energy content is high.



Predators appear as large, dark red circles in the exploratory mode (when no agent is perceived) and orange when they perceive and hunt an agent.



Toggles between rendering the living space with the agents at each action step or only at each generation.



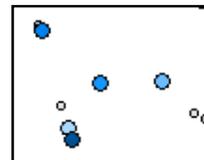
View or hide the rendering of the living space with the agents. The usual setting shows the agents moving around. Hiding this view is useful, because less time demanding, when long series of simulation have to be computed. In this case, only some generic information is displayed, like the number of the simulation run, the current generation and the name of the export file. All other dialog boxes should be closed in this case.



Renders agents according to their current mode of function. Agents appear yellow when food is in their focus (food-mode), green in fellow-agent-mode, red in predator-mode and blue in the exploratory mode (when they do not perceive any object).



Renders agents according to their energy. Agents appear dark blue if their accumulated energy is high, and light blue if their accumulated energy is low.



Renders agents according to the size of their group. Agents appear dark blue if they are member of a large group, light blue if they are member of a small group, or white when they are moving individually. Useful for observing the development and the distribution of group sizes.



Renders agents according to their individual group. Each group of agents is represented by an individual colour. Useful for observing and distinguishing different groups.

6 How to get information, statistics and export

6.1 General simulation statistics

27	generation	3.63	% exploratory mode
400	action step	92.1	% food mode
181	N agents	4.14	% agent / same group
5	N predators	0	% foreign group mode
2701	N food units	0.07	% predator
		972.24	A energy/agent
27	N groups	40	-14212 A energy/predator
2.25	A group size	129.61	A energy/food
33.7	% agents grouped	277	food alone
43.6	A group residence time	454	food 2 agents
3.41	N groups/agent	163	food 3 agents
51.2	% time grouped	552	food 4 agents
		707	food >4 agents
56.6	% in group towards food		
43.3	% alone towards food	822	predator attacks
1.18	% food units too big	1.21	% successful
17.3	% food units snatched away by other agents	0.24	% run away
0.0	% towards fellow	86.9	% defended alone
0	% met fellow	10.7	% defended in group
4.1	% away from fellow	100	% eaten and not in enemepredatory mode
		14.2	% Gruppe verlassen auf Flucht
Selection			% contagion regarding:
60.0	% death through debility		fellow-agent mode
0.61	% death during flight		change cog obj
2.05	% death predators eaten		
4.26	% death through		
37.2	% survived predator contact		Energy Dissipation/Action Step
0	Num gerett. Simul.	6.2	A consumed energy
0	Num gerett. Simul. Rep	6.3	A energy taken in
		0.0	A energy delta

The dialog box *Statistics of Simulation Dynamics* provides a number of different relevant statistics for the current state of a simulation run. It is continually updated at each action step.

Detailed description of the parameters:

generation	number of current generation
action step	number of current action step
N agents	current number of agents
N predators	current number of predators
N food units	current number of food units
N groups	current number of groups. The second number indicates additional clusters of agents which however are below the defined minimum time limit
A group size	Average group size
% agents grouped	Percentage of agents in the current generation that are grouped
A group residence time	Average time (number of action steps) that an agent remains in a group

N groups/agent	Average number of groups that an agent was belonging to
% time grouped	Percentage of time (action steps) per generation that an agent spent in a group
% in group towards food	Percentage of time (action steps) that a grouped agent spent in food mode
% alone towards food	Percentage of time (action steps) in food mode that an agent spent in approaching food individually
% food units too big	Percentage of cases when an agent who reaches a food unit is too weak to crack it that
% food units snatched away from other agents	Percentage of cases when a specific food unit, which was approaching by an agent, was eaten by another agent
% towards fellow	Percentage of action steps that an agent spent in fellow agent mode and moves towards a fellow agent
% met fellow	Percentage of cases, spent in fellow agent mode, that the agent is indeed meeting or grouping with this fellow agent
% away from fellow	Percentage of action steps that an agent is in fellow mode and moves away from a fellow
% died	Percentage of the initial population that died during the current generation
% death from debility	Percentage of the initial population that died during the current generation due to lack of energy
% death during flight	Percentage of the initial population that died on flight from predators
% death predators eaten	Percentage of the initial population that was eaten by a predator
% death through predator	Percentage of all deaths that are caused by predators
% exploratory mode	Percentage of action steps in exploratory mode
% food mode	Percentage of action steps in food mode
% fellow agent mode	Percentage of action steps in fellow agent mode
% foreign group mode	Percentage of action steps in foreign group mode
% predator mode	Percentage of action steps in predator mode
A energy/agent	Current average of energy/agent
A energy/predator	Current average of energy/predator (only with population dynamics of predators)
A energy/food	Current average of energy/food unit
food alone	number of cases that a food unit was eaten by one agent
food 2 agents	number of cases that a food unit was eaten by two agents
food 3 agents	number of cases that a food unit was eaten by three agents
food 4 agents	number of cases that a food unit was eaten by four agents
food > 4 agents	number of cases that a food unit was eaten by more than four agents
Predator attacks	Number of predator attacks in current generation
% successful	percentage of successful predator attacks
% run away	percentage of successful agent escapes / predator attacks
% defended alone	percentage of successful agent defends / predator attacks
% defended in group	percentage of successful agent defends in group / predator attacks
% eaten and not in predatory mode	percentage of agents not being in predator mode / successful predator attacks

% left group on flight

% of agents that left their group in predator mode (on flight)

A energy consume

average (agents, action steps) of consumed energy

A energy intake

average (agents, action steps) of energy taken in

A energy delta

average (agents, action steps) of delta between energy taken in and energy consumed

6.2 Statistics of gene values of the agent population

The dialog box *Statistics of Gene Values* provides important information concerning the current value and distribution of genotype values. It allows you to monitor the evolution of the genetic configuration of agents behaviour in detail.

Mean: the first row displays the average genotype value in the population

Std.Dev: the second row displays the standard deviation of the genotype value

Min.: the third row displays the smallest genotype value

Max.: the fourth row displays the largest genotype value

STS.: genotype value for the step size

CRF.: genotype value for the cognition range factor

cont.: not used

FFP.: genotype value for the fellow agent / food priority

Ffp G.: genotype value for the fellow agent in the same group / food priority

Ffp F.: genotype value for the fellow agent a foreign group / food priority

PFp.: genotype value for the predator / food priority

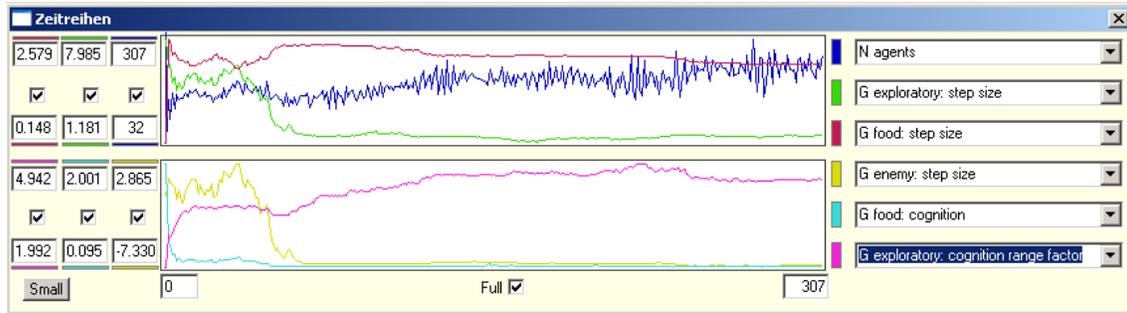
CTG: not used

Exploratory (no object)		Food Mode			Predator			Fellow Mode			Priorities of attention focus (food = 1)				Contagion				
STS	CRF	STS	CRF	cont	STS	CRF	cont	STS	CRF	cont	SIS	LHt	cont	FEL	Fel G	Fel F	Ene	CTG	
8.142	1.987	0.069	2.068	-0.279	0	0	0	-0.131	2.034	0.498	0	0	0	0.993	1.004	1.009	0	0	Mean
4.646	1.160	5.180	1.154	14.51	0	0	0	5.226	1.160	0.288	0	0	0	0.574	0.575	0.575	0	0	Std.Dev.
0.003	0.000	-8.991	0.001	-24.97	0	0	0	-8.995	0.001	0.000	0	0	0	0.000	0.000	0.000	0	0	Min
16.00	3.999	8.998	3.997	24.99	0	0	0	8.984	3.997	0.999	0	0	0	2.000	1.999	1.999	0	0	Max

For more information about how the genotype values translate into phenotype values please see chapter *Genotype and Phenotype*.

6.3 Time series of population properties

The dialog box *Time Series* provides you with information concerning development of specific population parameters over the course of generations. The displayed values are the values of the population in the last action step of a generation before it reproduces.



With the button *large* or *small* the dialog box can be enlarged in order to display six time series at once or it can be made smaller in order to display three time series only. The properties to display can be chosen in the drop down menus on the right hand side. The minimum and maximum values of the ordinate are displayed and can be edited for each parameter in the small boxes on the left hand side. By activating the small check boxes the scale will be automatically adjusted to the minimum and maximum value of the time series. Alternatively you can edit the minimum and maximum values manually. At any time the time series of population properties can also be exported, see chapter 4.8.

Description of the population properties

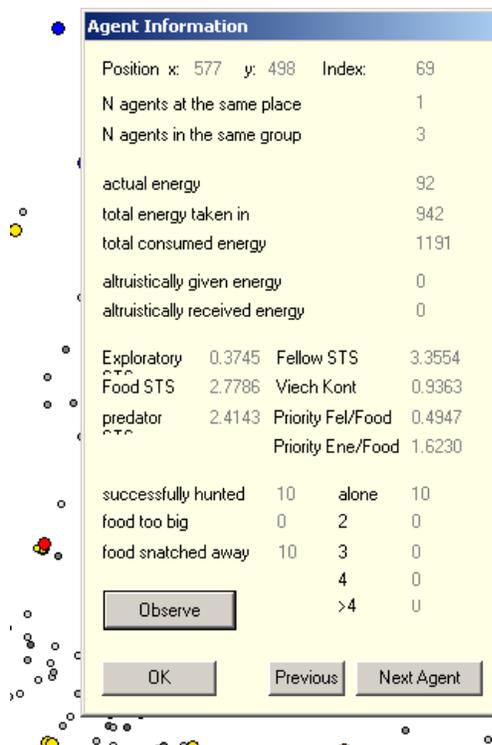
Find in the following the population properties and statistics at the end of each generation, before reproduction.

N agents	Number of agents
N food	Number of food units
N predators	Number of predators
G exploratory: step size	Average gene value for step size in exploratory mode
G exploratory: cognition range factor	Average gene value for the range of cognition in exploratory mode
G food: step size	Average gene value for step size in food mode
G food: cognition range factor	Average gene value for the range of cognition in food mode
G food: contact	
G predator: step size	Average gene value for step size in predator mode
G predator: cognition range factor	Average gene value for the range of cognition in exploratory mode
G predator: contact	
G fellow-agent: step size	Average gene value for step size in fellow agent mode

G fellow-agent: cognition range factor	Average gene value for the range of cognition in fellow agent mode
G fellow: contact	
G foreign group step size	Average gene value for step size in fellow agent in foreign group mode
G foreign group cognition range factor	Average gene value for the range of cognition in fellow agent in foreign group mode
G foreign group contact	
G contagion	
G priority: fellow-agent to food	Average gene value for the perceptive priority of fellow-agent to food
G priority: predator to food	Average gene value for the perceptive priority of predator to food
G priority: fellow in same group to food	Average gene value for the perceptive priority of fellow-agent in the same group to food
G priority: foreign group to food	Average gene value for the perceptive priority of fellow-agent in a foreign group to food
A agent energy	Average of accumulated energy
A energy intake	Average of total energy assimilated
A energy consumption	Average of total energy consumed
N predator attacks	Average number of predator attacks during lifespan of agent
A predator energy	Average of energy accumulated by predators
% death through debility	Percentage of agents at the begin of the generation that died by debility
% death through debility on flight	Percentage of agents at the begin of the generation that died by debility on flight in predator mode
% death eaten by predator	Percentage of agents at the begin of the generation that were caught by predators
% death through predator pressure	Percentage of agents at the begin of the generation that died in predator mode
% defended alone	Percentage of cases that agents overcame a predator attack alone
% defended in group	Percentage of cases that agents overcame a predator attack in a group
% successful attacks	Percentage of successful predator attacks
% Anteil Feind Selektion	Percentage of death through predator attacks
% contagion fellow mode	
% contagion mode change	
% exploratory mode	Percentage of action steps that agents spend in exploratory mode
% food mode	Percentage of action steps that agents spend in food mode
% predator mode	Percentage of action steps that agents spend in predator mode
% fellow-agent mode	Percentage of action steps that agents spend in fellow-agent mode
% alone towards food	Percentage of action steps in food mode that agents spent ungrouped
% in group towards food	Percentage of action steps in food mode that agents spent grouped

% time in Group	Percentage of all action steps that agents spent grouped
% towards fellow-agent	Percentage of action steps in fellow-agent mode that agents move towards from the perceived agent
% away from fellow-agent	Percentage of action steps in fellow-agent mode that agents move away from the perceived agent
% meets fellow-agent	Percentage of detected fellow-agents detected fellow-agents indeed met
% food not	Percentage of detected food units that the agent could not assimilate (to large or caught away by other agents)
N groups	Number of groups
A group size	Average group size during the life span
% agents grouped	Percentage of agents that are grouped
A residence time in each group	Average residence time of the agents in individual groups
N different groups per agent	Average number of different groups per agent

6.4 Information on individual agents during the simulation

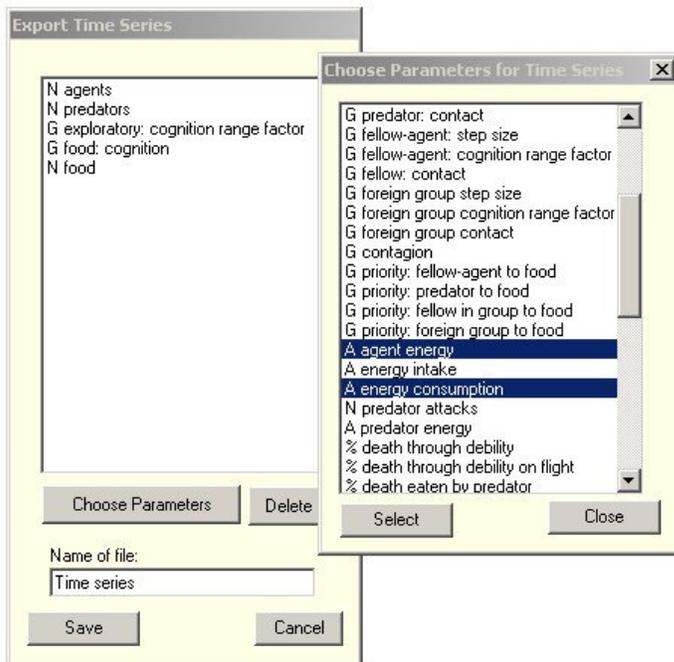


A left mouse-click into the action space will select the nearest agent to the position (red), it will select the object in its focus of attention (yellow), it will open the dialog box *Agent Information* and it will pause the simulation. In case that there is more than one agent at the same position you can iterate through them with the *Previous* and the *Next Agent* button. Pushing the *Observe* button will continue the simulation with the agent selected and you can observe its properties. Pushing the *OK* button will continue the simulation and close the dialog box.

6.5 Performing series of simulation runs and exporting results

Since the simulation runs are based on a random initial configuration of the population and subsequent random mutations, a single run is not representative for the dynamics under a specific set of simulation parameters. Only a series of simulation runs can provide this information. Therefore, AffectSim 4.0 comes with functionality that supports the configuration of simulation series and that compiles the results of specific property time series from different runs into efficiently arranged output files. These *.txt files have a comma-separated structure and can be imported into software for spreadsheet analysis like Microsoft Excel.

In the dialog box *Simulation Parameters* (chapter 4.2) choose the *Number of simulation runs* (1). If you have chosen a number > 1 the dialog box *Export Time Series* will pop up after you pressed the



button *New Run* (23). Select the *Choose Parameters* button and choose the parameters by selecting or multi-selecting them (by holding the control key). When finished, close the dialog box *Choose Parameters for Time Series* and enter a name for the time series files. Press *Save* to close the dialog box and to start the simulation runs. The parameters are the same as in the dialog box *Times Series*. See a detailed description of the population parameters in chapter 4.6.

Running whole simulation series typically can last hours or even days.

When doing this, you typically are not interested to render and to observe the population activities. Close all dialog boxes, switch to re-rendering every generation (and not every action step) with the  button and switch off the display of the action space with the  button.

After finishing all simulation runs AffectSim will export a spreadsheet for each single simulation run containing all time series of the chosen parameters in to the folder of the AffectSin.exe file. Additionally, AffectSim will export a spreadsheet for each single chosen parameter, containing the time series of the this parameter and some statistical analysis over all simulation runs.

By selecting the  button you can export time series at any time during a simulation run, too.