FEARLUS
Model 0-6-4

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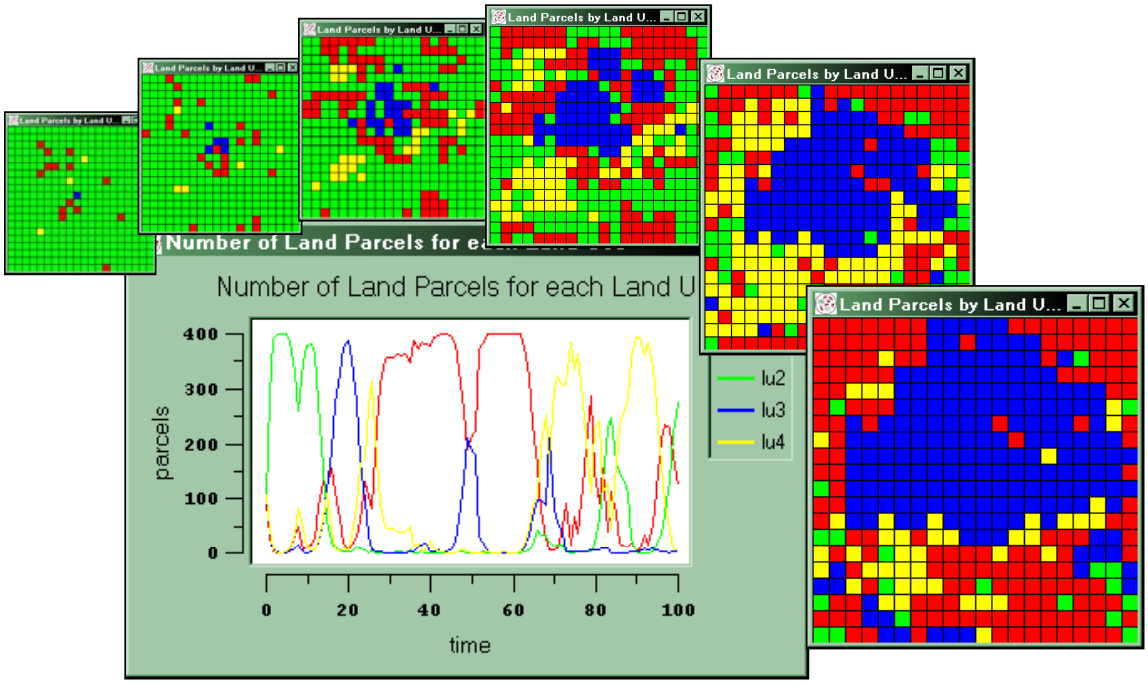

User Guide

by Gary Polhill

Contents

1 Introduction

This document outlines the usage of the FEARLUS model0-6-4 agent-based model of land-use change, developed at the Macaulay Institute by Nick Gotts, Alistair Law, and Gary Polhill. Model 0-6-4 is an abstract model of land use change (as are all FEARLUS models in the model 0 family), with no 'real' land uses, climate, economy, or biophysical properties of land parcels directly modelled on real-world data. Instead, these objects are represented using bitstrings (strings of binary digits), and the relationship between them designed to mirror certain aspects of how they relate in the real world.

The code is written in Objective-C, and is known to work with Swarm version 2.1.1 on a PC running Windows 2000 and with Swarm testing 2001-12-18 on a Sun running Solaris 8.

2 Installation

Assuming you have the appropriate version of Swarm installed on your platform, and your environment set up to use it, installation of FEARLUS model 0-6-4 involves unpacking the gzipped tar file, and compiling the source code therein from a terminal window in Unix, or the Swarm >> Terminal application in Windows:

```
gunzip -c FEARLUS-model0-6-4.tar.gz | tar xf -
cd model0-6-4
make
```

The application should compile successfully without error, creating the executable model0-6-4 on a Unix platform, or model0-6-4.exe on Windows.

3 Synopsis and command-line options

In the synopsis below, curly brackets { } are used to denote one of a series of options separated by a vertical bar | for an element value, square brackets [ ] are used to denote an optional element, and angle brackets < > to describe some value the user should provide. Greyed out options denote elements that are either deprecated or ignored.

```
model0-6-4 [-s] [-S <seed>] [-X {<seed>|TIME|DEFAULT}]
[-Z {<seed>|TIME}] [-b] [-m <mode>] [-t] [-v] [-R <report
configuration file> [-r <report output file> [-a]]]
[-h <history output file>] [-d] [-D <debug output flags>]
[-P <land parcel file>] [-U <land use file>] [-o <observer file>]
-p <parameter file>
```

As will be seen, the only required option is -p, to specify the parameter file. The other most commonly used flag is the -b flag, which is used to specify a batch mode run rather than the default GUI mode run. Batch mode is faster than GUI mode, and suitable for running as a background process.

The other command line options are explained below.

3.1 Controlling the seed

A number of options are provided for controlling the seed. Beyond version 2.1.1, the Swarm libraries have the default options -s and -S <seed> to do this. The option -X {<seed>|TIME|DEFAULT} applies to FEARLUS models compiled with versions 2.1.1 and earlier of Swarm that did not have the same flexibility in determining the seed. The -s option uses the current time to determine the seed value to use. The -S option allows the user to specify a 32-

bit integer to use as seed. It is recommended that these two options be used rather than -X where possible, but on a PC with version 2.1.1 of Swarm, use -X <seed> to get the same behaviour as -S <seed> in later versions of Swarm. Optionally, you can specify a second seed for use after the initialisation schedule has completed (see section 4.5.1) using the -Z {<seed>|TIME} option. This allows comparison between models with identical initial conditions. The seed specified using the -X, -s, or -S options is used for the initialisation schedule, and the seed specified using -Z is used thereafter.

3.2 Controlling the output

There are three forms of output that the FEARLUS model can generate, discussed in more detail in section 8. These output options are not mutually exclusive.

For debugging output, use the -D flag. The argument to this flag consists of one or more of a series of characters designed to denote a particular level of debugging or object being debugged. Table 1 contains a list of these characters and the kinds of messages that will be obtained. Any number of these characters may be specified and in any order. For example, to get messages from the Land Manager and Land Allocator objects, you would give -D MA as a command line option.

-D option character	Kinds of debugging message received
P	Messages from the Land Parcel objects
U	Messages from the Land Use objects
M	Messages from the Land Manager objects
A	Messages from the Land Allocator object
E	Messages from the Environment object
i	Very detailed messages from all objects
c	Detailed messages from all objects
o	Messages from the Observer Swarm object
m	Messages from the Model Swarm object
n	Messages relating to neighbourhood
b	Messages relating to bitstrings

Table 1 — List of options to be given as argument to the -D flag, and their arguments.

For history output, use the -h flag, and give as argument the name of a file to save the history to. History output records certain properties of objects such as climate, economy, land use, land parcels and land manager each year, in a text format suitable for importing into applications such as Microsoft Excel.

For specific report output, you need to create a report configuration file indicating what reports you want made and when you want them to be run. This file is specified using the -R option. Use the -r option to specify the file you want the report saved to, which if not specified, is fearlus-report.txt by default. The -a option is used if you are running the model several times, and rather than creating lots of different report files, you want the reports for all the runs to be stored in one file. If the -a option is given, then the report will be appended to the file specified with the -r option if it exists already.

The -d option is used to specify DOS mode output for history and report files. Here, each line is terminated with Carriage Return, Line Feed, rather than just Carriage Return.

3.3 Summary

For reference purposes, a summary of the command line options that can be given to the model0-6-4 executable is provided in Table 2.

Command line flag	Status	Effect
-a	Optional	Appends to report file rather than creating a new one if it exists.
-b	Optional	Run the model in batch rather than GUI mode.
-d	Optional	DOS mode output using CR+LF at the end of each line rather than just CR.
-D <flags>	Optional	Debugging output.
-h <file>	Optional	File to save the history to.
-m <mode>	Ignored	This is a Swarm argument.
-o <file>	Optional	Specify a file containing a set of observer displays you want in GUI mode.
-p <file>	Required	Specify a parameter file for the model.
-P <file>	Deprecated	Specify a land parcel file containing biophysical properties. This should be done in the parameter file instead.
-r <file>	Optional	File name to save report to if -R option specified.
-R <file>	Optional	Specify the report configuration file to generate the desired reports.
-s	Optional	Set the seed from the current system clock.
-S <integer>	Optional	Set the seed from the specified argument.
-t	Ignored	This is a Swarm argument.
-U <file>	Deprecated	Specify a land use file to load land uses in from. This should be done in the parameter file instead.
-v	Ignored	This is a Swarm argument.
-X {integer | TIME | DEFAULT}	Optional	Legacy way to set the seed — either specify an integer or use the word TIME to set the seed from the system clock, or DEFAULT to use the Swarm seed.
-Z {integer | TIME}	Optional	Specify a second seed to use after initialisation.

Table 2 — A list of the command line options that may be given to the model0-6-4 executable.

4 Ontology

FEARLUS model0-6-4 is an abstract agent-based spatially-explicit model of land use change. It is abstract in the sense that the phenomena simulated are modelled in a manner designed to mirror the kind of behaviour involved, but are not actually based on any fitted model of specific objects in the real world. It is agent-based in the sense that it contains objects intended to represent human decision-makers in the real world: farmers, or (more generally) land managers, and models these decision-makers individually. It is spatially-explicit in that it has land parcel objects that are topologically related to each other, decision-making processes that are bounded in their information sources to a spatial neighbourhood, and outcomes that change the pattern of certain spatial features (specifically, land use).

Henceforth, entities in the model will be referred to using Title Case to distinguish them from real-world entities.

4.1 Environment

The Environment consists of a rectangular grid of Land Parcels, and specifies the topological relationship between those Land Parcels, determining which Land Parcels in the grid have which other Land Parcels as spatial neighbours. The Topology of the Environment specifies what happens at the edges of the grid, and the Neighbourhood of the Environment specifies more generally the size and shape of cells' neighbourhoods.

The Topology may be Planar, Toroidal, or Cylindrical. In a Toroidal Topology, edge cells at the North of the grid 'wrap-around' to those at the South (and vice versa), as do those at the East and West. In a Cylindrical Topology wrap-around occurs in only in the North/South direction (HorizontalCylindrical) or only in the East/West direction (VerticalCylindrical). Figure 1 shows the topological effect of wrapping around. In a Planar Topology, no wrap-around of edge cells takes place.

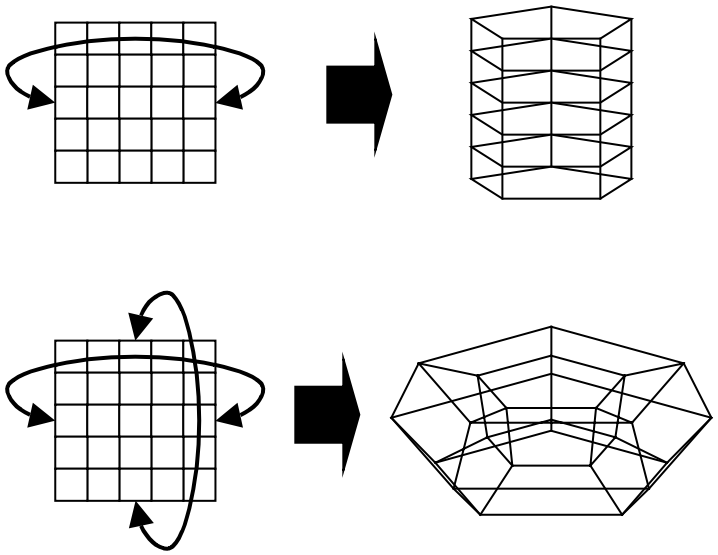

Figure 1 — Wrapping around a grid of cells in one dimension to form a cylinder and in two dimensions to form a torus.

The Neighbourhood Function of the Environment may be von Neumann (squares sharing an edge are neighbours) or Moore (squares sharing an edge or a corner are neighbours), the two standard neighbourhoods used in grids of squares, as well as hexagonal or triangular. These last two simulate a tessellation of cells of the appropriate shape using grids of squares, as illustrated in Figure 2. In addition, a global Neighbourhood is provided, in which all cells are neighbours of all other cells.

Note that in wrapped around environments with a triangular Neighbourhood, the number of cells in the wrapped around dimension of the grid must be even, or topological inconsistencies will occur. The software does not check for these inconsistencies, so beware.

The neighbourhood of a cell can also be adjusted using the neighbourhood radius. For all Neighbourhood Functions except global and von Neumann, the neighbourhood radius specifies the number of steps to be taken using the Neighbourhood Function to include all cells in the neighbourhood (i.e. a radius of 2 implies two steps of the Neighbourhood Function, radius 3 three steps, and so on). The neighbourhood radius is irrelevant in the case of the global Neighbourhood,

and in the von Neumann, it specifies the number of steps in a North, South, East or West direction. Examples are given in Figure 3.

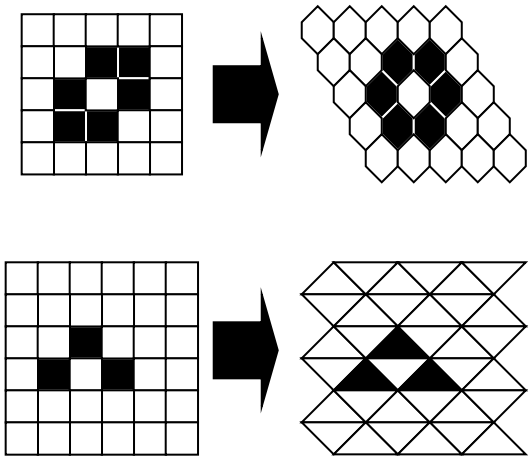

Figure 2 — Simulation of hexagonal and triangular neighbourhoods using grids of squares. In each case the neighbourhood of the third cell up and to the right from the bottom-left corner of the grid is shown.

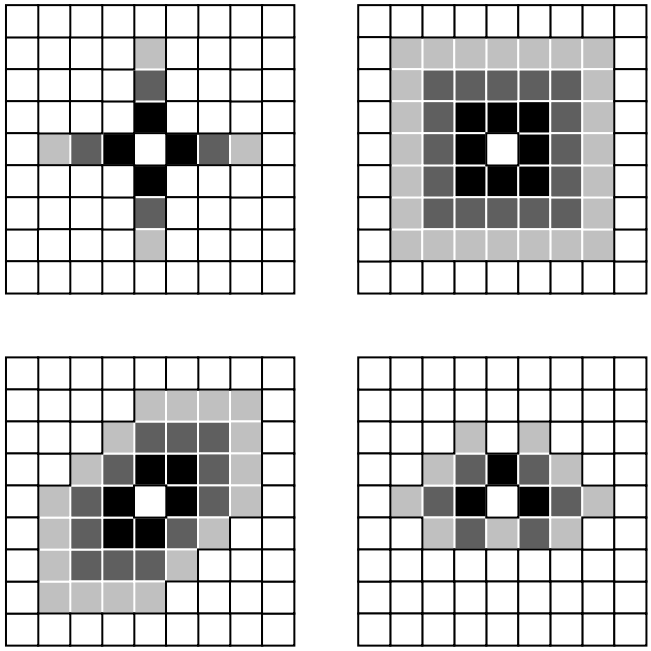

Figure 3 — The effect of neighbourhood radius on various different Neighbourhood Functions (clockwise from top left: von Neumann, Moore, triangular, and hexagonal). The outermost cells of the neighbourhood of the centremost cell is shown for a neighbourhood radius of 1 (black), 2 (dark grey) and 3 (light grey).

4.2 Yield generation

The Agents in the model survive by generating sufficient Yield from their Land Parcels to enable them to accrue Wealth. This mirrors the real world to the extent that farmers without any secondary source of income either continue in business or go bankrupt according to how much money they can sell their harvest for in comparison with their running costs. The amount of

money obtained for a particular crop in the real world depends on a number of factors. In model0-6-4, three such factors are considered: local Biophysical Properties of the Land Parcel, and global Climatic and Economic conditions. These three factors are simulated in an abstract fashion using strings of binary digits, or bitstrings. Land Managers must choose a Land Use for each Land Parcel they own that they expect to match well with these three factors. The amount of wealth accrued from a Land Parcel is given by how well the Land Use bitstring matches with a concatenated bitstring of Climate, Economy, and Biophysical Properties. The Land Use bitstring has two components, a 'match' string and a 'don't care' string. The latter of these two is used to simulate the possibility that the Wealth accrued from a Land Use might not be affected by some part of the state of the Biophysical Properties, Climate, or Economy. The Wealth accrued from a Land Use is also affected by the Break Even Threshold, which is the same for all Land Parcels and Land Uses, and does not change during the course of a run. It is intended to simulate the running costs associated with putting the Land Use on the Land Parcel, harvesting it, and selling it. Figure 4 illustrates the Wealth calculation process.

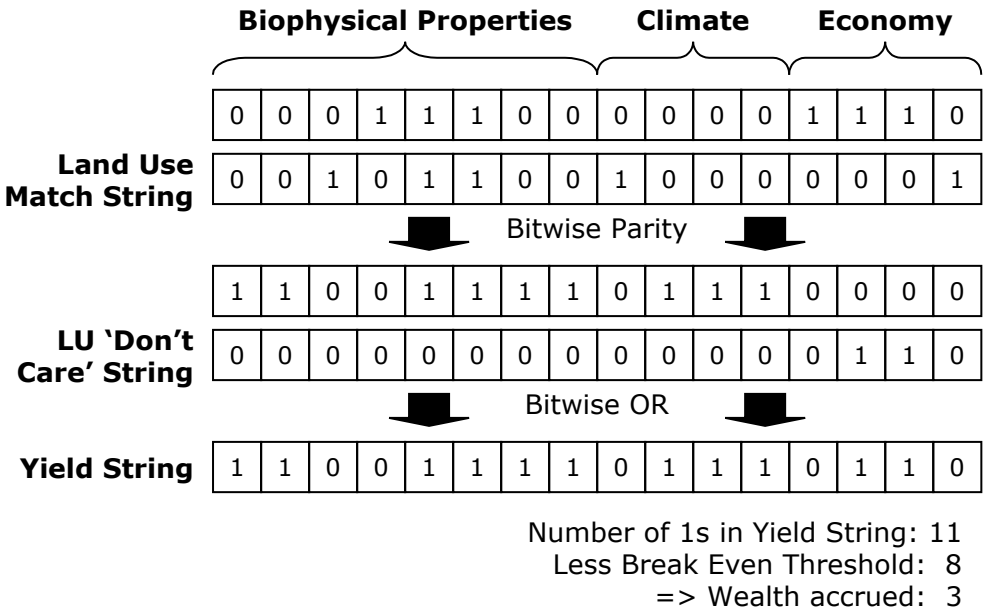

Figure 4 — Example Wealth calculation. The Biophysical Properties, Climate, and Economy are compared with the match string of the Land Use using the bitwise parity operator, and then the 'don't care' string applied to the result using a bitwise OR to give the Yield string. The Wealth accrued is the number of 1s in the Yield string less the Break Even Threshold.

The number of bits to use for each of the Biophysical Properties, Climate, and Economy are model parameters, allowing the user to vary the degree to which each of these factors influences the Wealth accrued from a particular Land Use. The Biophysical Properties vary spatially (in that each Land Parcel has its own individual Biophysical Properties bitstring), but not temporally (i.e. this bitstring remains unchanged during the course of a run). The Climate and Economy, by contrast, do not vary spatially, but may change with each cycle of the model. The bitstrings for the Land Uses do not change temporally, and do not vary spatially either.

There are two ways in which any of these bitstrings can be set — either using model parameters to control a stochastic process for setting them, or specifying a file containing the bitstrings to use. The following discusses the stochastic processes. For Land Uses, the match bitstring is chosen at random at the beginning of the run, with an equal probability of a 1 or a 0. The 'don't care' bitstring is also determined during initialisation, using a parameter that specifies, for each bit, the probability that it will have value 1.

The Climate and Economy are determined initially at random, with an equal probability of either bit value. Their change over time is determined by a set of parameters with one parameter for each bit of Climate and Economy specifying the probability that the bit will change in value from one cycle to the next. A toggle probability of 0 means no change, 1 a certain change. A random bit value each cycle would be achieved through specifying a toggle probability of 0.5.

The Land Parcel Biophysical Properties are determined at the beginning of the run randomly with an equal probability of 1 or 0 for each bit. Optionally, a clumping algorithm may be specified, with the purpose of making neighbouring Land Parcels more similar in their Biophysical Properties. Model 0-6-4 has two clumping algorithms. One (CAVNT3Clumper) is a cellular automaton which is run on each bit in the Biophysical Properties bitstring in turn. The transition rule for each bit is to change its value if three or more of its von Neumann neighbours have the opposite value. The other clumping algorithm (Same10PropClumper) is designed to maximise the spatial clumpiness of each bit in the Biophysical Properties bitstring whilst maintaining the same number of 1s and 0s as the initial random setting. The CA clumper takes as parameter a number of cycles — the more cycles, the more clumped the space. Typically 6 or 7 cycles are sufficient for the CA to converge to a state in which no change is made. The other clumper takes as a parameter the number of bits in the Biophysical Properties bitstring to clump. The effect of each clumper is contrasted in Figure 5.

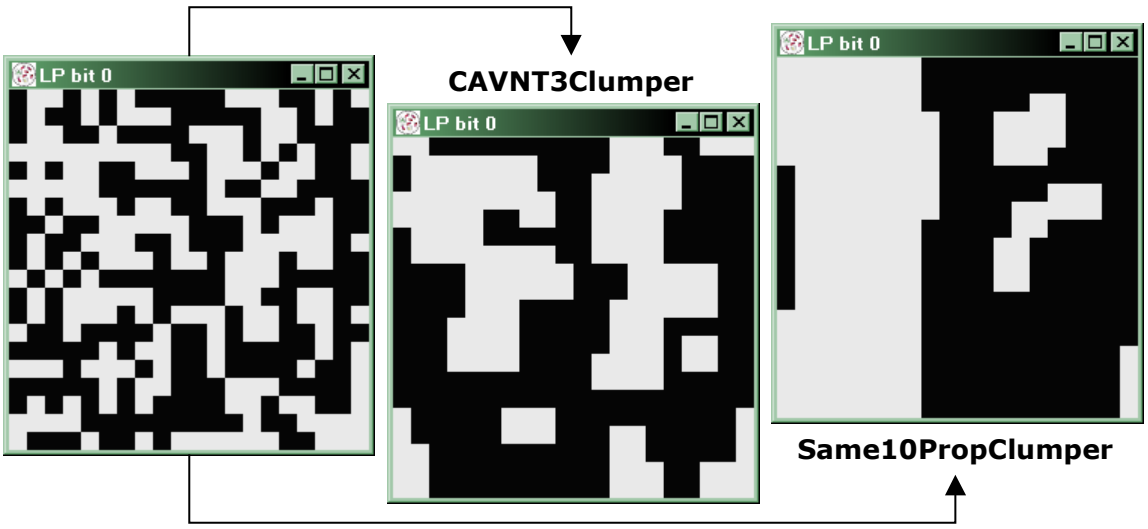

Figure 5 — The effect of the two clumpers. *Left*: Original Biophysical Properties generated at random, which was used as the initial state for both clumpers shown. *Middle*: CAVNT3Clumper after 6 cycles (the 7th having no effect). *Right*: Same10PropClumper.

4.3 Land Parcel transfer

The rules for transfer of Land Parcels depend in part on which class of Land Manager is being used by a Subpopulation. Two such classes are available: LandManager and PositiveLandManager. In both classes, the transfer of Land Parcels between Land Managers is done on the basis of Wealth, but a simple mechanism is used, that more reflects a process of allocation by some official body than a market. The idea is to create a situation, as simply as possible, whereby successful Land Managers gain more Land, whilst unsuccessful Managers lose it.

Land Managers from the LandManager class who have negative accrued Wealth must sell off their Land Parcels until their Wealth is no longer negative, whilst those from the PostiveLandManager class must sell off their Land Parcels if they have non-positive Wealth until their Wealth is positive. Land Parcels are sold in order of Yield, with lowest Yielding Parcels being sold first. A global parameter, the Land Parcel Price, specifies the amount of Wealth received by a Land Manager for selling a Land Parcel, and this parameter does not change in value during the course of a run. If a Land Manager has to sell off all of their Land Parcels to achieve non-negative (LandManager) or positive (PositiveLandManager) Wealth, then they are regarded as having gone out of business, and are retired from the simulation. Since this is the only restriction on the length of time a Land Manager may spend in the simulation, a Land Manager is better thought of as representing a farming business or family, than an individual farmer.

A list of Parcels for transfer having thus been established, a new owner is selected at random from a list of eligible Land Managers plus one potential new Land Manager. Eligible Land Managers are those from the LandManager class with Wealth equal to or greater than the Land Parcel Price and those from the PositiveLandManager class with Wealth greater than the Land Parcel Price, who own a Land Parcel neighbouring that for sale. Ownership of *n* neighbouring Land Parcels gives *n* chances to be selected, while the potential new Land Manager always has a single chance. The Wealth of an existing Land Manager selected to own the Parcel is diminished by the Land Parcel Price on transfer. If a new Land Manager is selected, then their initial Wealth is zero. Land Managers have no option to refuse a Land Parcel transfer.

4.4 Land Use decision making

Land Managers are divided into Subpopulations according to their decision-making process. Each Subpopulation is defined by a set of parameters that determine how its member Land Managers will decide a Land Use for each Land Parcel. The decision-making process of all Subpopulations has a common underlying structure (Figure 6). The structure consists of three main elements — three different ways in which the Land Manager might choose a Land Use according to contextual factors — satisfaction, imitation, and innovation. A fourth element, entirely artefactual, specifies how the Land Use will be decided in the initialisation phase of the model (usually a Random Strategy is used here).

Subpopulations specify a range of Aspiration Thresholds for their Land Managers. This can either be specified using a uniform distribution (with given maximum and minimum Aspiration Threshold), or a normal distribution (with the mean and variance being specified). If the Yield of the decision Parcel meets or exceeds the Aspiration Threshold of the Land Manager, then the Manager uses a satisfaction strategy. A typical satisfaction strategy is the Habit Strategy — just use the Land Use that was used last year on the Land Parcel.

If the Aspiration Threshold is not met, then Land Managers have an individual propensity to choose a Land Use either by imitation or innovation. This is simulated using a probability, and Subpopulations specify a range of values (again using either a normal or uniform distribution) that their members have for this probability. An imitative strategy uses only information about Land Uses, Wealth and Biophysical Properties of Land Parcels belonging to Land Managers in the social neighbourhood of the Land Manager. This is intended to simulate transfer of information between Land Managers on a social basis. Some imitative strategies available in the model use physical neighbourhoods instead, however. The physical and social neighbourhoods are contrasted in Figure 7.

There are two other parameters that imitative strategies may or may not use as part of their algorithm. One is the Neighbourhood Weighting, for which a range of values for Land Managers is specified at the Subpopulation level. This is intended to represent the degree to which Land Managers weight information from neighbouring Land Parcels as opposed to their own when

choosing a Land Use to imitate. At a Neighbourhood Weighting of zero, Land Managers only pay attention to their own Land Parcels, and at a Neighbourhood Weighting of one, Land Managers give equal weight to all information. The Neighbourhood Weighting otherwise be any positive floating point number. The one way in which Land Managers' decision-making processes may be changed during a simulation run is a legacy provision for the Neighbourhood Weighting to change. This, somewhat inconveniently, is specified at the global, rather than Subpopulation level. It specifies the amount to add to the Neighbourhood Weighting of a Land Manager for each Land Parcel lost, and to subtract from it for each Land Parcel gained.

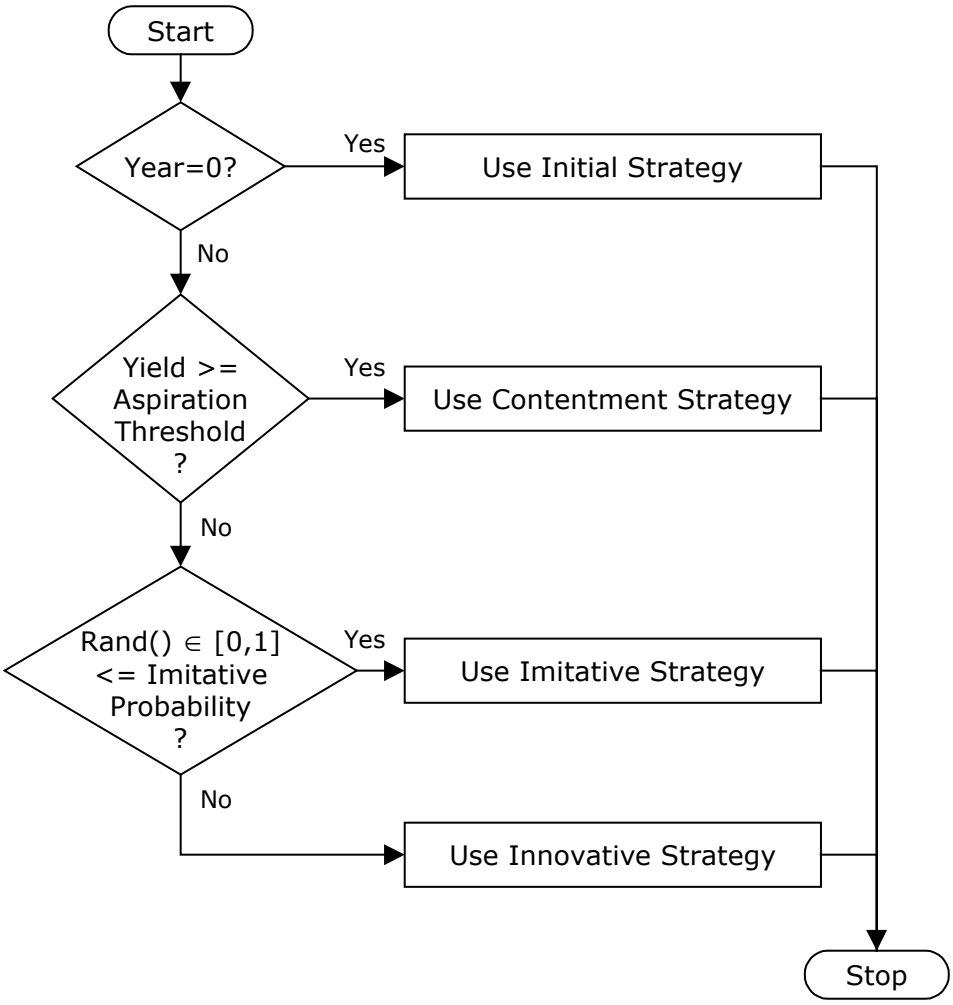

Figure 6 — Flowchart of underlying structure of the Land Manager Land Use Decision Algorithm.

The other parameter is Neighbourhood Noise, which is determined at the Land Manager level from a globally specified uniform distribution. (Again, this might be more appropriately specified at either the Subpopulation level — or even the Environment for that matter.) It is intended to represent the fact that Land Managers might not always be able to get accurate information about their neighbours' Land Parcels. When getting information about neighbouring Parcels' Biophysical Properties, the Neighbourhood Noise specifies a probability applied to each bit in the bitstring that a random value will be substituted for the true value of that bit in the bitstring the Land Manager receives. A Neighbourhood Noise of zero means the Land Manager gets the true bitstring when querying neighbouring Biophysical Properties, whilst a value of one means the Land Manager gets an entirely random bitstring.

Innovative strategies do not use neighbourhood information, but involve some other principled algorithm for deciding a Land Use to apply from those available. Both imitative and innovative strategies may involve examining data from earlier cycles. To this end, Subpopulations specify a range of values for the Memory of Land Managers — which specifies the maximum number of cycles' Climate, Economy, Land Use and Yield data the Land Manager may examine when choosing the Land Use. Table 3 compares the list of strategies available for use in model 0-6-4. More detail is given in section 9.

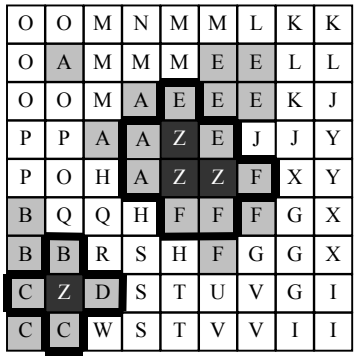

Figure 7 — The social and physical neighbourhoods contrasted. Each cell in the Environment above is given a letter according to the Land Manager who owns it. The solid line denotes the boundary of the physical neighbourhood of Land Manager Z in an Environment with a von Neumann neighbourhood radius 1. These consist of those Parcels that share a border with one of the Parcels owned by Z. By contrast, the social neighbourhood, shown by a grey shading to the included cells, consists of all Land Parcels owned by Land Managers with Land Parcels in the physical neighbourhood of Z.

The use of Aspiration Thresholds represents a "satisficing" element to Land Manager behaviour – i.e. the acceptance of a course of action which is "good enough", as opposed to a (riskier) attempt to find the optimum. This satisficing element may be eliminated in a Subpopulation by setting the minimum threshold higher than the maximum possible Yield — the length of the Land Use bitstring. In this way, Land Manager decision-making behaviour has some basis in established theory.

4.5 Schedule

The model contains two schedules, one to run during initialisation, the other to run thereafter. The main difference between the two (apart from the creation of various objects) is that Land Managers do not accrue Wealth or exchange Land Parcels during the initialisation schedule, and they use a different strategy to decide the Land Use.

4.5.1 Initial schedule

- Create the Land Parcels, and give them random initial Biophysical Properties.
- If a file name is given for the Biophysical Properties and the file exists, then load them from that file, else if they are to be clumped, then apply the clumper. If a file name for the Biophysical Properties was given, but the file did not exist, then save them in a file of that name.
- Create the Land Uses, and give them random initial match and 'don't care' bitstrings.
- If a file name is given for Land Uses and the file exists, then load them from that file, else if a file name was specified but the file did not exist, then save them to a file of that name.

- Determine the bitstring for the initial Climate, which may involve it being loaded from a file if a file name was given and the file exists. If a file name was given but the file does not exist, the Climate bitstrings will be saved to that file each cycle.
- Determine the bitstring for the initial Economy, which may involve it being loaded from a file if a file name was given and the file exists. If a file name was given but the file does not exist, the Economy bitstrings will be saved to that file each cycle.
- Create the Land Managers and assign them to the Land Parcels. Parameters exist that allow Land Managers to be initially assigned more than one Land Parcel. Essentially they specify the size of a rectangle of Land Parcels to give to each Land Manager. A whole number of these rectangles must fit into the Environment grid.
- Each Land Manager then determines the initial Land Use of the Land Parcel(s) they own.
- Calculate the Yield from each Land Parcel.
- If the user has requested a second seed to use after the initialisation schedule (with the -Z option) then set the random generator to use that seed.
- Activate the main schedule.

Strategy name	Imitative?	Historical?	Memory?	Phys/Soc	Optimum?	Deterministic?	Nbr wgt?	Nbr noise?	Land Use scoring basis / description
CautiousImitativeOptimumStrategy	Y	Y	N	S	Y	N	N	Y	Expected yield with minimum variance
EccentricSpecialistStrategy	N	Y	N	-	-	-	-	-	Random LU first time retained thereafter
FickleStrategy	N	N	N	-	-	-	-	-	Random LU selected to use on all Parcels
HabitStrategy	N	Y	N	-	-	-	-	-	Retain LU on Parcel
ImitativeOptimumStrategy	Y	Y	N	S	Y	N	Y	Y	Expected yield
LastNYearsOptimumStrategy	N	Y	Y	-	Y	Y	-	-	Expected yield
LastYearsOptimumStrategy	N	Y	N	-	Y	Y	-	-	Expected yield
MatchWeightedOptimumStrategy	N	N	N	-	Y	Y	-	-	BP match
MatchWeightedRandomStrategy	N	N	N	-	N	-	-	-	BP match
NoStrategy	-	-	-	-	-	-	-	-	For when a particular decision algorithm element won't be used
ParcelCorrectedYieldWeightedCopyingStrategy	Y	Y	N	S	N	-	Y	Y	BP match * Last yield
ParcelWeightedCopyingStrategy	Y	Y	N	S	N	-	Y	Y	BP match
RandomCopyingStrategy	Y	Y	N	S	N	-	Y	N	Random if alternative exists in neighbourhood
RandomStrategy	N	N	N	-	N	-	-	-	Random
SimpleCopyingStrategy	Y	Y	N	S	N	-	Y	N	Times LU appears in neighbourhood
SimplePhysicalCopyingStrategy	Y	Y	N	P	N	-	Y	N	Times LU appears in neighbourhood
StableImitativeOptimumStrategy	Y	Y	N	S	Y	Y	Y	Y	Expected yield
StochasticLastYearsOptimumStrategy	N	Y	N	-	Y	N	-	-	Expected yield
StochasticMatchWeightedOptimumStrategy	N	N	N	-	Y	N	-	-	BP match
YieldAverageWeightedTemporalCopyingStrategy	Y	Y	Y	S	N	-	Y	N	Last N years' average yield
YieldWeightedCopyingStrategy	Y	Y	N	S	N	-	Y	N	Last year's yield
YieldWeightedTemporalCopyingStrategy	Y	Y	Y	S	N	-	Y	N	Last N years' yield

Table 3 — A list of strategies available in model0-6-4, their properties and a brief description. BP refers to Biophysical Properties, and LU refers to Land Use. The column

headings indicate the following: '*Imitative*?' — Can the strategy be used as an imitative strategy? '*Historical*?' — Does the strategy use any data from previous years? (Meaning it would be unsuitable for an initial strategy) '*Memory*?' — Does the strategy use the Land Manager's memory? '*Soc/Phys*' — Does an imitative strategy use a social or physical neighbourhood? '*Optimum*?' — Does the strategy choose a Land Use with the highest score? (If not, Land Uses are selected at random weighted by their score.) '*Deterministic*?' — Does the optimising strategy deal with two or more equally maximum high scores by choosing consistently (or at random)? '*Nbr wgt*?' — Does an imitative strategy use the Land Manager's neighbourhood weighting property? '*Nbr noise*?' — Does an imitative strategy mutate the bitstrings of any neighbouring Parcels' Biophysical Properties?

4.5.2 Main schedule

- Increment the Year counter. (Each cycle in the model is intended to represent one year.)
- Land Managers each choose a Land Use for the Land Parcels they own.
- Determine the Climate (and save it to a file if this was specified).
- Determine the Economy (and save it to a file if this was specified).
- Calculate the Yield.
- Land Managers harvest their Yield and accrue Wealth accordingly.
- Land Managers with negative Wealth put Land Parcels up for sale.
- New Land Managers are chosen for the Land Parcels put up for sale.

5 Parameter files

In the following section, a **`bold Courier`** font is used to indicate text that must appear in the file as is, whilst an *italic Times* font is used for text that should be replaced by some appropriate value. Comments are in a red Arial Narrow font and should not appear in the file.

5.1 Model parameters

Many model parameters take double precision floating point values. Floating point arithmetic is a means of doing calculations with non-integers and large numbers whilst using a finite number of bits. In the case of double precision, this is typically an 8-byte word, or 64 bits. Clearly, using this finite number of bits means that not all numbers between -1.7976931348623157E+308 and +1.7976931348623157E+308 (see /usr/include/float.h) can be represented accurately. Trivially, in fact, only 2^{64} or just over 10^{19} such numbers can maximally be represented. Inevitably, therefore, floating point arithmetic involves a degree of approximation. Whilst this may be acceptable for most intents and purposes (double precision giving 15 significant figures of accuracy), there are some quite simple cases where inaccuracies can occur (try comparing 0.4 + 0.4 + 0.4 – 0.4 – 0.4 – 0.4 with zero, for example). In non-linear applications, such as FEARLUS, where decisions depend critically on such things as comparisons of floating point numbers with zero, even slight inaccuracies can have unexpected emergent effects. These inaccuracies can occur simply because the number in question has a recurring fraction in binary notation (e.g. 0.4 = 0.0110 0110 …), or because a small number is added to a large number (e.g. 134217728 + 0.00000001 = 134217728). FEARLUS model 0-6-4 does not currently deal effectively with such problems, other than to issue a warning in one particular case where they are known to have a detectable effect. In general they should be avoidable by ensuring that any floating point parameters set to non-integral values uses decimals that are sums of negative powers of two — e.g. 0.5 (2^{-1}), 0.75 ($2^{-1} + 2^{-2}$), 0.1875 ($2^{-3} + 2^{-4}$), and that the model is not left running for a huge number of Years (which makes the sum of large and small numbers more likely to be an issue).

5.1.1 Model file

The model file is the main parameter file, and it is this that should be supplied as argument to the –p flag on the command line. The 'environmentType' parameter needs a little explanation. The value given is a string consisting of a Topology and Neighbourhood Function, separated by a

minus sign. The Topology may be one of 'Global', 'Planar', 'HorizontalCylindrical', 'VerticalCylindrical', or 'Toroidal'. The Neighbourhood Function may be one of 'TriangularVonNeumann', 'VonNeumann', 'HexagonalParallelogram', 'Moore', or 'Global'. Thus examples for this parameter value are such strings as 'Planar-VonNeumann', 'Toroidal-HexagonalParallelogram', or 'HorizontalCylindrical-Moore'. The 'Global' Topology and 'Global' Neighbourhood are intended to be used exclusively together, in the environment type 'Global-Global'. Combining the Global Topology or Neighbourhood with any other Neighbourhood or Topology is an error, but will not cause the model to fail.

The 'clumping' parameter also needs some explanation. The value to use for this parameter is a string in which the type of clumper and any parameters it needs are given. The format of this string is *clumper*`:`*param1*`=`*value1*`;`*param2*`=`*value2*`; ... ;`*paramN*`=`*valueN*. Two clumpers are available in model0-6-4: 'CAVNT3Clumper', and 'Same10PropClumper', described earlier in this document. The 'CAVNT3Clumper' has one parameter 'Cycles' which should always be specified, and tells the clumper how many cycles of the CA to do. The 'Same10PropClumper' has one parameter 'bitsToClump' which specifies how many bits of the Biophysical Properties bitstring should be clumped (the CA clumper does not have such an option). This is an optional parameter, as by default the 'Same10PropClumper' will clump all bits. Examples of settings for the 'clumping' parameter are 'CAVNT3Clumper:Cycles=6', 'Same10PropClumper', or 'Same10PropClumper:bitsToClump=1'. If no clumping is required, then the string 'None' should be used.

The model file format is given below:

@begin	
environmentType	*Environment type string, as described in the main text*
neighbourhoodRadius	*Neighbourhood radius (integer)* The neighbourhoodRadius must be less than half of both envXSize and envYSize. This is not validated, but will result in invalid neighbourhoods being computed.
climateBSSize	*Number of bits to use for the Climate bitstring (integer)*
economyBSSize	*Number of bits to use for the Economy bitstring (integer)*
landParcelBSSize	*Number of bits to use for the Land Parcel Biophysical Properties bitstring (integer)* The length of the Land Use bitstring is always the sum of the Climate, Economy, and Biophysical Properties bitstring lengths
nLandUse	*Number of Land Uses (integer)*
pLandUseDontCare	*Probability of a 1 in the 'Don't care' bitstring of any Land Use*
clumping	*Clumping algorithm to use and any parameter settings as described in the main text*
envXSize	*Number of horizontal cells to use in the Environment grid (Integer)*
envYSize	*Number of vertical cells to use in the Environment grid (Integer)*
landParcelFile	*File to use to load (or save) Biophysical Properties from* The useLandParcelFile parameter must be set to 1 for this file to be used. If the file already exists (and useLandParcelFile = 1), then the Biophysical Properties will be loaded from it. If not, then they will be saved to it.
useLandParcelFile	*Flag indicating whether or not to use the landParcelFile*
landUseFile	*File to use to load (or save) Land Use bitstrings from*
useLandUseFile	*Flag indicating whether or not to use the landUseFile* The useLandUseFile and landUseFile parameters are linked in

	the same way as the useLandParcelFile and landParcelFile parameters, and the same behaviour relative to the existence of the file also applies here.
economyFile	*File to use to load (or save) Economy bitstrings from* If the file contains fewer Years' worth of Economy bitstrings than are used in the model run, then once the bitstrings in the file are used up random bitstrings are generated using the toggle probabilities.
useEconomyFile	*Flag indicating whether or not to use the economyFile* Again, the file won't be used unless the corresponding 'use…' parameter = 1, and the load/save behaviour is the same.
economyToggleProbFile	*File to load the Economy toggle probabilities from*
climateFile	*File to use to load (or save) Climate bitstrings from*
useClimateFile	*Flag indicating whether or not to use the climateFile* climateFile behaviour is just the same as economyFile behaviour.
climateToggleProbFile	*File to load the Climate toggle probabilities from*
maxYear	*Number of iterations of annual cycle* Essential for batch runs! The number entered here should actually be one more than the maximum Year you want reported.
infiniteTime	*Flag indicating whether or not to run indefinitely (1 to run indefinitely, 0 to use maxYear)* Must be 0 for batch runs!
nSubPops	*Number of subpopulations in this run (integer)*
subPopFile	*File to load subpopulation contest data from*
strategyChangeUnit	*Amount by which to update all Land Managers' Neighbourhood Weighting (floating point)*
neighbourNoiseMax	*Maximum probability of corrupting each bit in a neighbouring Parcel Biophysical Properties query to endow Land Managers with (floating point)*
neighbourNoiseMin	*Corresponding minimum probability (floating point)*
breakEvenThreshold	*Amount to subtract from Yield to get Wealth accrued to Land Manager from one Land Parcel (floating point)*
landParcelPrice	*Amount gained by Land Managers selling a Land Parcel (and lost by Land Managers buying it) (floating point)*
nInitXParcels	*Number of initial horizontal Land Parcels to endow the Land Managers created at the beginning of the run with (integer)* envXSize must be an integer multiple of this parameter value
nInitYParcels	*Number of initial vertical Land Parcels to endow the Land Managers created at the beginning of the run with (integer)* envYSize must be an integer multiple of this parameter value
dumpHistory	*Flag indicating whether or not to save off the history gathered so far into an intermediate file (to save memory and size of each history file) (1 to use intermediate files, 0 to save everything to one big file at the end of the run)*
maxHistoryLength	*How many Years' data to save in each intermediate history file (integer)* To use these history parameters, the -h option must be specified on the command line.
@end	

5.1.2 Climate and Economy toggle probability files

The Climate and Economy toggle probability files both have the same format. They are used to specify the probability of changing value each Year for each bit of their respective bitstrings. Zero length Climate and Economy bitstrings are permitted in model0-6-4, but unfortunately you still have to provide a toggle probability file (which consists of a single line saying "NumberOfElements: 0"). The format is given below:

`NumberOfElements:` *Number of bits for which probabilities are provided (integer)*
The number entered here must correspond to the model file parameters climateBSSize or economyBSSize according to which of the Climate or Economy this file is for.
`d` *Probability this bit will flip each Year (floating point)*
The above line should appear the number of times indicated by the NumberOfElements entry.

5.1.3 Subpopulation contest file

The Subpopulation contest file specifies which Subpopulations will be competing for land ownership in this run of the model.

`NumberOfSubPopulations:` *Number of Subpopulations in the contest (integer)*
The number entered here must correspond to the model file parameter nSubPops.
`SubPopulationFile` *Subpopulation file number (integer)***`:`** *Subpopulation file name*
The above line should appear the number of times indicated by the NumberOfSubPopulations entry. The Subpopulation file number should start at 1 on the first SubPopulationFile line and increase in steps of 1.

5.1.4 Subpopulation file

The Subpopulation file contains details of the ranges of parameters that will be assigned to Land Managers belonging to this Subpopulation. Some ranges of parameters can be specified using a normal or a uniform distribution. In each of these cases, there will be a parameter called '…Dist' that specifies which to use (the value for which should be either 'normal' or 'uniform'). If the '…Dist' parameter is 'uniform', then the range of values is specified using the corresponding '…Min' and '…Max' parameters, otherwise, the '…Mean' and '…Var' parameters should be used. The file also contains a pointer to the strategy selector file, which determines which strategies member Land Managers will use for contentment, imitation, innovation or initially.

`@begin`
`label` *String containing a unique name for this Subpopulation*
The label is optional — a label will be generated automatically if none is specified. The label is of most use in GUI mode to tell the Subpopulations apart on the graphs.
`colour` *A colour to use for this Subpopulation (integer)*
The colour is also optional, and only relevant in GUI mode. Colours are preset in a colourmap, and they are indexed by this integer, which should be a positive integer. Colours will be automatically assigned to Subpopulations if not specified here. The only reason to specify the colour is for consistency across a number of runs.

probability	*The probability that any newly created Land Manager will belong to this Subpopulation (floating point)*
landMgrClass	*Which class to use to represent the Land Managers.* This parameter should either be 'LandManager' or 'PositiveLandManager', depending on the Land Parcel transfer mechanism required.
strategySelectorFile	*The name of a file to get the strategies for this Subpopulation from*
memorySizeMin	*The minimum number of Years a member of this Subpopulation will be able to recall Climate, Economy, Yield and Land Use data for.*
memorySizeMax	*The maximum number of Years…*
neighbourWeightDist	*Distribution from which to set the neighbourhood weighting of member Land Managers* This parameter should either be 'normal' or 'uniform'.
neighbourWeightMin	*Minimum neighbourhood weighting (floating point)* This parameter should only appear if 'neighbourWeightDist' is 'uniform'.
neighbourWeightMax	*Maximum neighbourhood weighting (floating point)* This parameter should only appear if 'neighbourWeightDist' is 'uniform'.
neighbourWeightMean	*Mean neighbourhood weighting (floating point)* This parameter should only appear if 'neighbourWeightDist' is 'normal'.
neighbourWeightVar	*Neighbourhood weighting variance (floating point)* This parameter should only appear if 'neighbourWeightDist' is 'normal'.
imitateProbDist	*Distribution from which to set the probability of imitation of member Land Managers* This parameter should either be 'normal' or 'uniform'.
imitateProbMin	*Minimum imitation probability (floating point)* This parameter should only appear if 'imitateProbDist' is 'uniform'.
imitateProbMax	*Maximum imitation probability (floating point)* This parameter should only appear if 'imitateProbDist' is 'uniform'.
imitateProbMean	*Mean imitation probability (floating point)* This parameter should only appear if 'imitateProbDist' is 'normal'.
imitateProbVar	*Imitation probability variance (floating point)* This parameter should only appear if 'imitateProbDist' is 'normal'.
habitImitateThresholdDist	*Distribution from which to set the aspiration threshold of member Land Managers* This parameter should either be 'normal' or 'uniform'.
habitImitateThresholdMin	*Minimum aspiration threshold (floating point)* This parameter should only appear if 'habitImitateThresholdDist' is 'uniform'.
habitImitateThresholdMax	*Maximum aspiration threshold (floating point)* This parameter should only appear if 'habitImitateThresholdDist' is 'uniform'.
habitImitateThresholdMean	*Mean aspiration threshold (floating point)* This parameter should only appear if 'habitImitateThresholdDist' is 'normal'.
habitImitateThresholdVar	*Aspiration threshold variance (floating point)* This parameter should only appear if 'habitImitateThresholdDist' is 'normal'.

```
@end
```

5.1.5 Strategy selector file

The strategy selector file contains a list of strategies to use for each element in the Land Manager Decision Algorithm, and the probability that the strategy will be selected. This allows, if required, Subpopulations to consist of Land Managers using different strategies for different elements in the Decision Algorithm.

NumberOfStrategyClasses: *Number of strategies appearing in this file (integer)*
**Class AboveThresholdProbability **
**BelowThresholdNonImitativeProbability **
BelowThresholdImitativeProbability InitialProbability

The above headings should all appear on one line. The file is designed to be readable in a spreadsheet package, so separating the headings with tabs is a good idea, though not necessary.

Name of strategy *Probability1* *Probability2* *Probability3* *Probability4*

The strategy names are given in Table 3. The first probability is the probability the strategy will be assigned as the contentment strategy of a Land Manager. The second probability is the probability it will be assigned as the innovative strategy. The third is for the imitative strategy, and the fourth the initial strategy (typically 'RandomStrategy'). Where the distributions of parameters in the corresponding Subpopulation file have been appropriately set, 'NoStrategy' should be used with probability 1 to generate an error message if the Land Manager attempts to use it. Thus, for example, if the minimum aspiration threshold is greater than the maximum possible yield, then NoStrategy should be in here with Probability1 replaced with 1.0, and 0.0 for Probability2-4. The number of strategy lines in the file should correspond to the number entered for 'NumberOfStrategyClasses' above.

5.1.6 Land Parcel Biophysical Properties file

If you provide a landParcelFile entry in the main parameter file (say, `file1.lp`), and set the useLandParcelFile flag to 1, then unless `file1.lp` already exists, the model will save the Land Parcel Biophysical Properties bitstrings for you to a file of that name with the format below. You can then have them loaded in to a later run using an Environment with the same size and setting for the Biophysical Properties bitstring length, if the useLandParcelFile flag is set to 1, and the landParcelFile parameter again contains the filename `file1.lp`.

EnvironmentXSize: *Number of horizontal cells in the Environment (integer)*
EnvironmentYSize: *Number of vertical cells in the Environment (integer)*
LandParcelBitStringLength: *Number of bits in the Biophysical Properties (integer)*

XCoord **YCoord** **BitString**
Cell X co-ordinate *Cell Y co-ordinate* *Biophysical Properties bitstring*

The line above is repeated for each cell (Land Parcel) in the Environment. Note that when the file is saved from the model, tabs separate each item on a line, with the intention of making the file readable in a spreadsheet.

5.1.7 Land Use file

The landUseFile parameter in the main parameter file may specify a file name. If the file does not exist, and the useLandParcelFile parameter is set to 1, this will cause the model to save the Land Use match and 'don't care' bitstrings in a file of that name. These bitstrings can then be loaded in to a run with the same nLandUse parameter value, and Land Use bitstring length (given by the sum of the lengths of the Biophysical Properties, Climate and Economy bitstrings). The useLandParcelFile parameter should be set to 1, and the landUseFile contain the name of the file saved from the earlier run.

`NumberOfLandUses:` *Number of Land Uses (integer)*

When loading in Land Uses, the 'NumberOfLandUses' value given here must equal the nLandUse parameter in the main model file.

`LandUseBitStringLength:` *Number of bits in the Land Use bitstring (integer)*

`LandUseIndex`	**`MatchBitString`**	**`DontCareBitString`**
LU number (integer)	*Match bitstring of Land Use*	*'don't care' bitstring of Land Use*

The line above is repeated for each Land Use, with the 'LandUseIndex' starting at 0 and increasing in steps of 1 (it is ignored when loading in the Land Uses). Note that when the file is saved from the model, tabs separate each item on a line, with the intention of making the file readable in a spreadsheet.

5.1.8 Climate and Economy files

The Climate and Economy files both have exactly the same format. The Economy will be saved to a file for each Year the model runs if the economyFile parameter in the main parameter file names a file that does not yet exist, and the useEconomyFile flag is set to 1. The Economy will be loaded in if the economyFile parameter contains the name of an existing file and the useEconomyFile flag is set to 1. If the economyBSSize parameter is not set to the length of the bitstrings in the file, then the model will generate an error message. The same applies to the Climate, and the climateBSSize, climateFile and useClimateFile parameters.

The format of the file is simple: one line per Year, with each line having the required bitstring. If the run is loading in bitstrings from a file, and the file ends before the run's termination Year, then subsequent Climates/Economies will be generated using the toggle probabilities. Note that these probabilities *must* be set, even if it is not expected they will be needed.

5.2 Observation parameters

5.2.1 Report configuration file

The report configuration file is used to specify the reports that are required as output from the model, any options for those reports, and in what Years the reports are to be made. Reports are discussed in more detail in section 0, where a table of currently available reports is also to be found (Table 5).

The format of this file is a series of statements separated by white space in a simple language. Every report configuration file must finish with the word "End". The simplest configuration file consists solely of this word, and will call every report each Year. Optionally, the first statement in the file can be one saying "**`DefaultYearsToReport:`** *Year list*" (without the quotes). A Year list is a comma-separated list of terms, where each term may be one of the following:

- *integer1*
- *integer2-integer3*

- **`Every`** *integer4*

Here, *integer1* is greater than or equal to 0, and specifies a fixed Year in which the report will be made. Next, *integer2* is also greater than or equal to 0, and *integer3* is greater than *integer2*, and they together specify an inclusive fixed range of Years in which to report. Finally, *integer4* is a repeat interval. The report will be called in Year 0 (the initialisation Year), and then in intervals of *integer4* thereafter. There must be no white space between a term and a comma following it.

For example: "DefaultYearsToReport: 7, 9, Every 20, 70-80, Every 99, 199" would, in a run with the maxYear parameter set to 200, stipulate the default that reports would be called in Years 0, 7, 9, 20, 40, 60, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 99, 100, 120, 140, 160, 180, 198, and 199. Note that Year 200 is not reported on; the maxYear parameter specifies the Year to stop the simulation, and reports are never issued for that Year.

The next simplest report configuration file besides that consisting only of the word "End" is one consisting of a DefaultYearsToReport statement followed by the word "End". For example, a file containing "DefaultYearsToReport: 200 End" would specify (in a run with maxYear more than or equal to 201) that all reports were to be written in Year 200.

More typically, however, only a few of the available reports in Table 5 will be required. Following the optional DefaultYearsToReport statement, a series of statements should be specified for each report required. Each such statement consists of the name of the report class (as given in Table 5), followed (if required) by a list of options, followed (if DefaultYearsToReport have not been specified and the report is not required every Year, or the defaults are to be over-ridden for this report) by a Year list. An option list is preceded by the term "**`Options:`**" if it appears, and a Year list by the term "**`YearsToReport:`**".

Report configuration file	What it does
`End`	Every report, every Year.
`DefaultYearsToReport: Every 10` `End`	Every report, every 10 Years.

`ParcelSubPopReport`
`  YearsToReport: 200`
`End`
	ParcelSubPopReport
	in Year 200 only.

`DefaultYearsToReport: Every 1`
`ClimateBitStringReport`
`EconomyBitStringReport`
`ClumpinessReport`
`  Options: Histo`
`  YearsToReport: 0`
`ParcelSubPopReport`
`  YearsToReport: 200`
`End`
	ClimateBitStringReport and
	EconomyBitStringReport every Year,
	ClumpinessReport
	showing a histogram
	in Year 0 only,
	and ParcelSubPopReport
	in Year 200 only.

Table 4 — Some example report configuration files. Note that spacing in the file is irrelevant so long as white space of some kind appears where it appears in the example — the layout shown here is to improve readability.

An option list is a comma-separated list of option terms specifying the value of each option. Options come in two forms, *variables* and *flags*. The following shows the format for setting them:

- *variable1*=*value*
- *flag1*
- **No***flag2*

Here, *variable1* is set to the specified *value*, *flag1* is set to "True" and *flag2* is set to "False". When specifying a list of options, there must be no white space between an option term and any following comma. Any report having options will have default values for them. In model0-6-4 the only report with any option is the ClumpinessReport, which has a Histo flag. Some examples are given in Table 4.

5.2.2 Observer file

The observer file specifies which displays are required when the model is being run in GUI mode. The default is to show all displays, which, unless you have an unusually large screen, is likely to lead to rather a lot of clutter. Examples of each of the displays are given in section 7 which discusses GUI mode in more detail. The format of the observer file is given below:

@begin	
showStrategyColourKey	*boolean* The Strategy raster shows a colour on each Land Parcel for the Strategy used to determine its Land Use. This display shows the key to those colours. The value 1 means the raster should be shown the value 0 that it should not.
showUseRaster	*boolean* Show the Land Parcels coloured by their current Land Use
showLPBitStringRaster	*boolean* Show a raster containing a display of the setting of a particular bit in the Biophysical Properties of the Land Parcels. You can cycle through the bit displayed by left and right clicking in the raster.
showLPBitStringDiffs	*boolean* If the Land Use raster is displayed, setting this flag to 1 will show on the border between each von Neumann neighbouring Land Parcel a grey line whose shade indicates the number of bits that match between that pair of Land Parcels' Biophysical Properties. Black is no match, white is all matching.
showManagerRaster	*boolean* Show the Land Parcels coloured by the Land Managers owning them.
showSubPopRaster	*boolean* Show the Land Parcels coloured by the Subpopulation of the Land Managers owning them.
showStrategyRaster	*boolean* Show the Land Parcels coloured by the Strategy used to choose their Land Use.
showUseChangeRaster	*boolean* Show the Land Parcels in shades of grey according to the relative number of times their Land Uses have been changed (black = least, white = most).
showManagerChangeRaster	*boolean* Show the Land Parcels in shades of grey according to the relative number of times their Land Managers have been changed (black = least, white = most).
showParcelsOwnedGraph	*boolean* Show a time series graph of the total number of Land Parcels

	owned by members of each Subpopulation. If there is only one Subpopulation, show the mean, minimum and maximum over all Land Managers.
showYieldGraph	*boolean* Show a time series graph of the mean, minimum and maximum Yield from the Land Parcels.
showPopulationGraph	*boolean* Show a time series graph of the number of Land Managers in each Subpopulation.
showUseGraph	*boolean* Show a time series graph of the number of Land Parcels assigned to each Land Use.
showWealthGraph	*boolean* Show a time series graph of the mean Wealth accumulated by members of each Subpopulation. If there is only one Subpopulation, show the mean, minimum and maximum over all Land Managers.
showAgeGraph	*boolean* Show a time series graph of the mean Age (in Years) of members of each Subpopulation. If there is only one Subpopulation, show the mean, minimum and maximum over all Land Managers.
showNWeightDist	*boolean* Show (if appropriate) a distribution of the Neighbourhood Weighting over members of each Subpopulation — so, one graph for each Subpopulation with parameters set to allow this to vary.
showThresholdDist	*boolean* As showNWeightDist, but for the Aspiration Threshold.
showImitProbDist	*boolean* As showNWeightDist, but for the Imitation Probability.
nHistogramBins	*integer* Number of bins to use in the distribution graphs. (So, all graphs have the same number of bins…)
zoomSize	*integer* How many units of 250 pixels to make the rasters. This multiple of 250 pixels will determine the number of pixels to use for the larger dimension of the Environment. So, if the zoomSize is 2 and the Environment has 10 horizontal Land Parcels and 4 vertical, then all raster displays will be 500 pixels across by 200 pixels down.
displayFrequency	*integer* How often to update the display of all rasters and graphs.
saveDumpedHistory	*boolean* Set to 1 to use history output in GUI mode.
@end	

6 Batch mode

As mentioned in section 3, to run FEARLUS in batch mode, give the -b flag to the command line. Any debugging output specified with the -D flag will be sent to stdout, along with standard messages that can't be optionally made to disappear showing (among other things) when each Year is started. You should give at least one of -D, -h, or the -R and -r flags to get some output from the model, otherwise there is little point in running it. If you are not giving the -D flag, then stdout should be redirected to /dev/null to discard it, particularly if you are running the process in

the background (this works on both Unix and Cygwin — see below for an example command). Successful termination is indicated by a 0 exit status. More on the output options can be found in section 8. The -p flag should also be used to specify the model parameters for the run, and unless the run is being used to test the model, the -s flag should be given to specify an arbitrary seed (or -S with a specific seed).

Bear in mind that using the -s flag to vary the seed could result in duplicate seeds being used (though this is not very likely), as the -s flag generates a seed from the system clock and process ID. There are two ways of approaching this: either check the output (all the output options give the seed used) and discard duplicates, or prepare a list of unique seeds in advance for each sequence of runs, and cycle through them using the -S option. The latter option would require some sort of script to start off each run.

Another point to note for series of runs is that the -a flag will append any reports specified with the -R option to the file specified with the -r option. For large numbers of runs, this can prevent directories being cluttered with large numbers of report files.

A typical command to run the model in batch mode would look like this:

```
/full/path/to/model0-6-4 -p MyParams.model -R MyReports.cfg -r
MyReportOutputFile -s -a > /dev/null
```

One point to note from this example is that the model is being run from the directory containing all the parameter files. If this is not done, then all filenames in parameter files should use full paths. This latter approach could be useful in maintaining a database of parameter file settings using the filesystem, but would impact the portability of the parameter files.

7 GUI mode

GUI mode is typically used for exploratory runs of the model, and for generating pictures for diagrams. A large number of displays are possible in GUI mode, and it is suggested that an observer file (section 5.2.2) be used to select the displays required. These, and any options for setting them, are all illustrated in the ensuing subsections.

First, however, it is worth noting that the GUI can be used (to a certain extent) to enter parameters for the model and for the observer. This is not strictly recommended, as no record of the parameters will be saved unless you are using reporting or history output. It also has to be said that the GUI entry of some of the Subpopulation parameters in particular should be regarded as alpha release at best[*]. Further, there is no ability to enter the toggle probabilities for the Climate and Economy, so at the very least you will have to create these files (even if you have zero-length bitstrings for them!). Thus, although, in section 3 the -p option was specified as mandatory, strictly speaking, it is not, and the model can be run without any command-line options. This, however, is not recommended practice.

When the model is first started, three windows appear, Figure 8 illustrating the contents of these windows when no command-line arguments are given. In this case, you should enter values for all parameters (making sure you press return after each entry) except climateToggleProbs, economyToggleProbs, subPops, and panel. Some parameters are optional — in particular landParcelFile, landUseFile, climateFile and economyFile need not be entered if their corresponding use… flags are set to 0. You should also be able to get away without entering the subPopFile, as the GUI lets you enter Subpopulation details manually. If you have specified a parameter file with the -p option, then you can use the GUI to make changes to the parameters if you want to, before pressing ‘Next’ or ‘Start’ to begin running the model. You can also enter

[*] … and is unlikely ever to be beta.

values for the seed for the run, and, if required, the seed to use after initialisation. You cannot change the parameters once the run has started.

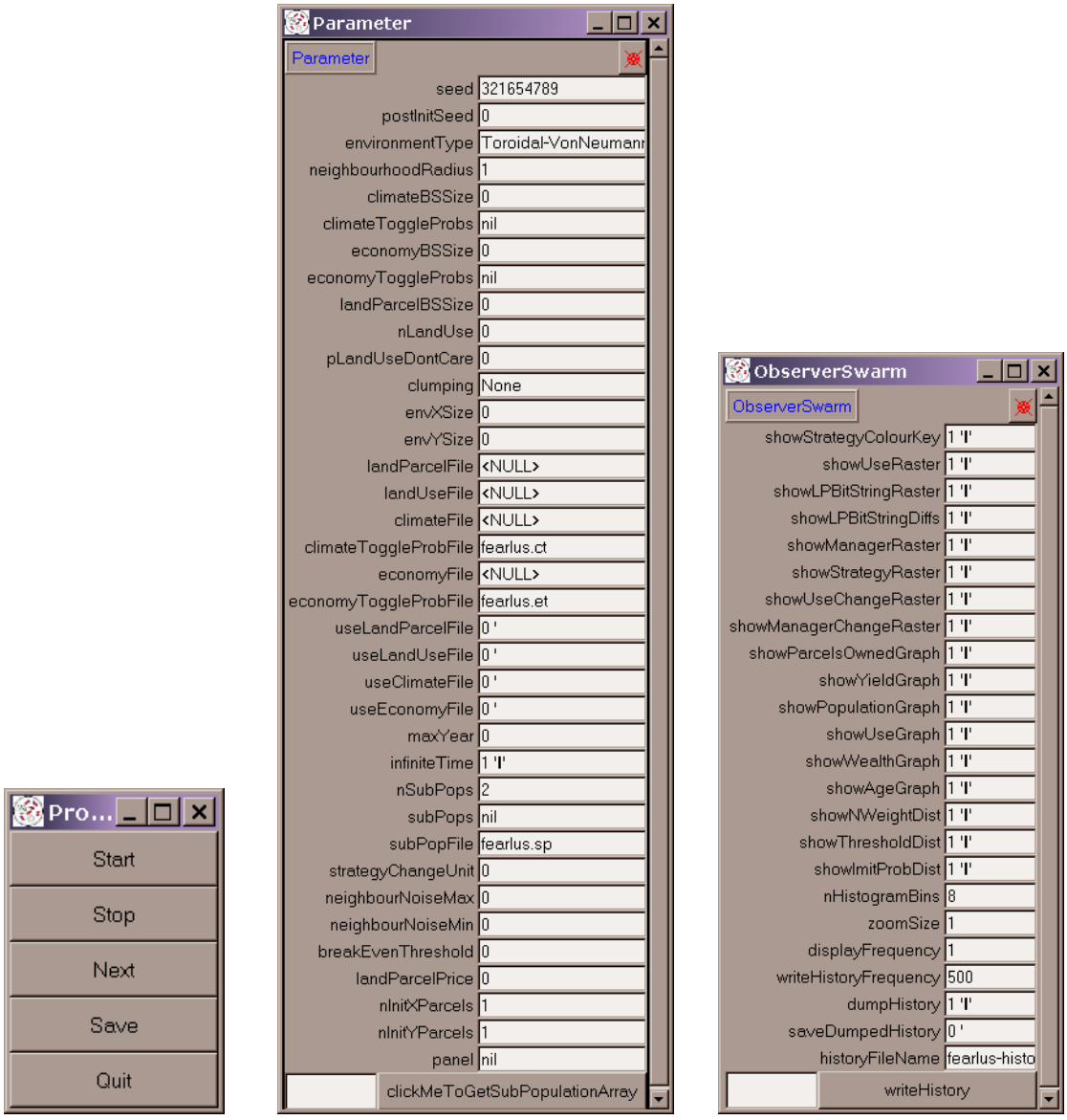

Figure 8 — The three windows that pop up on starting model0-6-4. The illustration here shows what appears if you start model0-6-4 without any parameter file specified using the -p or -o flags. In the parameter window, the user has entered '2' in the box against the 'nSubPops' parameter.

To enter the Subpopulation details, make sure you have entered a value in the nSubPops parameter and pressed 'Return'. You can then press the 'clickMeToGetSubPopulationArray' button. A window will pop up as shown in Figure 9 that contains one button for each Subpopulation you require. You will need to click on each of these buttons in turn to enter the details for each Subpopulation. When you click on such a button, you get a window like that shown in Figure 10 (which unfortunately has nothing to tell you which Subpopulation it belongs to). When you have entered the details in this window, you further have to enter the strategies this Subpopulation uses. It will come as no surprise that the 'clickMeToGetStrategySelectorGUI' button is what you have to press to achieve this, and the window you get is shown in Figure 11.

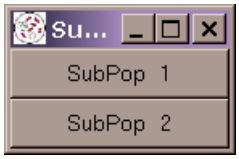

Figure 9 — The Subpopulation array window that appears when you click on the 'clickMeToGetSubPopulationArray' button on the Parameter window. There is one button from 1 to nSubPops as entered on the Parameter window.

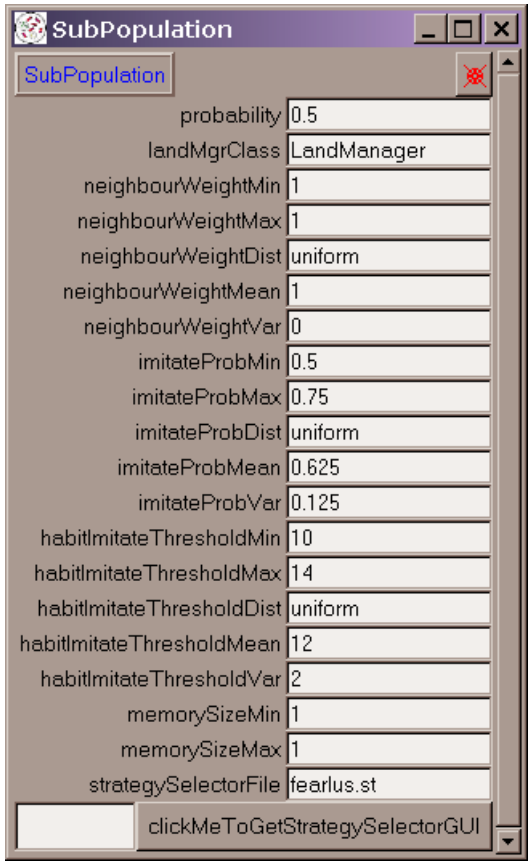

Figure 10 — The Subpopulation parameter entry window.

To be absolutely clear, you have to get the Subpopulation and Strategy selector GUIs for each Subpopulation in separate windows, and enter all the details. If you are intending to use several Subpopulations, that's a lot of windows, and a lot of entering. If you are entering all that data on the GUI, then you might as well be putting it in files using a text editor, and then you can use it again in a later run.

One other point worth mentioning about GUI mode is that the maxYear parameter behaves differently in GUI mode than it does in batch mode. In batch mode, maxYear is necessary to specify when the simulation should terminate. In GUI mode, however, this is not required, as the 'Quit' button is there for you to exit at any time. If the infiniteTime parameter is 0, then the simulation will pause at maxYear. You can then click 'Next' or 'Start' to keep running, or 'Quit' to exit.

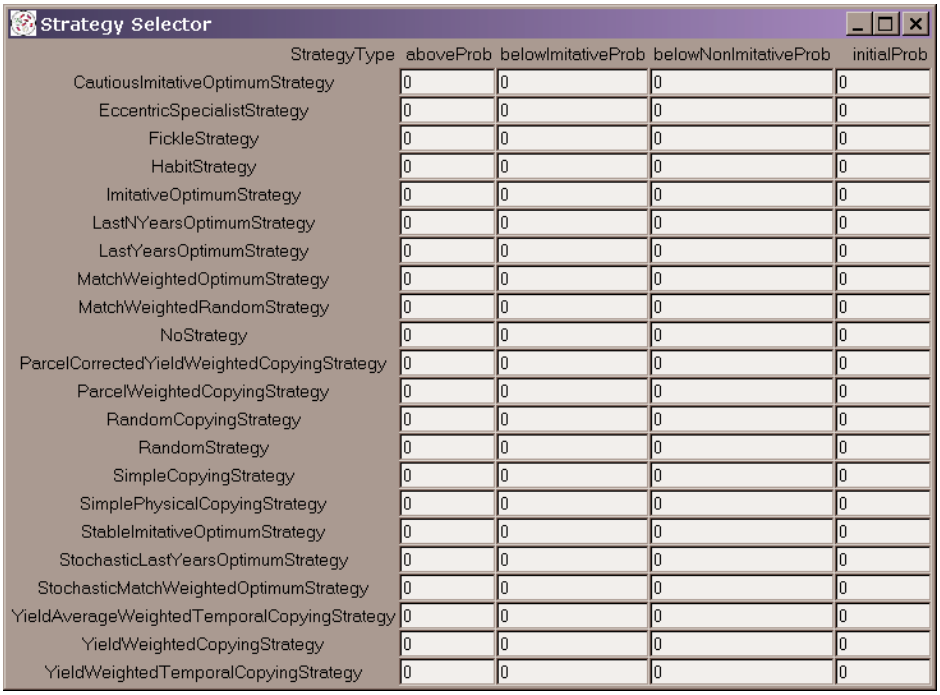

Figure 11 — The Strategy selector GUI. Each box contains a probability that the Strategy in the row will be used in the context in the column, which (from left to right) are the contentment, imitative, innovative and initial strategies. The probabilities in the columns must sum to 1.

7.1 Strategy displays

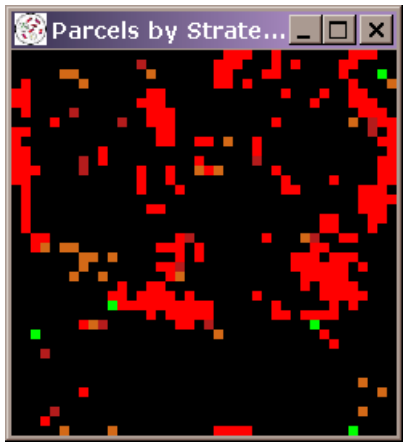

Figure 12 — The Strategy raster display. Each Land Parcel is given a colour according to the Strategy used to select its current Land Use.

Two parameters in the observer file relate to strategies: showStrategyColourKey and showStrategyRaster. The Strategy raster display is shown in Figure 12. It shows a different colour in each Land Parcel according to the Strategy used to select its current Land Use. (Bear in mind that Land Managers owning more than one Land Parcel may nevertheless use different Strategies to choose Land Uses on each Parcel. This depends on the contexts of the Land Parcels' Yields, and on how the Subpopulation for that Land Manager has been configured for the contexts.) If you want to know what Strategy is represented by which colour on the Strategy raster, you will need the Strategy colour key. It is therefore very unlikely that any observer file would have these two flags set to different values. Note also that the Land Parcel with co-ordinate (0, 0) is displayed at the top-left corner of the raster. This applies to all raster displays.

Figure 13 — The key to the colours shown on the Strategy raster.

7.2 Land Manager displays

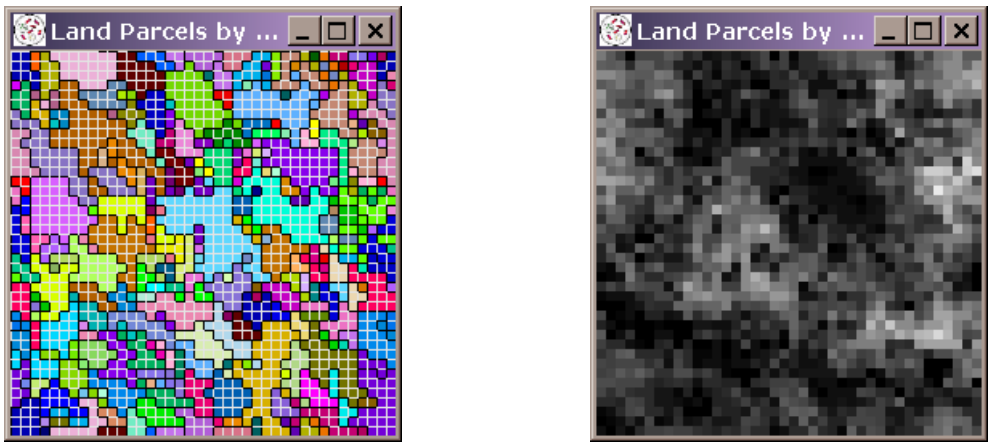

Figure 14 — The Land Manager (left hand side) and Land Manager change (right hand side) rasters. On the Land Manager raster, Land Parcels are coloured by the Land Manager owning them. As there is a 256 colour limit to the raster, in Environments with more than this number of cells, some Land Managers can end up with the same colour. To clarify things, a black boundary is drawn between cells owned by different Land Managers, and a white boundary between cells owned by the same Land Manager. On the Manager change raster, cells are given a shade of grey according to how often they have changed Managers, with lighter shades indicating more changes.

The showManagerRaster and showManagerChangeRaster observer parameters are available to give a spatial display of Land Manager ownership boundaries, and of the relative number of times

a Land Parcel has changed Land Managers respectively. Examples of these rasters are shown in Figure 14. Right-clicking on a cell in the Land Manager raster brings up a window showing information about the Land Parcel, shown in Figure 15.

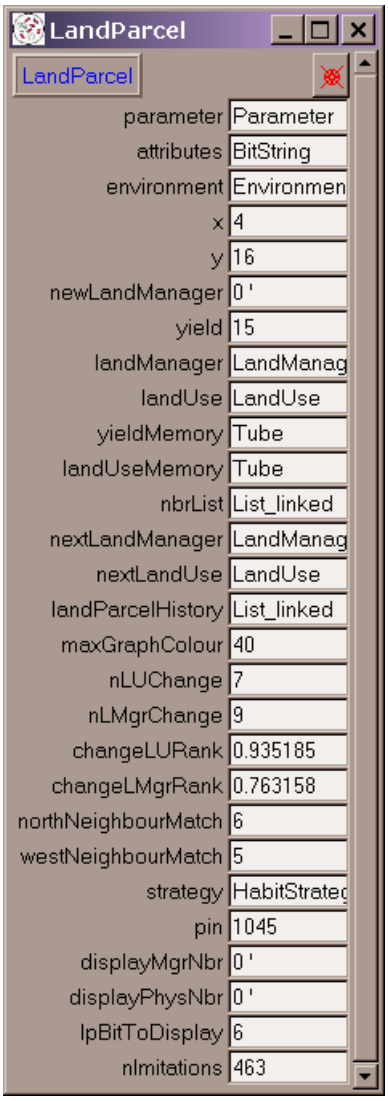

Figure 15 — The Land Parcel window obtained by right-clicking on a cell in the Land Manager raster.

7.3 Land Use displays

There are a number of displays that relate to Land Use. Just like the Land Managers, Land Uses can be displayed on a raster with the cells coloured by Land Use, and another raster exists to show the relative number of times Land Parcels have changed Land Use. The showUseRaster and showUseChangeRaster settings in the observer file control whether or not these displays will appear. The Land Use raster has two options for its display. If the showLPBitStringDiffs parameter is 1 in the observer file, then the borders of cells will be drawn with a thick line, using a shade of grey to indicate the number of matching Biophysical Properties bits between the two Parcels sharing the border. These lines will not be shown if the parameter is zero. Left-clicking any cell in the Land Use raster causes the cell's neighbourhood to be shown in the next cycle, with a grey cross drawn on the cell clicked. Left-clicking again will make the neighbourhood disappear in the following cycle. The Land Use raster is shown in Figure 16.

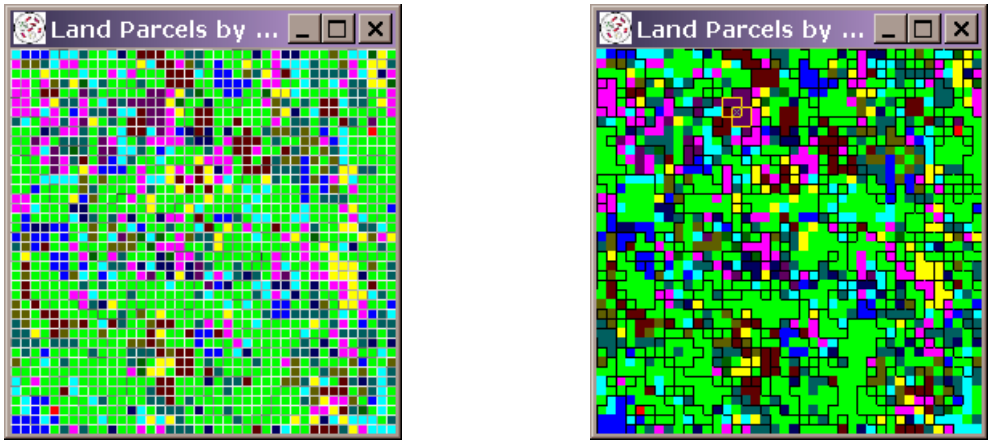

Figure 16 — The two options for the Land Use raster display. On the left, with showLPBitStringDiffs set to 1, the borders between cells are shaded according to how many bits match in the Biophysical Properties of the Land Parcels on either side (the darker the border, the more bits fail to match). On the right, with this parameter set to 0, a black line is drawn between Parcels owned by different Land Managers. Also illustrated is the effect of left-clicking on a cell (15th from the right, and 7th from the top). A yellow boundary is drawn showing the cells included in the physical neighbourhood of the cell clicked (in this case, Hexagonal with radius 1).

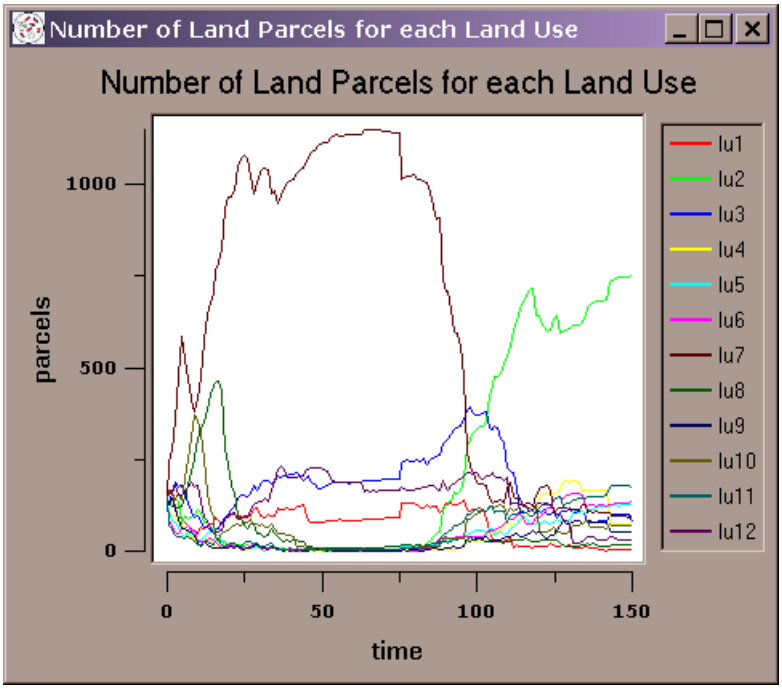

Figure 17 — The Land Use time-series graph.

In addition to the rasters, two graphs are available. One, a Land Use time-series graph reflects the historical state of the Land Use raster (Figure 17). To get this, set showUseGraph to 1 in the observer file. The other shows the Yield history (Figure 18), which is displayed if the observer file has showYieldGraph set to 1. On all time-series graphs, you can zoom by left-clicking in the top-left of the area you want magnified, and again in the bottom-right. To zoom out again, right-click in the graph. You can also emphasise a particular series by left-clicking on it in the legend. Left-clicking again de-emphasises. This is a useful facility when there are several traces on a graph and you want to highlight one of them to make it easier to follow.

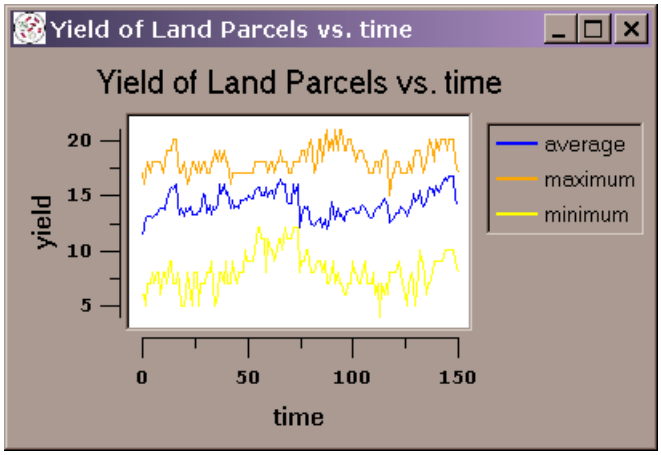

Figure 18 — The Yield history time-series graph.

7.4 Land Parcel display

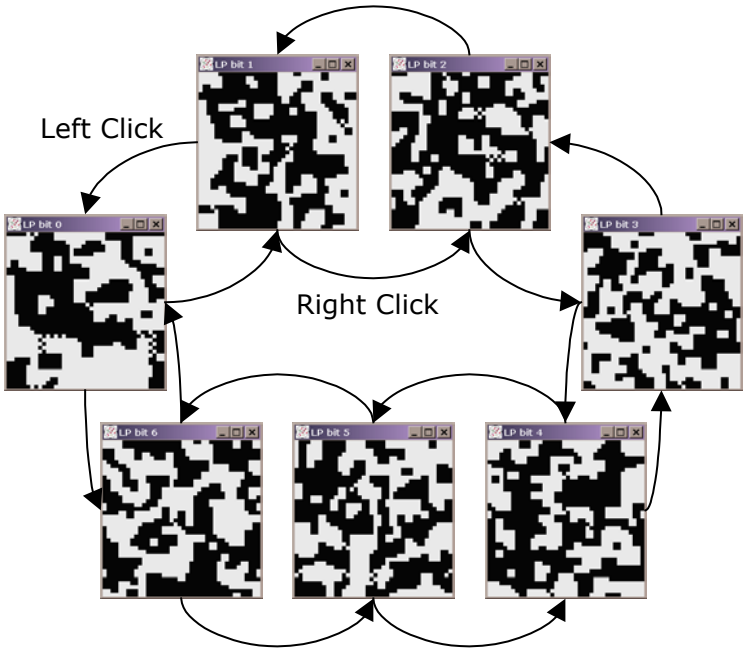

Figure 19 — The Biophysical Properties raster, which is displayed if the showLPBitStringRaster parameter is set to 1 in the observer file. This shows the spatial distribution of one bit of the Biophysical Properties at a time. Black is used for a value of 1, white for 0. The bits are numbered from 0 to one less than the Biophysical Properties bitstring length. Left-clicking decreases the number of the bit displayed, and right-clicking causes it to increase, wrapping round from the 0th bit to the maximum bit and vice versa. The bit displayed is shown in the title bar of the window.

7.5 Subpopulation displays

Four time-series graphs, showing Age, Wealth, population, and number of Land Parcels owned allow comparison of Subpopulations. With the exception of the population graph, if there is only one Subpopulation, minimum, maximum, and average sequences are generated over all Land Managers (Figure 22). The population graph is obtained by setting showPopulationGraph to 1 in the observer file (Figure 20). To get the Age graph, set showAgeGraph to 1 in the observer file (Figure 21).

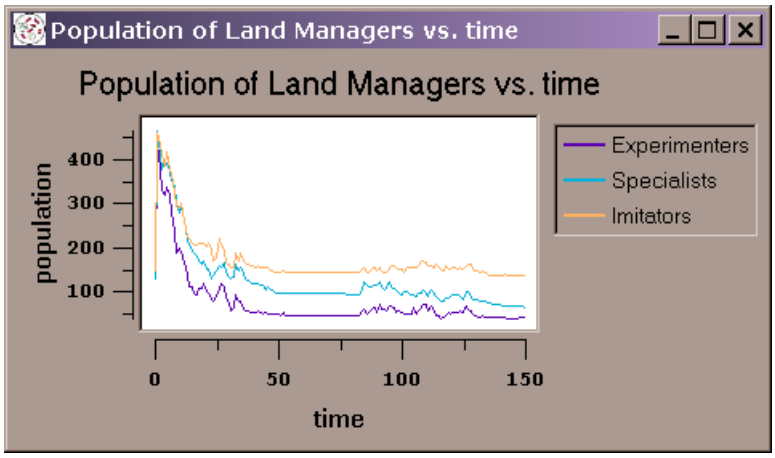

Figure 20 — Time-series graph showing the number of members in each of three Subpopulations during the course of a run.

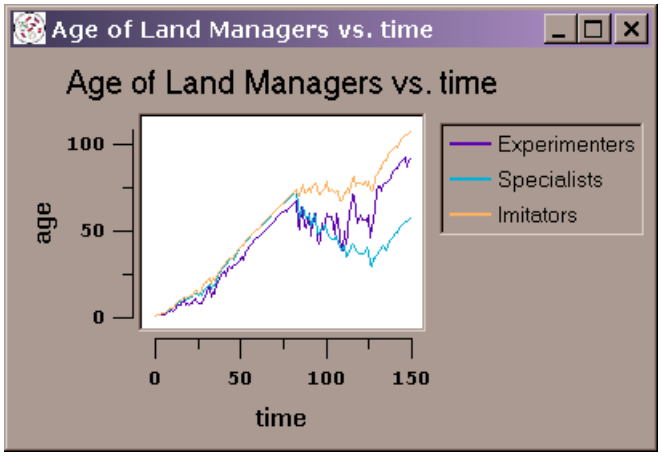

Figure 21 — Time-series graph of average Age of members of three Subpopulations.

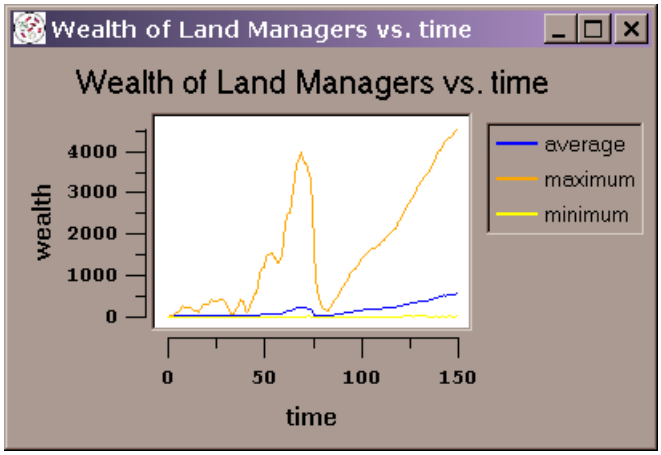

Figure 22 — An example Wealth time-series graph, which also illustrates the kind of graph shown for Age and number of Parcels owned when there is only one Subpopulation.

If there is more than one Subpopulation in the model, then a sequence for average Age of each Subpopulation is generated. If you give a label in the Subpopulation file, then that label will appear in the legend against the Subpopulation. To get the Wealth graph, set showWealthGraph to 1 in the observer file (Figure 22). Behaviour is similar to showAgeGraph. To get the number of Land Parcels owned graph, set showParcelsOwnedGraph to 1 in the observer file (Figure 23). This shows the total number of Land Parcels owned by members of each Subpopulation if there are two or more Subpopulations in the run.

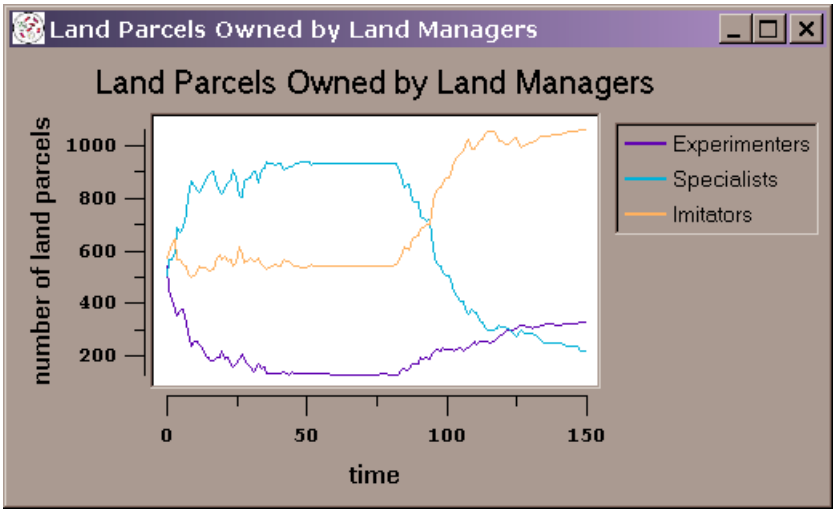

Figure 23 — Time-series graph of total Land Parcels owned by Land Managers belonging to each of three Subpopulations during the course of a run.

The Parcels owned graph is to the Subpopulation raster what the Land Use graph is to the Land Use raster. To get a raster showing Land Parcels coloured by the Subpopulation owning them, set showSubPopRaster to 1 in the observer file (Figure 24).

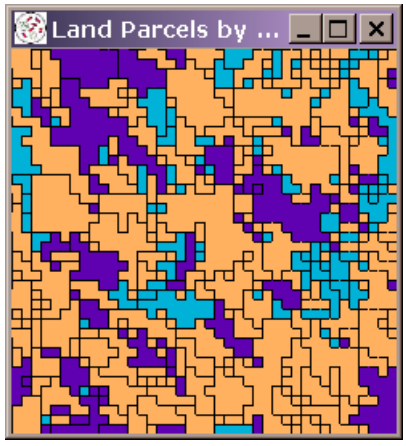

Figure 24 — Raster with Land Parcels coloured by the Subpopulation of the owning Land Manager. Boundaries between Land Managers are shown using black lines between cells.

It is also possible to get distributions of Land Manager parameters in each Subpopulation, where the Subpopulation parameters allow these to vary through either specifying a normal distribution with a non-zero variance, or specifying a uniform distribution with different minimum and maximum values. Distributions are available for the Imitation Probability (if showImitProbDist is set to 1 — Figure 25), Neighbourhood Weighting (if showNWeightDist is set to 1 — Figure 26),

and Aspiration Threshold (if showThresholdDist is set to 1 — Figure 27). The number of bins shown in all histograms is controlled by nHistogramBins.

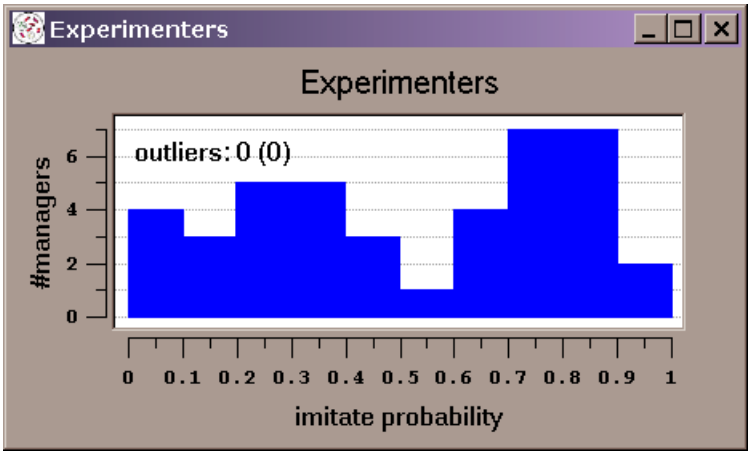

Figure 25 — Distribution of Imitation Probability in a Subpopulation whose Land Managers are created from a uniform distribution of this parameter. The graph shows the state of play after 150 cycles.

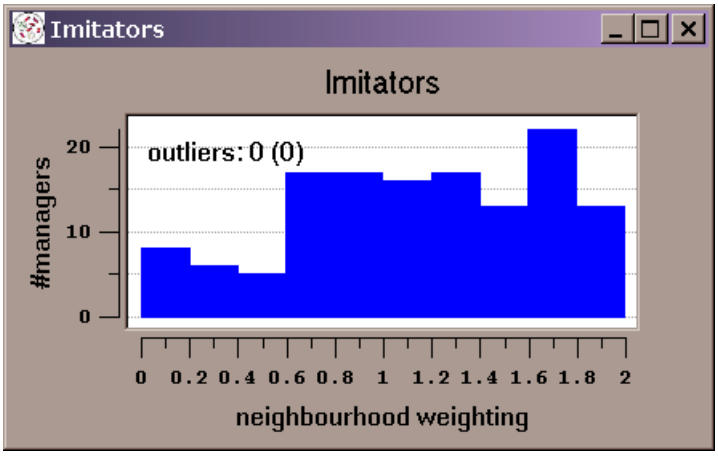

Figure 26 — Distribution of Neighbourhood Weighting after 150 cycles in a Subpopulation whose Land Managers are created with initial value of this parameter from a uniform distribution between 0 and 2.

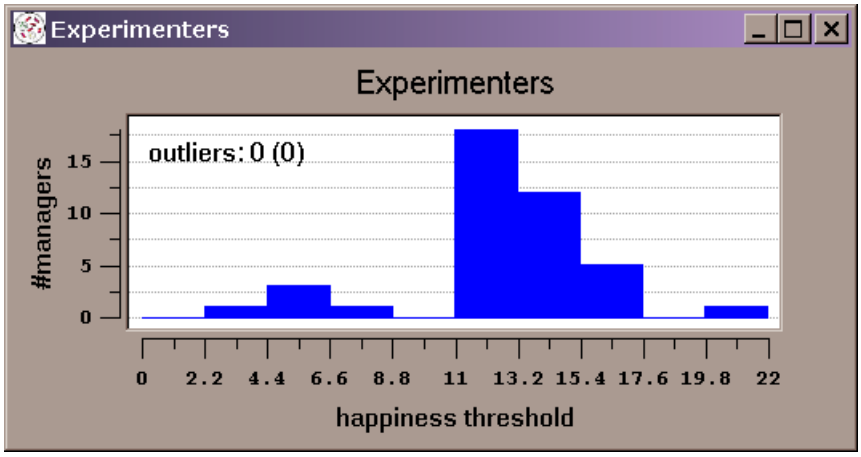

Figure 27 — Distribution of Aspiration Threshold after 150 cycles, in a Subpopulation whose Land Managers are created with a uniform distribution of this parameter between 0 and 22 (the Land Use bitstring length in this run was 22).

8 Output

There are three forms of output the model can be made to generate. With the -D option, various debugging messages will be written to stdout, which can be useful for checking the inner workings of a number of key methods in the model. The debugging output is not overly well structured, however, making it difficult to reproduce what went on in the model automatically. The history output is designed to have a more structured output, aimed for processing with a spreadsheet application. To get history output, give the -h option on the command line. With history output, however, the information obtained, though potentially voluminous, is limited to only certain properties of key objects in the model. It was this that led to the development of the report outputs, designed to provide a flexible programming environment that allowed reports to be created with structured output focussed on the particular information required. The downside being, of course, that you have to program them yourself if none of the existing reports provide the information required.

8.1 History

History output is deprecated somewhat by the advent of reports, and, whilst the output can be obtained easily, some features do not quite function as advertised. In batch mode, history will be output to a single file specified using the -h option. The maxHistoryLength and dumpHistory parameters are ignored.

In GUI mode, things are more complicated. If the saveDumpedHistoryParameter is set to 1 in the observer file, then a history will be created every maxHistoryLength Years regardless of the setting of the dumpHistory parameter. If you give the -h option on the command line, the history will be saved to the filename you specify (with a few caveats — see below), otherwise it will be saved to 'fearlus-history.txt' by default. If the saveDumpedHistoryParameter is 0 in the observer file, the -h option is ignored[*], and if you want any history output, then set the historyFileName parameter in the ObserverSwarm GUI to the name of the history file you want to use (be sure to hit return after editing), and click on the 'writeHistory' button. A history file will then be created, but only if you *didn't* give a -h option on the command line! If you did, a message is written to stdout saying "History will be written when you quit", but it won't be.[**]

The name of the file to which the history is saved is determined from what you give the -h option (or enter in the historyFileName field in the ObserverSwarm GUI) as follows:

1. If the filename does not end with '.txt', then add this string to the end of the filename.
2. If the file exists, then insert a 5 digit number between the terminating .txt and the rest of the name, starting at 00001 and incrementing in steps of 1 until a non-existing file name is found.

The history file is designed to be readable by a spreadsheet. All fields are separated by tabs. The contents of the file are divided into five sections:

(i) *Parameters*. The same format for writing the parameters is used here as in the Report output. Refer to section 0 for more details.
(ii) *Climate and Economy*. The bitstrings for the Climate and Economy are specified for each Year of the history.

[*] This is arguably a bug…
[**] … and so is this. The reason for both bugs is the same: Clicking on the Quit button in Swarm 2.1.1 no longer returns control to main.m, where, after running the top-level Swarm, the history file is written if specified on the command line with the -h option. In the earlier version of Swarm used to build the model when we did write history output, this worked. The simulation is stopped differently in batch mode, which explains why it works there in the current version of Swarm. This bug is unlikely to be fixed because (a) we don't use history file output so much any more, and (b) you can still get it if you want it.

(iii) *Land Parcels*. The Yield, Land Use, owning Land Manager, Strategy used to select the Land Use, X and Y co-ordinates, and Biophysical Properties are specified for each Year of the history.

(iv) *Land Uses*. The number of Parcels using the Land Use, and the match and 'don't care' bitstrings are specified for each Year of the history.

(v) *Land Managers*. The Subpopulation, number of Parcels Gained, Age, Wealth (in a column headed 'Barn'), Neighbourhood Weighting, Neighbourhood Noise, Aspiration Threshold (in a column headed 'Habit Imitation Yield Threshold'), Imitation Probability, Initial Strategy, Contentment Strategy (in a column headed 'Above Habit Threshold Strategy') , Imitative Strategy, and Innovative Strategy (in a column headed 'Below Habit Threshold Non-Imitative Strategy) are specified for each Year of the history. Details for Land Managers who lost all their Land Parcels during the period of the history are also provided, and are listed as 'Dead Manager' in the Type column.

This information is deemed sufficient to reconstruct the bare bones of a simulation run: Who owned what Parcels, what Land Uses they chose for them, how they chose those Land Uses and how much Yield they got. Even so, the amount of data generated can get unmanageably large (especially in Environments with several Land Parcels, or that are run for many Years), whilst still perhaps not providing sufficient detail to get all the information one might require.

8.2 Reports

The report software environment was created to provide a flexible infrastructure for users to create their own reports — generating an efficient set of outputs in the sense that the output generated is only that which is required. The list of reports compiled in with model0-6-4 is given in Table 5. Detail on creating your own reports is provided in section 10.1.

To get report output, you need to create a report configuration file, the format of which is described in section 5.2. You then need to specify the configuration file on the command line using the -R option, and a name for report files with the -r option. The name of the file actually created corresponds to the argument for the -r flag in much the same way as the history file name corresponds to the -h flag (see section 8.1), though with reports, the -a flag can be specified to cause the reports to be appended to an existing file. (The '.txt' suffix will still be enforced, however.)

The report output is designed to be highly structured, making it easy to parse using appropriately written software. It is also intended to be readable with spreadsheet applications (using a tab delimiter as the history output). The output consists of two sections — the parameters and the report itself. The parameters section begins with the line 'BEGIN<tab>Parameters', and includes the following information:

- The version of the model (in this case model0-6-4).
- The path used to the executable command.
- The version of Swarm.
- The real and effective user IDs.
- The name, operating system, and CPU architecture of the machine running the model.
- The date the model was run.
- The seed(s) for the simulation.
- Full details of the parameter settings, including the model, Subpopulations, and Climate and Economy toggle probabilities.

The parameter section then ends with the line 'END<tab>Parameters'.

Report	Description	Parameters
ClimateBitStringReport	Shows the Climate bitstring.	-
ClumpinessReport	Shows the mean and median number and proportion of bits in the Biophysical Properties bitstring with the same value, over all pairs of Moore-neighbouring Land Parcels in the Environment.	Histo (flag — default False): Display a histogram of the distribution of the number of neighbours with *x* matching bits in their Biophysical Properties bitstring.
EconomyBitStringReport	Shows the Economy bitstring.	-
LandUseBitStringReport	Shows all Land Use match and 'don't care' bitstrings.	-
LandUseReport	Shows the number of Land Parcels using each Land Use.	-
LockInReport	If there has been a change in the truth of the statement "All Land Parcels are using the same Land Use" this Year, then give a message to that effect.	-
MeanSubPopParamParcelReport	Displays the mean value of the Neighbourhood Weighting, the Imitation Probability, the Aspiration Threshold and the Memory Size of the Land Managers owning each Land Parcel. This mean is over the Land Parcels, so Land Managers owning *n* Land Parcels will be counted *n* times.	-
ParcelBitStringReport	Shows all Land Parcel Biophysical Properties bitstrings.	-
ParcelSubPopReport	Shows the number of Land Parcels owned by Land Managers of each Subpopulation	-
SubPopDeathReport	Shows the number of Land Managers from each Subpopulation that have lost all their Land Parcels this Year.	-

Table 5 — The reports available in model0-6-4, what they do, and any options they take

Following the parameter section, the output from reports is given for each Year in which the configuration file specified a report to be made. The format of the output for each Year is as detailed below:

```
BEGIN<tab>Report for end of year:<tab>Year of report
BEGIN<tab>Report class name
                                Report output goes here
END<tab>Report class name
BEGIN<tab>Another report class name
                                Another report output goes here
END<tab>Another report class name
                                Any other reports for this Year are similarly delimited by BEGIN
                                and END sections
END<tab>Report for end of year:<tab>Year of report
```

8.3 Debugging

The debugging output provides the capacity to give very detailed information about the progress and inner workings of various parts of the model. The following gives more information on what the output generated by each of the options given to the -D flag is likely to be. Any of these options can be given to the -D flag in any order. For example, to get debugging information from Land Parcels and Land Managers, give -D PM on the command line. The output is not particularly structured, and intended largely for human consumption, as it were, rather than software, though since each message will be consistent in the way it is printed, constructing a parser (or even just grepping the output!) is, of course, not precluded.

8.3.1 Land Parcels (P)

Giving the P option to the -D flag generates messages from LandParcel objects as follows:

- A message if the Land Use is the same from one Year to the next, indicating the Yield generated on the Land Parcel, and, if far enough into the simulation, the previous Yield and the Yield before that (as [Yield (t–1) [Yield (t–2)]]).
- A message when the Land Use is changed.
- A message when the Land Manager is changed.
- A message detailing the amount of Yield generated on the Land Parcel when this is calculated.

8.3.2 Land Uses (U)

Giving the U option to the -D flag generates a message from LandUse objects whenever the degree of match between their bitstrings and a Land Parcel, Climate and Economy is sought.

8.3.3 Land Managers (M)

Giving the M option to the -D flag generates messages from LandManager objects as follows:

- What new Land Use they have chosen for a Land Parcel and the Strategy used.
- The initial Land Use selected and Strategy used.
- Messages indicating whether or not the Manager must put Parcels up for sale. If they do have to put some up for sale, which Parcels have been sold, what their Wealth is, and whether they have had to sell them all.
- What Land Parcels the Land Manager has bought.
- Any change in the Neighbourhood Weighting of a Land Manager.

8.3.4 Land Allocator (A)

Giving the A option to the -D flag generates messages from the LandAllocator object as follows:

- When a new Land Manager is created, a message indicating the Parcel they are assigned to.
- A number of messages when transferring Parcels, indicating whether there are any to transfer in the first place, and if there are, whether a new Land Manager has been created to own any of them and in general who the new owner of the Land Parcel is.
- A message when a Land Manager is being removed from the simulation, having sold all their Land Parcels, or if there are no Land Managers to remove that Year, a message to that effect.

8.3.5 Environment (E)

Giving the E option to the -D flag generates some messages from the Environment object as follows:

- A message informing that Yield is being calculated.
- A message when data in any Economy or Climate file specified has run out, and the bitstrings will henceforth be generated using toggle probabilities.
- The Climate and Economy bitstrings each year.
- The number of colours left in the colour map to distribute among the Land Uses (only relevant in GUI mode).
- The Land Use match and 'don't care' bitstrings on creation thereof.
- The Land Parcel Biophysical Properties bitstring on creation thereof.
- The Land Parcel Biophysical Properties bitstrings after clumping.
- A message indicating the file the Biophysical Properties are being loaded from and the bitstrings loaded in, if appropriate.
- A message indicating the file the Land Use bitstrings are being loaded from and the bitstrings loaded in, if appropriate.

8.3.6 Core (c)

Giving the c option to the -D flag generates messages from all kinds of objects as indicated below. The volume of data generated is quite large, so think carefully before using this option. Some of the messages involve details of a selection process that is made at random. Here, typically, there are a number of things being selected among, and a score or weighting that determines their probability of selection. A random number is chosen uniformly between 0 and the sum of the scores, and this is used to select the option that will be applied. The message generated will usually show the options, the score, the cumulative score, the random number, and the option selected. An example (from the StrategySelector of a Subpopulation) showing how a non-imitative strategy is selected is given in Figure 28.

```
SS: selectBelowNonImitativeStrategy: Selection of below habit-imitation
    threshold non-imitative strategy achieved as follows:
        Strategy                          Probability (Cumulative)
                             NoStrategy  0 (0)
                         RandomStrategy  0 (0)
              LastNYearsOptimumStrategy  0.5 (0.5) <-- choice = 0.336573
            MatchWeightedOptimumStrategy  0.5 (1)
```

Figure 28 — Example debugging output showing how selection from a number of alternatives is typically printed (in this case, which Strategy to use for the innovative Strategy of a newly created Land Manager).

- CAVNT3Clumper, Same10PropClumper: Messages during the clumping process indicating the state of the Biophysical properties bitstrings at regular intervals.
- LandAllocator: Details on the list of Managers eligible to buy a Parcel during the Land Parcel transfer process.
- LandAllocator: Details on how the new owner of a Land Parcel was selected.
- LandAllocator: Details on how the Subpopulation of a new Land Manager was selected.
- LandManager: Details on the context of a Land Use decision (i.e. contentment, imitative or innovative).
- LandManager: The Yield gained from each Land Parcel and the consequent increase in Wealth.
- SelectUseBucket: Details on how a choice of new Land Use is made given a set of scores created by the Strategy object.
- StrategySelector: Details on how the Strategy assigned to each context is chosen for each Land Manager created.

- StrategySelector: A message indicating the file from which the Strategy selection probabilities have been loaded, and the contents of that file.

A number of messages are also generated from various Strategy objects, giving details on the mechanism of the choice made.

8.3.7 Inner Core (i)

Think carefully before using the i option to the -D flag on the command line, particularly when clumping using the Same10PropClumper, as this generates a vast amount of information. The messages from the i option are detailed below:

- LandManager: When a Land Manager has to sell Land Parcels, these are sold least Yield first. The output generated details this order, showing the Land Parcels of the Land Manager sorted in ascending order of Yield.
- LandParcel: When drawing the physical neighbours of a Land Parcel on a raster, a message is printed indicating that the Parcel has been selected for this treatment, and a number of other messages are displayed showing whether various Parcels are within the physical neighbourhood of the selected Parcel.
- LandUse: A breakdown of the match calculation between a Land Use and the Biophysical Properties, Climate and Economy.
- LandUse: A message each time a Strategy changes the score of a Land Use.
- Same10PropClumper: A message each time a bit of a Biophysical Properties bitstring is considered for swapping with that from another Land Parcel, showing how this would affect the clumpiness of that particular bit over the Environment as a whole.
- Same10PropClumper: A message indicating when a bit has been swapped between two Land Parcels' Biophysical Properties bitstrings.

A number of messages are also generated from the Strategy objects, giving further details on the mechanism of the choice made.

8.3.8 ObserverSwarm (o)

Giving the o option to the -D flag generates messages from the ObserverSwarm object as follows:

- A message indicating that the parameters are being loaded in from the specified file.
- A message indicating the number of colours that have been successfully allocated to the main colourmap. (This dates back to a time when the X terminals we were using had only a limited number of colours that could be allocated by all applications, and those available to FEARLUS depended on what other applications had allocated.)

8.3.9 ModelSwarm (m)

Giving the m option to the -D flag generates messages from the ModelSwarm object as indicated below. Note that this is a lower case 'm', to avoid a clash with Land Managers.

- A message detailing the parameters loaded in to run the model with (same format as history and report).
- A message informing that the Land Allocator is being created.

8.3.10 Neighbourhood (n)

Giving the n option to the -D flag generates messages relating to neighbourhood as indicated below:

- During initialisation, a grid showing the physical neighbourhood of each cell, and some information on how it was derived. More detailed messages about physical neighbourhood construction can be obtained through giving the c option to the -D flag in addition to the n option.
- For the remainder of the run, a grid showing, for each Land Use decision, the set of parcels that were consulted in making that decision and the number of times they were consulted.

8.3.11 Bitstring (b)

Giving the b option to the -D flag generates messages relating to bitstrings as indicated below:

- A break down of the method for calculating the number of 1s in a bitstring.
- A break down of the method for computing the degree of match between two bitstrings.

9 Strategies

This section gives more detail on the algorithms used to select a Land Parcel by various Strategies, than was given in Table 3. Note that many of the imitative Strategies do a little more than their name implies — the score calculated is often affected by the number of times each Land Use appears in the social neighbourhood. Thus, a Land Use with a low score in each individual Parcel could end up being chosen simply because it appears more often in the neighbourhood than one with a high individual-Parcel score. Such imitative Strategies therefore make an implicit assumption that their neighbours are choosing good Land Uses.

9.1 Strategies following the ImitativeStrategy Protocol (see 10.2)

9.1.1 Cautious Imitative Optimum

This method chooses a new Land Use for a decision Parcel LP at random among the Land Uses with the highest score, where the score for each Land Use is determined as follows:

- Initialise scores for all Land Uses to 0.
- Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
  - Get the last Yield Y and Land Use LU of LPS.
  - Get the number of bits U in the Land Use bitstring.
  - Get the Biophysical Properties of LPS and determine the degree of difference D between LPS and LP. (This is the number of bits with different values in both bitstrings.)
  - Compute the expected Yield $E_{LU}(Y_{LP})$ and variance $Var_{LU}(Y_{LP})$ of LU on LP using equations [1] and [3] below*:

$$E_{LU}(Y_{LP}) = \frac{\sum_{i=0,Y} (Y + D - 2i)^{D} C_i \, {}^{U-D}C_{Y-i}}{{}^{U}C_{Y}} \quad [1]$$

$$E_{LU}(Y_{LP}^2) = \frac{\sum_{i=0,Y} (Y + D - 2i)^2 . {}^{D}C_i \, {}^{U-D}C_{Y-i}}{{}^{U}C_{Y}} \quad [2]$$

$$Var_{LU}(Y_{LP}) = E(Y_{LP}^2) - [E(Y_{LP})]^2 \quad [3]$$

* The term ${}^{n}C_{r}$ means $n!/(r!(n-r)!)$.

    - If the score for LU has not been set, then set it to $E_{LU}(Y_{LP})$ and save $Var_{LU}(Y_{LP})$. Otherwise, if $Var_{LU}(Y_{LP})$ is less than the currently saved value for LU, set the score to $E_{LU}(Y_{LP})$ and save the new variance.
- Loop through all Land Parcels LPN in the social neighbourhood of LM.
    - Get the last Yield Y and Land Use LU of LPN.
    - Get the number of bits in the Land Use bitstring U and the degree of difference D between LP and LPN in the Biophysical Properties bitstrings.
    - Compute the expected Yield and variance as before, and update the score as before.

This algorithm chooses a Land Use based on the greatest expected Yield of the neighbouring Land Use where that expectation has the greatest certainty (minimum variance). It will choose a high-expected-Yield Land Use with low certainty (i.e. high variance) over a low-expected-Yield Land Use with high certainty, however, so it's probably not strictly accurate to call this a cautious Strategy. To implement this properly, however, we'd need another parameter in the Subpopulation indicating how risk-averse the Land Manager is, which would mean an extension to the ontology.

Note that with more than 24 Land Use bits, this strategy will generate invalid results due to integer overflow problems.[*]

9.1.2 Habit

Retain the same Land Use on the Land Parcel as was used the previous Year.

9.1.3 Imitative Optimum

This algorithm computes the scores in a similar way to Cautious Imitative Optimum, except that it does not calculate the variance. The algorithm chooses a Land Use at random among those with the maximum score, where the score is computed as follows:

- Initialise scores for all Land Uses to 0.
- Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
    - Get the last Yield Y and Land Use LU of LPS.
    - Get the number of bits U in the Land Use bitstring.
    - Get the Biophysical Properties of LPS and determine the degree of difference D between LPS and LP. (This is the number of bits with different values in both bitstrings.)
    - Compute the expected Yield $E_{LU}(Y_{LP})$ of LU on LP using equation [1] above.
    - If the score for LU has not been set, then set it to $E_{LU}(Y_{LP})$, otherwise ignore this Parcel.
- Loop through all Land Parcels LPN in the social neighbourhood of LM.
    - Get the last Yield Y and Land Use LU of LPN.
    - Get the number of bits in the Land Use bitstring U.
    - Get the Biophysical Properties bitstring of LPN and mutate it according to the Neighbourhood Noise.
    - Calculate the degree of difference D between the Biophysical Properties LP and the mutated Biophysical Properties of LPN.
    - Compute the expected Yield as before, and multiply it by the Neighbourhood Weighting. If the score for the LU has not been set, then set it to this product, else ignore this Parcel.

Note that with more than 24 land use bits, this strategy will generate invalid results due to integer overflow problems.

[*] This applies to a Sun 64-bit architecture. On PCs the maximum number of Land Use bits could be less.

9.1.4 Parcel Corrected Yield Weighted Copying

This Strategy chooses a Land Use at random, weighted by a score which is calculated as follows:

- Initialise scores for all Land Uses to 0.
- Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
  - Get the last Yield Y and Land Use LU of LPS.
  - Get the Biophysical Properties of LPS and determine the degree of match M between LPS and LP. (This is the number of bits with the same value in both bitstrings.)
  - Add Y × M to the score for LU.
- Loop through all Land Parcels LPN in the social neighbourhood of LM.
  - Get the last Yield Y and Land Use LU of LPN.
  - Get the Biophysical Properties bitstring of LPN and mutate it according to the Neighbourhood Noise.
  - Calculate the degree of match M between the Biophysical Properties LP and the mutated Biophysical Properties of LPN.
  - Add Y × M × Neighbourhood Weighting to the score for LU.

9.1.5 Parcel Weighted Copying

This Strategy chooses a Land Use at random, weighted by a score which is calculated as follows:

- Initialise scores for all Land Uses to 0.
- Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
  - Get the Land Use LU of LPS.
  - Get the Biophysical Properties of LPS and determine the degree of match M between LPS and LP. (This is the number of bits with the same value in both bitstrings.)
  - Add M to the score for LU.
- Loop through all Land Parcels LPN in the social neighbourhood of LM.
  - Get the Land Use LU of LPN.
  - Get the Biophysical Properties bitstring of LPN and mutate it according to the Neighbourhood Noise.
  - Calculate the degree of match M between the Biophysical Properties LP and the mutated Biophysical Properties of LPN.
  - Add M × Neighbourhood Weighting to the score for LU.

9.1.6 Random Copying

Choose a new Land Use (i.e. one not currently applied to the Land Parcel) at random from the set of Land Uses appearing in the social neighbourhood. If all Land Uses in the social neighbourhood are the same, keep the same Land Use. If the neighbourhood weighting is zero, then choose a Land Use at random from the set of Land Uses currently being used on the Land Manager's own Land Parcels.

9.1.7 Simple Copying

Choose a Land Use at random, weighted by a score calculated as follows:

- Initialise scores for all Land Uses to 0.
- Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
  - Get the Land Use LU of LPS.
  - Add 1.0 to the score for LU.
- Loop through all Land Parcels LPN in the social neighbourhood of LM.
  - Get the Land Use LU of LPN.
  - Add Neighbourhood Weighting to the score for LU.

9.1.8 Simple Physical Copying

The Simple Physical Copying Strategy chooses a Land Use in the same way as the Simple Copying Strategy, but the physical rather than the social neighbourhood is used. That is, the set of Land Parcels examined are those belonging to the Land Manager and the physical neighbours of these Parcels.

9.1.9 Yield Average Weighted Temporal Copying

Choose a Land Use at random, weighted by a score calculated as follows:

- Initialise scores for all Land Uses to 0.
- Initialise counters for all Land Uses to 0.
- Loop i through the last T Years of data according to the Land Manager's memory.
  - Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
    - Get the Yield Y and Land Use LU of LPS for Year i.
    - Add Y to the score for LU.
    - Increment the counter for LU.
  - Loop through all Land Parcels LPN in the social neighbourhood of LM.
    - Get the Yield Y and Land Use LU of LPN for Year i.
    - Add Y × Neighbourhood Weighting to the score for LU.
    - Increment the counter for LU.
- For each Land Use, divide its score by its counter.

This Strategy is similar to Yield Weighted Temporal Copying Strategy, but it averages out the scores according to the number of times the Land Use appears in the social neighbourhood during the period of time examined.

9.1.10 Yield Weighted Copying

Choose a Land Use at random, weighted by a score calculated as follows:

- Initialise scores for all Land Uses to 0.
- Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
  - Get the last Yield Y and Land Use LU of LPS.
  - Add Y to the score for LU.
- Loop through all Land Parcels LPN in the social neighbourhood of LM.
  - Get the last Yield Y and Land Use LU of LPN.
  - Add Y × Neighbourhood Weighting to the score for LU.

9.1.11 Yield Weighted Temporal Copying

Choose a Land Use at random, weighted by a score calculated as follows:

- Initialise scores for all Land Uses to 0.
- Loop i through the last T Years of data according to the Land Manager's memory.
  - Loop through each Land Parcel LPS owned by the Land Manager LM making the decision.
    - Get the Yield Y and Land Use LU of LPS for Year i.
    - Add Y to the score for LU.
  - Loop through all Land Parcels LPN in the social neighbourhood of LM.
    - Get the Yield Y and Land Use LU of LPN for Year i.
    - Add Y × Neighbourhood Weighting to the score for LU.

This Strategy is the Yield Weighted Copying Strategy, but looks back over a longer period of time than just the last Year.

9.2 Strategies following the NonImitativeStrategy Protocol (see 10.2)

9.2.1 Eccentric Specialist

The algorithm for choosing the Land Use is as follows:

- The first time this Strategy is asked for a Land Use, choose one at random from all Land Uses, remember that chosen, and return it as the Land Use selected.
- Thereafter, return the Land Use chosen the first time.

Land Managers using this Strategy have a favourite Land Use chosen at random when they first decide a Land Use, which they always use thereafter.

9.2.2 Fickle

The algorithm for choosing the Land Use is as follows:

- The first time this Strategy is asked for a Land Use this Year, choose one at random, remember it, and return it as the Land Use selected.
- For all other Parcels on which the Land Manager has to decide a Land Use using this Strategy this Year, return the remembered Land Use.

Land Managers using this Strategy use the same Land Use chosen at random on all Land Parcels they own (whose context means they use this Strategy) each Year.

9.2.3 Last N Years' Optimum

This Strategy chooses deterministically among those Land Uses with the highest score. It does so in such a way that *all* Land Managers using this Strategy will have the same preference in the event of equal maximum score. The score is computed according to the total Yield each Land Use would have got had it been used continuously on the decision Parcel over the last N Years, where N is the memory size of the Land Manager.

9.2.4 Last Year's Optimum

The Land Use decision is made in exactly the same way as Last N Years' Optimum, but it only looks at the previous Year.

9.2.5 Match Weighted Optimum

Just like Last N Years' Optimum, this strategy chooses deterministically in the same way for all Land Managers among those Land Uses with the maximum score. This score is the degree of match between the Biophysical Properties and the Land Use. That is, the effect of the Climate and Economy on the Yield is ignored, and the Land Manager chooses a Land Use to maximise the guaranteed Yield based only on the unchanging Biophysical Properties.

9.2.6 Match Weighted Random

This Strategy uses the same scoring mechanism as Match Weighted Optimum, but rather than choosing the Land Use with the best score, it chooses at random, weighted by the score. For example, if there are four Land Uses with score 2, 6, 7, and 5, then they are selected with probability 0.1, 0.3, 0.35 and 0.25 respectively.

9.2.7 Random

Choose a Land Use at random.

9.2.8 Stochastic Last Year's Optimum

As Last Year's Optimum Strategy, but when two or more Land Uses have the same maximum score, choose at random between them rather than deterministically.

9.2.9 Stochastic Match Weighted Optimum

As Match Weighted Optimum Strategy, but when two or more Land Uses have the same maximum score, choose at random between them rather than deterministically.

10 Advanced features

Model 0-6-4 has been designed to allow new reports and Land Manager Strategies to be moderately easy to create and plug in to the system. As model 0-6-4 is programmed in Objective-C, if you want to add new Strategies or reports, you will have to do so using this language, which the following assumes you are familiar with. The design is based on the use of protocols, which means your new Strategy and report classes have a number of methods they should implement.

Both Strategies and reports access data from the model without changing it. There is therefore a section (10.3) indicating the information accessible from objects that you might want to use. If methods do not exist to get the information you want, further hacking may be required in the target objects.

Finally, if you do write Strategies and reports, we would like to invite you to send them to us so we can consider putting them in future versions of FEARLUS, or making them available for other users to include.

10.1 Creating new reports

All reports must follow the Report protocol, which is contained in Report.h. Reports are also subclassed from SwarmObject. Your main objectives in creating a new report are to:

- decide what information the report will print
- make sure the report output format is consistent with other reports
- think about whether the report will have any options or flags
- create the report interface file
- identify how you will obtain the information you need in the report from objects in the model
- create the report implementation file
- add the report to the Makefile and recompile

The report output format is intended to be readable from a text file into a spreadsheet package, and to be easily parsed by any bespoke software designed to do so. Each report will typically contain a number of lines of output, each line consisting of a description of a value of interest that the report is providing, followed by a tab, followed by the value of interest as calculated by the report. Where some value of interest has, say, a number of components to it, or alternative ways of expressing it, these components could be included on the same line, separated by tabs, and possibly including tab-separated descriptions if this is not obvious from the main description. For example:

```
Wealth mean:<tab>104.3<tab>median:<tab>67
```

or:

```
Land use<tab>Match bitstring:<tab>01110<tab>Don't care \
  bitstring<tab>00000
```

10.1.1 Creating the report interface file

The following is a template report interface file, which should be named MyReport.h, where hereafter, MyReport is the name of the new report class. Note that all reports should be given a classname that ends with "Report".

```
#import <objectbase/SwarmObject.h>
#import "Report.h"

@class ModelSwarm, Parameter;
/* @class list for any other FEARLUS classes in the instance
   vars or method arguments of this class */

@interface MyReport: SwarmObject <Report> {
  Parameter *parameter;
  ModelSwarm *model;
  id <List> fixedYears;
  id <List> repeatYears;
  /* Other instance variables you need for the report, if any */
}

+(id <Report>)create: aZone;
-(void)setModelSwarm: (ModelSwarm *)m
       andParameters: (Parameter *)p;
-(void)reportForYear: (unsigned) year toFile: (FILE *)fp;
-(BOOL)setOption: (char *)option toValue: (char *)value;
-(BOOL)setOptionFlag: (char *)option toValue: (BOOL)value;
-(void)setFixedYears: (id <List>)y;
-(void)setRepeatYears: (id <List>)y;
-(BOOL)reportingForYear: (unsigned)year;

@end
```

The model and parameter instance variables are your way in to access data about the model for the report. The +create: method is for you to create the MyReport object and initialise any instance variables. The –setModelSwarm:andParameters: method is for MyReport to receive the model and parameter instance variable values. The –reportForYear:toFile: method is the method used to print the report. This is where the main difference between MyReport and any other report class will lie. The –setOption:toValue: and –setOptionFlag:toValue: methods are provided to pass in any options or flags the report might need to set. In the –setOption:toValue: method, if the value argument is required to be a string to be saved, it will need to be strdup-ed or strcpy-ed to an instance variable. The address that value points to should not be regarded as being safe beyond the method call.

The –setFixedYears:, –setRepeatYears:, and –reportingForYear: methods are the same in each report class, and should be copied straight out of another report unchanged (except LockInReport, which does things a little differently). This is not the most elegant of requirements, and the reporting infrastructure design should be improved so that Reports subclass from an abstract class as well as implementing the Report protocol.

10.1.2 Creating the report implementation file

A template implementation file for MyReport would look like this (and should be named MyReport.m):

```
#import "MyReport.h"

#import "Parameter.h"
#import "ModelSwarm.h"
#import "FearlusArguments.h"
#import "Number.h"

/* #imports for any FEARLUS classes used in instance variables,
   method arguments, or local variables in this class */

@implementation MyReport

+(id <Report>)create: aZone {
  MyReport *r;

  r = [super create: aZone];
  /* creation of any instance variables if required */

  return r;
}

-(void)setModelSwarm: (ModelSwarm *)m
       andParameters: (Parameter *)p {
  /* declaration of any variables required in this method for
     instance variable initialisation */

  parameter = p;
  model = m;

  /* initialisation of instance variables if required */
}

-(void)reportForYear: (unsigned)year toFile: (FILE *)fp {
  /* your report code here */
  /* make sure you do any printing using fprintf(fp, … rather than
     printf(… */
}

-(BOOL)setOption: (char *)option toValue: (char *)value {
  /* if your report takes no options, then print an error message
     and exit, otherwise check option is legal and set the value.
     A typical example would look like this */
  if(strcmp(option, "thisOption") == 0) {
    thisOptionInstVar = atoi(value);    // type int
  }
  else if(strcmp(option, "thatOption") == 0) {
    thatOptionInstVar = strdup(value);  // type char * -- note use
                                        // of strdup.
  }
  /* else if … etc */
  else {
    fprintf(stderr, "Option %s is not a valid option for "
            "report %s in report configuration file %s\n",
            option, class_get_class_name([self class]),
            [FearlusArguments getReporterCFFile]);
                              // keep error messages informative
    abort();
  }
  return YES;
}
```

```
-(BOOL)setOptionFlag: (char *)option toValue: (BOOL)value {
  /* much like –setOption:toValue:, but all the options have
     type BOOL. */
  if(strcmp(option, "thisFlag") == 0) {
    thisFlagInstVar = value;
  }
  /* else if … etc */
  else {
    fprintf(stderr, "Flag %s is not a valid flag for report "
            "%s in report configuration file %z\n", option,
            class_get_class_name([self class]),
            [FearlusArguments getReporterCFFile]);
                              // keep error messages informative
    abort();
  }
  return YES;
}

/*** Don't change any of the following methods, but you do have to
     implement them ***/

-(void)setFixedYears: (id <List>)y {
  fixedYears = y;
}

-(void)setRepeatYears: (id <List>)y {
  repeatYears = y;
}

-(BOOL)reportingForYear: (unsigned)year {
  BOOL reportingYear;
  id inx;
  Number *n;

  reportingYear = NO;
  if(([fixedYears getCount] > 0)
     && ([(Number *)[fixedYears atOffset: 0] getUnsigned]
         == year)) {
    [[fixedYears removeFirst] drop];
    reportingYear = YES;
  }
  else {
    for(inx = [repeatYears begin: scratchZone], [inx next];
        [inx getLoc] == Member;
        [inx next]) {
      n = [inx get];
      if((year % [n getUnsigned]) == 0) {
        reportingYear = YES;
        break;
      }
    }
    [inx drop];
  }
  return reportingYear;
}

@end
```

In the –reportForYear:toFile: method, you will need to access data from the model, and some parameter data. This is discussed in more detail in section 10.3.

10.1.3 Adding the report to the Makefile

To get your report compiled in to the model, you will need to add it to the Makefile. To do this, open the Makefile in your favourite (non-PC) editor, and look for a line beginning "FEARLUS_REPORT_OBJECTS". Add MyReport.o to the end of this line. Run make in the model0-6-4 directory (where, of course, MyReport.h and MyReport.m have been created) to compile your report into the model.

You should find that MyReport can now be used in a report configuration file without complaint.

10.2 Creating new Strategies

Strategies all follow the Strategy protocol, and are subclassed from SwarmObject. In addition, you should also identify whether the your new Strategy is imitative (it only uses Land Uses that appear in the social neighbourhood), and whether it is historical (it examines data from previous Years). (So, all imitative Strategies are historical, because they look at what their neighbours have just done.) Four protocols are given to indicate this: ImitativeStrategy and NonImitativeStrategy, and HistoricalStrategy and NonHistoricalStrategy. All Strategies should specify that they follow one or other of the first pair, and one or other of the second. These protocols do not require any methods to be implemented, but act as a means of typing Strategies, and could be used as a way of verifying their suitability for use in a particular context. (This isn't done just now to keep things flexible.)

As section 9 indicates, most Strategies make use of some kind of scoring mechanism, and to provide a common mechanism for dealing with scores, the SelectUseBucket class is provided, though by no means is it necessary that you should use this. Looking at the algorithms for Strategies, it should also be clear that the template for a new Strategy will depend on whether it is imitative, and whether it uses memory.

When creating a new Strategy there are the following objectives:

- decide how your strategy will choose between Land Uses
- determine if it is imitative and if it is historical
- create the Strategy interface file
- choose a template that most closely matches what you are trying to do
- identify the information you will need from other objects and how it will be obtained
- create the Strategy implementation file
- update the Makefile and recompile

The ensuing sections cover this ground in more detail, and assume throughout that the new Strategy is called MyStrategy.

10.2.1 Strategy interface file template

The interface file should be created in a file called MyStrategy.h in the same directory as the model 0-6-4 source code .

```
#import <objectbase/SwarmObject.h>
#import "Strategy.h"

/* @class statement for any instance variables or method arguments
   using FEARLUS classes */

@interface MyStrategy: SwarmObject
  /* Now you have a protocol declaration that is one of these four
     according to what is appropriate for MyStrategy */
  <NonImitativeStrategy, NonHistoricalStrategy>
```

```
  <NonImitativeStrategy, HistoricalStrategy>
  <ImitativeStrategy, NonHistoricalStrategy>
  <ImitativeStrategy, HistoricalStrategy>
  /* End of the four options for protocol declaration */
  {
    Parameter *parameter;
    LandManager *lm;
    /* any other instance vars MyStrategy needs */
  }

/* if you require any other methods besides
   +create:withManager:andParameters: and -decideUseForLandParcel:
   then declare them here */

@end
```

10.2.2 Imitative Strategy implementation file template

The structure of the implementation file depends very much on what the imitative Strategy will be doing. Will it be looking at last Year's data only, or will it be using the Land Manager's memory to look back over a number of recent Years' data? Will it be using the physical or social neighbourhood? Will it be implementing neighbourhood noise or neighbourhood weighting? How will the choice be made — using a score, or some other way? (Section 10.2.4 deals with scoring Land Uses.) This section will work through the implementation file in stages, showing example code as you work through this minefield of options.

The beginning of the implementation file is, at least, less of a problem. Name it MyStrategy.m, and put it in the same directory as the model0-6-4 source.

```
#import "MyStrategy.h"
#import "Parameter.h"
#import "LandManager.h"
#import "LandUse.h"
#import "LandParcel.h"
#import "Environment.h"
#import "SelectUseBucket.h"            // If you are using scores
#import "BitString.h"             // If using neighbourhood noise

/* You will need to #import any other FEARLUS objects used in
   local variables or non-protocol-standard method arguments */

@implementation MyStrategy

+(id <ImitativeStrategy, HistoricalStrategy>)
           create: aZone
      withManager: (LandManager *)lmgr
    andParameters: (Parameter *)p {
  MyStrategy *obj;

  obj = [super create: aZone];
  obj->lm = lmgr;
  obj->parameter = p;
  /* initialisation of any other instance vars */
  return obj;
}
```

The Parameter object is passed in to give you access to all the model parameters, and the Land Manager is passed in to give you access to the Land Manager's settings and their neighbourhood. From this it should be clear that Land Managers get a Strategy object created for them

individually, and so you should think of the Strategy class you are creating as having instances that will belong to Land Managers on a one-to-one basis.

The only other method you have to create is the –decideLandUseForParcel: method, which is where the selection of a Land Use is made for the Parcel sent in as argument by the Land Manager owning this Strategy object. In an imitative Strategy, this method has the same basic structure:

- declaration of local variables
- initialisation of local variables
- possibly loop through memory
- loop through Land Manager's own Parcels and add scores
- loop through Land Manager's neighbouring Parcels and add scores
- select a land use based on the score
- tidy up (free memory, drop locally created objects)
- return the selected land use

The beginning of the method therefore looks like this:

```
-(LandUse *)decideLandUseForParcel: (LandParcel *)lp {
  id lpInx;
  int y, ymax;               // if you are looping through memory
  id <List> physList;   // if you are using physical neigbourhood
  id <List> socList;     // if you are using social neighbourhood
  id lmInx;              // if you are using social neighbourhood
  BitString *biophys;     // if you are using neighbourhood noise
  /* any other declarations you need */

  /* any initialisation you need */
```

If you are using the memory of a Land Manager, you might then want to proceed with a loop over this memory, inside which loops over the Land Manager's own and neighbouring Parcels will be nested. By no means is it a requirement to do this (it depends on how you want to handle memory), but if you do want to, your next few lines of code would look like this:

```
  ymax = [lm getMemorySize];
  for(y = 0; y < ymax; y++) {
    /* nested loops over Land Manager's own and neighbouring
       Parcels -- see text below */
  }
```

The ymax variable is used to save repeated message calls to the Land Manager to get the memory size, which improves performance.

Looping over the Land Manager's own Parcels is achieved like this:

```
  for(lpInx = [[lm getLandParcels] begin: scratchZone],
       [lpInx next];
      [lpInx getLoc] == member;
      [lpInx next]) {
    LandParcel *myParcel = [lpInx get];

    /* Land Use information gathered here */

    if(/* myParcel influences the choice of Land Use
          somehow (e.g. by affecting a score for the
          Land Use) */) {
```

```
      [myParcel incNImitations];
    }
  }
  [lpInx drop];
```

The information you might access depends on what your Strategy is doing. Section 10.3 contains information on how to access the information you require from the model, but just to be clear about the difference between Strategies using memory and those not, the following shows how to access information that can be accessed through the memory:

```
LandUse *lu = [anyParcel recallLandUseAgo: (unsigned)y];
unsigned yield = [anyParcel recallYieldAgo: (unsigned)y];
BitString *climate = [lm recallClimateAgo: (unsigned)y];
BitString *economy = [lm recallEconomyAgo: (unsigned)y];
```

The y argument to the various recall… methods is the number of Years back from the last Year you want data recalled, and corresponds to the y variable in the loop over the Land Manager's memory size earlier. Be prepared that the methods might return nil if the current Year is less than y. To get the same information in a Strategy not using memory, you would do the following (respectively):

```
LandUse *lu = [anyParcel getLandUse];
unsigned yield = [anyParcel getLastYield];
BitString *climate = [[anyParcel getEnvironment] getClimate];
BitString *economy = [[anyParcel getEnvironment] getEconomy];
```

Having considered the Land Uses in the Land Manager's own Parcels and their contribution to the Land Use decision, as an imitative Strategy you now need to consider the Land Uses in the neighbourhood. If you are using the social neighbourhood, you use two nested loops, one over the Land Managers in the social neighbourhood, and inside that, over the Land Parcels owned by those Managers. If you are using the physical neighbourhood, you obtain the list of physically neighbouring Land Parcels directly from the Land Manager owning the Strategy instance, and loop through them.

Thus, for the social neighbourhood, do this[*]:

```
socList = [List create: scratchZone];
[lm getSocialNeighbourList: socList];
for(lmInx = [socList begin: scratchZone], [lmInx next];
    [lmInx getLoc] == Member;
    [lmInx next]) {
  LandManager *nbrManager = [lmInx get];

  for(lpInx = [[nbrManager getLandParcels] begin: scratchZone],
        [lpInx next];
      [lpInx getLoc] == Member;
      [lpInx next]) {
    LandParcel *nbrParcel = [lpInx get];

    /* Land Use information gathered here */

    if(/* nbrParcel influences the choice of Land Use
          somehow (e.g. by affecting a score for the
          Land Use) */) {
      [nbrParcel incNImitations];
```

[*] If you look at the code for existing Strategies, you will see they use a different method for looping through the social neighbourhood than that shown here. The one shown here is better.

```
    }
  }
  [lpInx drop];
}
```

For the physical neighbourhood, do this:

```
physList = [List create: scratchZone];
[lm getPhysicalNeighbourList: physList];
for(lpInx = [physList begin: scratchZone], [lpInx next];
    [lpInx getLoc] == Member;
    [lpInx next]) {
  LandParcel *nbrParcel = [lpInx get];

  /* Land Use information gathered here */

  if(/* nbrParcel influences the choice of Land Use
        somehow (e.g. by affecting a score for the
        Land Use) */) {
    [nbrParcel incNImitations];
  }
}
[lpInx drop];
[physList drop];
```

If your strategy makes use of Neighbourhood Weighting or Neighbourhood Noise, then when gathering Land Use information inside the neighbourhood loops, you will need to do things in a slightly different way than you did for the Parcels owned by the Land Manager owning the Strategy instance. Neighbourhood Noise only applies if you are getting information about neighbouring Parcels' Biophysical Properties. This shows how you should apply Neighbourhood Noise:

```
biophys = [BitString create: scratchZone
                setBitCount: [parameter parcelBitStringSize]];
/* neighbourhood loop */ {
  LandParcel *nbrParcel = [lpInx get];

  [biophys setToCopyOf: [nbrParcel getAttributes]];
  [biophys mutateWithProbability: [lm getNeighbourNoise]];

  /* Land Use information gathered here */
}
[biophys drop];
```

How you apply Neighbourhood Weighting is up to you. The Neighbourhood Weighting is a double with an arbitrary range of values, with 0.0 meaning "I pay no attention to neighbouring data" and 1.0 meaning "I pay the same amount of attention to neighbouring data as I do to mine". Values greater than 1.0 could be taken to mean "Neighbouring data is more important than mine". Negative values are not currently allowed within the model, but could theoretically be taken to mean something like "I actively avoid what my neighbours are doing". Most Strategies using Neighbourhood Weighting compute some kind of score and use SelectUseBucket to tot up the scores and make a selection. They then apply the NeighbourhoodWeighting by multiplying scores for neighbouring Land Uses by the Neighbourhood Weighting. This would be achieved like this:

```
double score;

score = /* some function of Land Use information gathered */
  * [lm getNeighbourWeight];
```

Having looped through the Land Manager's Parcels and the neighbouring Parcels, you should now be in a position to make a selection of Land Use. Having done so, you should make sure you have dropped any objects created to free up their memory before returning the selected Land Use from the method. One technique, if you are concerned about making sure you have dropped everything, is to create a temporary memory zone in this method, allocate all objects created in this method to that zone and then drop the zone before returning. To do that, your method looks something like this:

```
-(LandUse *)decideLandUseForParcel: (LandParcel *)lp {
  id tempZone;
  LandUse *selection;
  /* other declarations */

  tempZone = [Zone create: scratchZone];
  /* other initialisations, all to tempZone */

  /* loops gathering Land Use information, indexes allocated
     to tempZone */

  /* Land Use selection */

  [tempZone drop];              // this is the only drop you need
  return selection;
}
```

If your Strategy implements any other methods (which is not really recommended — consider using static functions if you have commonly used code in the –decideLandUseForParcel: method), then implement them, and finally put the @end at the bottom of the implementation file.

10.2.3 Innovative Strategy implementation file template

Innovative Strategies are rather easier than imitative to implement. The main difficulty is deciding whether the Strategy is historical or not. This is not too much of a problem. Clearly, any innovative Strategy using memory is historical. Similarly, any Strategy accessing Climate, Economy, Yield, or Land Use data is historical, as these data always refer to the previous Year's settings at the time the Land Use decision is made. Accessing Biophysical Properties data is not historical, however. The purpose of discriminating between historical and non-historical Strategies is to determine which are suitable for use in the initialisation cycle, where no historical data are available for obvious reasons.

The beginning of the implementation file, which should be called MyStrategy.m and sit in the same directory as the model 0-6-4 source, looks like this:

```
#import "MyStrategy.h"
#import "LandManager.h"
#import "LandParcel.h"
#import "LandUse.h"
#import "Parameter.h"
#import "Environment.h"
#import "SelectUseBucket.h"            // if you are using scores

/* other #imports for instance variable and method argument
   classes that are not included above */

@implementation MyStrategy

+(id <NonImitativeStrategy, /*Non?*/HistoricalStrategy>)
```

```
            create: aZone
        withManager: (LandManager *)lmgr;
      andParameters: (Parameter *)p {
  MyStrategy *obj;

  obj = [super create: aZone];
  obj->lm = lmgr;
  obj->parameter = p;

  /* other instance variable initialisations */

  return obj;
}
```

Just as with the imitative template, there are a few issues to consider that will determine the structure of the –decideLandUseForParcel: method (use of memory being one), but with innovative Strategies, the commonality between implementations of this method is likely to be rather less. The following assumes you will be looping through the Land Uses one by one, doing some processing on them, and using that to form the basis of a final decision. It is therefore rather more of a suggestion than a hard-and-fast statement of the way things ought to be done.

```
-(LandUse *)decideLandUseForParcel: (LandParcel *)lp {
  id landUses;
  int i, nUses;
  int y, ymax;                          // if you are using memory

  landUses = [[lp getEnvironment] getLandUses];

  /* other local variable initialisations */
```

If you are using the memory of a Land Manager, you might then want to proceed with a loop over this memory, inside which a loop over the Land Uses will be nested, depending on how you want to handle memory:

```
  ymax = [lm getMemorySize];
  for(y = 0; y < ymax; y++) {
    /* nested loop over Land Uses -- see text below */
  }
```

Refer to the imitative Strategy template (section 10.2.2) for more information on accessing data using the memory.

The loop over Land Uses then proceeds thus:

```
  nUses = [parameter nUses];
  for(i = 0; i < [parameter nUses]; i++) {
    LandUse *lu = [landUses atOffset: i];

    /* Land Use information gathered here */
  }
```

You would then be in a position to make some sort of selection, after which you should free the memory of any objects created locally by calling their drop method, and return the selected Land Use.

The rest of the file contains any extra methods you wish to implement, followed by @end.

10.2.4 Scoring Land Uses with the SelectUseBucket class

The SelectUseBucket class is provided to have a standard mechanism for selecting among Land Uses based on a numerical score that reflects their relative desirability. It provides three mechanisms for setting the scores, and three mechanisms for choosing a Land Use based on the scores set. The following shows the layout of a typical –decideLandUseForParcel: method in a Strategy using a scoring mechanism:

```
-(LandUse *)decideLandUseForParcel: (LandParcel *)lp {
  SelectUseBucket *bucket;
  LandUse *selection;
  /* other local vars here */

  bucket = [SelectUseBucket create: scratchZone
                   withParameters: parameter
                      andLandUses: [[lp getEnvironment]
                                    getLandUses]];
  /* other initialisations here */

  /* loop through land parcels or land uses */ {
    LandUse *lu;
    double score;

    lu = /* however you are getting the LandUse */;
    /* get the data you need to calculate the score */
    score = /* some formula for the score */;

    /* now update the score */
    [bucket addScore: score toBucketForLandUse: lu];
        // do it this way if you want a total score
    [bucket addAverageScore: score toBucketForLandUse: lu];
        // do it this way if you want an average score (over the
        // number of times a score for this Land Use has been
        // added to)
    [bucket setScore: score inBucketForLandUse: lu];
        // do it this way if you want to set the score directly
  } /* end of loop */

  /* now choose the Land Use */

  selection = [bucket getChoice];
      // do it this way if you want a choice weighted by total,
      // average or set score
  selection = [bucket getDeterministicOptimumChoice];
      // do it this way if you want an optimum scoring Land Use
      // chosen, with equally maximum scoring Land Uses chosen
      // among in the same way common to all Land Managers
  selection = [bucket getRandomOptimumChoice];
      // do it this way if you want an optimum scoring Land Use
      // chosen, with equally maximum scoring Land Uses chosen
      // among at random

  /* clean up */
  [bucket drop];

  /* return */
  return selection;
}
```

The SelectUseBucket is created using the +create:withParameters:andLandUses: method, and initialises all scores to zero. As you loop through either the array of Land Uses (in a non-imitative Strategy) or through the Manager's Land Parcels and neighbouring Parcels (in an imitative Strategy), you set the score in the bucket of each Land Use in one of three ways as shown in the code above. When you've finished the loop, get the selection from the bucket in one of the three ways shown, and then free up the memory used by the bucket before returning the selection made.

One method not mentioned of the SelectUseBucket class is the –getScoreInBucketOfLandUse: method, which takes a LandUse object as argument, and returns its current score. This could be useful, for example, in the formula for the score.

The selection methods all assume that scores are positive for Land Uses that are to be chosen among. That is to say, if you want a Land Use not to be chosen, set its score to zero and make sure other Land Uses have a positive score. There is one exception, however, which is when all Land Uses have zero score. In this case, the choice will be made as though they all have equal score, which in the case of –getChoice and –getRandomOptimumChoice will result in a Land Use being selected at random, and in –getDeterministicOptimumChoice will result in the same Land Use being returned each time (the Land Use at element 0 in the Land Use array).

As the end of the last paragraph hinted, the –getDeterministicOptimumChoice method returns the Land Use with the lowest position in the Land Use array when two or more Land Uses have an equal maximum score. This will be the same for all Land Managers using a Strategy that chooses a Land Use in this way. Although this is arbitrary, there might be special cases when you want to bear this in mind, such as when you are configuring a Land Use file to be loaded in for some specific experiment requiring a non-random setup.

10.2.5 Adding the Strategy to the Makefile

Two lines in the Makefile are used to keep a list of Strategy objects to compile. If your Strategy is imitative, add MyStrategy.o to the end of the line beginning FEARLUS_IMITATIVE_STRATEGY_OBJECTS=; if innovative, add MyStrategy.o to the end of the line beginning FEARLUS_INNOVATIVE_STRATEGY_OBJECTS=. Save the Makefile and then recompile the model using the make command. You should now be able to use the Strategy in a Strategy selector file without any problems.

10.3 Accessing information from the model in the code

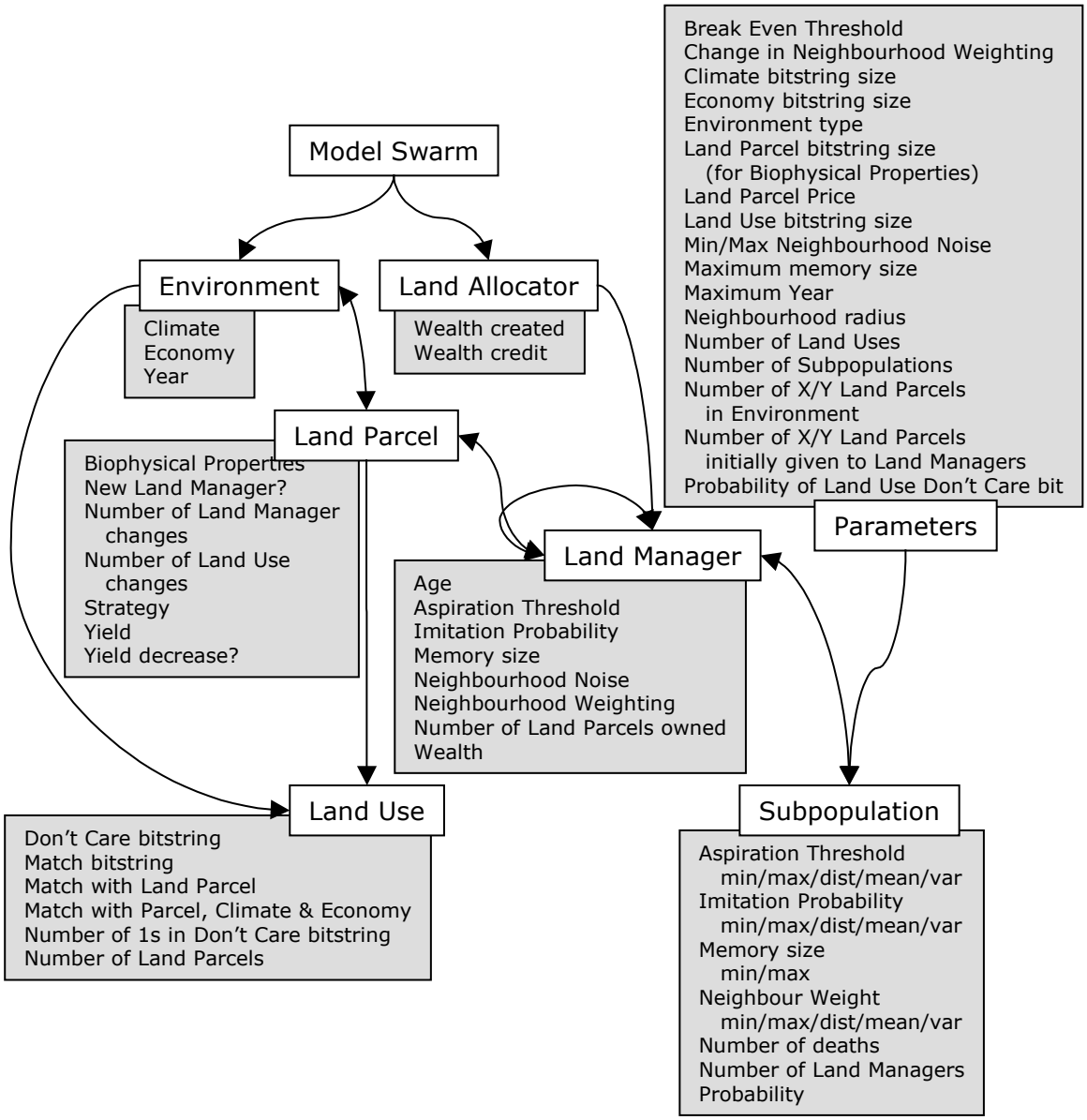

Figure 29 — The information available from various objects. Arrows show that there exists a method to call, in the "from" object, that gets an instance of the "to" object. The following text contains more detail on how to access this information from each of the classes shown.

10.3.1 Model Swarm

The following methods return other objects in the model:

- –(Environment *)getEnvironment — This method returns the Environment object.
- –(LandAllocator *)getLandAllocator — This method returns the Land Allocator object.

10.3.2 Parameters

The following methods return other objects in the model:

- –(SubPopulation *)subPopulation: (unsigned)i — This method returns the ith Subpopulation, where i is in the range 0 to the number of Subpopulations – 1 inclusive.

The following methods return constants:

- –(double)breakEvenThreshold — Returns the Break Even Threshold.
- –(double)strategyChangeUnit — Returns the change in Neighbourhood Weighting a Land Manager should make on receipt/loss of a Land Parcel.
- –(unsigned)climateBitStringSize — Returns the number of bits in the Climate bitstring.
- –(unsigned)economyBitStringSize — Returns the number of bits in the Economy bitstring.
- –(char *)environmentType — Returns the type of the Environment. This is a string containing the Topology class followed by a dash followed by the Neighbourhood class, as entered in the model parameter file (i.e. do not expect the 'Topology' or 'Neighbourhood' part of the respective class strings to appear in this string).
- –(unsigned)parcelBitStringSize — Returns the number of bits in the Land Parcel Biophysical Properties bitstring.
- –(unsigned)useBitStringSize — Returns the number of bits in the Land Use bitstrings. (This is simply the sum of the Climate, Economy and Biophysical Properties bitstring sizes.)
- –(double)neighbourNoiseMin — Returns the minimum Neighbourhood Noise to assign to a Land Manager.
- –(double)neighbourNoiseMax — Returns the maximum Neighbourhood Noise to assign to a Land Manager.
- –(unsigned)maximumMemorySize — Returns the largest memory that any Land Manager may be given.
- –(unsigned)maximumYear — Returns the termination Year of the simulation if it is not running in infinite time. To find that out, the –(BOOL)infiniteTime method is provided, which returns NO if the simulation has a termination Year.
- –(unsigned)neighbourhoodRadius — Returns the neighbourhood radius.
- –(unsigned)nUses — Returns the number of Land Uses.
- –(unsigned)nSubPopulations — Returns the number of Subpopulations.
- –(unsigned)environmentXSize — Returns the width of the Environment, i.e. the number of Land Parcels constituting a horizontal row reaching across the Environment.
- –(unsigned)environmentYSize — Returns the height of the Environment, i.e. the number of Land Parcels constituting a vertical column reaching from top to bottom of the Environment.
- –(unsigned)nInitXParcels — Returns the width of the initial patch of Land Parcels given to each Land Manager.
- –(unsigned)nInitYParcels — Returns the height of the initial patch of Land Parcels given to each Land Manager.
- –(double)pUseDontCareBit — Returns the probability that a 'don't care' bit in a Land Use bitstring will be set to 1.

10.3.3 Environment

The following methods return other objects in the model:

- –getLandUses — Returns a Swarm Array of all the Land Uses in the simulation. Section 10.2.3 contains an example of using this array.
- –getLandParcels — Returns a Swarm List of all the Land Parcels in the Environment.
- –(LandParcel *)getLandParcelAtX: (int)x Y: (int)y — Returns the Land Parcel at the specified X and Y co-ordinate in the Environment.
- –getClimate — Returns a BitString object containing the most recently determined Climate bitstring.
- –getEconomy — Returns a BitString object containing the most recently determined Economy bitstring.

The following method returns a scalar:

- –(unsigned)getYear — Returns the current Year.

10.3.4 Land Allocator

The following method returns another object in the model:

- –getLandManagers — Returns a Swarm List containing all the current Land Managers in the model.

The following methods return scalars:

- –(double)getWealth — Returns the total Wealth of all Land Managers less an allowance for their initial Land Parcel endowments plus the Wealth of all dead Land Managers.
- –(double)getBarnCredit — Returns the amount credited to Land Managers for their initial Land Parcel endowments (the Land Parcel Price multiplied by the number of Land Managers created) plus the Wealth of all dead Land Managers at the time they were removed from the simulation.

10.3.5 Land Use

The following methods return other objects in the model:

- –(BitString *)getDontCareBitString — Returns the 'don't care' bitstring of the Land Use
- –(BitString *)getMatchBitString — Returns the match bitstring of the Land Use.

The following methods return scalars:

- –(unsigned)getParcelMatchWith: (LandParcel *)lp — Returns the contribution to the Yield of the Biophysical Properties of Land Parcel specified in the argument if it had this Land Use.
- –(unsigned)getMatchWithLandParcel: (LandParcel *)aLandParcel climate: (BitString *)aClimate economy: (BitString *)anEconomy — Returns the Yield on the Land Parcel given its Biophysical Properties and the Climate and Economy passed as arguments.
- –(unsigned)countClimateEconomyDontCare1s — Returns the number of 1s in the Climate and Economy part of the Land Use 'don't care' bitstring.
- –(unsigned)getNLandParcels — Returns the number of Land Parcels most recently assigned to this Land Use.

10.3.6 Land Parcel

The following methods return other objects in the model:

- –(Environment *)getEnvironment — Returns the Environment a Land Parcel belongs to.
- –(LandUse *)getLandUse — Returns the Land Use most recently applied to this Land Parcel.
- –(LandManager *)getLandManager — Returns the current Land Manager of this Land Parcel.
- –(BitString *)getAttributes — Returns the Biophysical Properties bitstring of this Land Parcel.
- –(id <Index>)nbrBegin: (id <Zone>)aZone — Returns a Swarm Index on the list of neighbours of this Land Parcel. To loop through the neighbours of a Land Parcel, do this:

```
id <Index> ix;
LandParcel *lp, *nbr;

for(ix = [lp nbrBegin: scratchZone], nbr = [ix next];
    [ix getLoc] == Member;
```

```
      nbr = [ix next]) {
    /* Whatever */
  }
  [ix drop];
```

The following methods return scalars:

- –(BOOL)hasANewLandManager — Returns YES if the current Land Manager is different from the one in the previous Year.
- –(unsigned)getNLMgrChange — Returns the number of changes of Land Manager on this Land Parcel.
- –(unsigned)getNLUChange — Returns the number of changes of Land Use on this Land Parcel.
- –(id <Strategy>)getStrategy — Returns the Strategy most recently applied to set the Land Use on this Land Parcel. To get the string containing the class name of this strategy, use the Obj-C API, as follows:

```
#import <objc/objc-api.h>

  id <Strategy> strategy;
  LandParcel *lp;
  char *strategy_name;

  strategy = [lp getStrategy];
  strategy_name = class_get_class_name([strategy class]);
```

- –(unsigned)getYield — Returns the most recently calculated Yield of this Land Parcel
- –(unsigned)getLastYield — Returns the Yield guaranteed to apply to the previous Year regardless of where you are in the schedule.
- –(int)yieldDown — Return 1 if the Yield has gone down from the Year before last to last Year, 0 if it has stayed the same, and –1 if it has gone up.

10.3.7 Land Manager

The following methods return other objects in the model:

- –getLandParcels — Returns a Swarm List containing the Land Parcels currently owned by this Land Manager.
- –(void)getPhysicalNeighbourList: (id <List>)l — The argument should be a created Swarm List into which this method puts all Land Parcels neighbouring Parcels owned by this Land Manager.
- –(void)getSocialNeighbourList: (id <List>)l — The argument should be a created Swarm List into which this method puts all Land Managers owning Land Parcels neighbouring Parcels owned by this Land Manager. Section 10.2.2 contains an example of how to use this method.
- –(SubPopulation *)getSubPopulation — Returns the Subpopulation this Land Manager belongs to.

The following methods return scalars:

- –(int)getAgeAsInt — Returns the Age of the Land Manager in Years.
- –(double)getHabitThreshold — Returns the Aspiration Threshold of the Land Manager.
- –(double)getImitateProb — Returns the Imitation Probability of the Land Manager.
- –(double)getNeighbourNoise — Returns the Neighbourhood Noise of the Land Manager. (Section 10.2.2 contains an example of how this should be used.)
- –(double)getNeighbourWeight — Returns the Neighbourhood Weighting of the Land Manager.

- –(int)getNumberOfLandParcelsOwned — Returns the number of Land Parcels the Land Manager currently decides the Land Use of.
- –(double)getBarn — Returns the current Wealth of the Land Manager.

10.3.8 Subpopulation

The following methods returns another object in the model:

- –(id <List>)getLandManagers — Returns a Swarm List of the Land Managers who belong to this Subpopulation and have not been removed from the simulation.
- –(Class)getLandManagerClass — Returns the class of Land Managers that will be used to construct members of this Subpopulation.

The following methods return scalars:

- –(double)getHabitThresholdMin — Returns the minimum Aspiration Threshold assigned to members of this Subpopulation if the distribution is uniform.
- –(double)getHabitThresholdMax — Returns the maximum Aspiration Threshold assigned to members of this Subpopulation if the distribution is uniform.
- –(char *)getHabitThresholdDist — Returns the distribution used to assign Aspiration Thresholds to members, which may be normal or uniform.
- –(double)getHabitThresholdMean — Returns the mean Aspiration Threshold assigned to members of this Subpopulation if the distribution is normal.
- –(double)getHabitThresholdVar — Returns the variance in Aspiration Threshold assigned to members of this Subpopulation if the distribution is normal.
- –(double)getImitateProbMin — Returns the minimum Imitation Probability assigned to members of this Subpopulation if the distribution is uniform.
- –(double)getImitateProbMax — Returns the maximum Imitation Probability assigned to members of this Subpopulation if the distribution is uniform.
- –(char *)getImitateProbDist — Returns the distribution used to assign Imitation Probabilities to members, which may be normal or uniform.
- –(double)getImitateProbMean — Returns the mean Imitation Probability assigned to members of this Subpopulation if the distribution is normal.
- –(double)getImitateProbVar — Returns the variance in Imitation Probability assigned to members of this Subpopulation if the distribution is normal.
- –(unsigned)getMaxMemorySize — Returns the maximum memory size assigned to Land Managers of this Subpopulation. (There's no getMinMemorySize.[*])
- –(double)getNeighbourWeightMin — Returns the minimum Neighbourhood Weighting to assign to members of this Subpopulation if the distribution is uniform.
- –(double)getNeighbourWeightMax — Returns the maximum Neighbourhood Weighting to assign to members of this Subpopulation if the distribution is uniform.
- –(char *)getNeighbourWeightDist — Returns the distribution used to assign Neighbourhood Weightings to members, which may be normal or uniform.
- –(double)getNeighbourWeightMean — Returns the mean Neighbourhood Weighting assigned to members of this Subpopulation if the distribution is normal.
- –(double)getNeighbourWeightVar — Returns the variance in Neighbourhood Weighting assigned to members of this Subpopulation if the distribution is normal.
- –(unsigned)getNRemovals — Returns the number of Land Managers that have been removed from this Subpopulation (following the loss of all their Land Parcels) in the most recent Year this was calculated.
- –(unsigned)getManagerCount — Returns the number of Land Managers belonging to this Subpopulation.

[*] This is a *feature* ☺!

- –(double)getProb — Returns the probability that any newly created Land Manager will be a member of this Subpopulation.

10.3.9 Bitstrings

A number of methods return instances of the BitString class. This section briefly describes the methods that are available to you in this class.

There are three ways in which a BitString can be created:

- +create: (id)aZone setBitCount: (unsigned)aBitCount — Use this method to create an empty bitstring (initialised to all 0s) of the specified length.
- +create: (id)aZone setToString: (char *)aString — Use this method to create a bitstring, setting it according to the string, which should be something like "10111010101".
- +create: (id)aZone setToString: (BitString *)aBitString — If you want to create a copy of a BitString to do some processing with it, then this is the method to use. This is a particularly important method in terms of creating Strategies and reports. When you get a bitstring from a Land Parcel, Land Use or the Climate or Economy, you get a pointer to the bitstring from that object, not a copy of it. Any modifications you make to the bitstring will therefore change the bitstring belonging to the object. Strategies and reports should not make changes to the Climate, Economy, Biophysical Properties of a Land Parcel or to the Land Uses!

The following methods provide access to the bitstring in one way or another:

- –(unsigned)getBitCount — Returns the number of bits in the bitstring.
- –(int)getBit: (unsigned)n — Gets the value of the nth bit in the bitstring.
- –(unsigned)countOnes — Returns the number of 1s in the bitstring.
- –(unsigned)getMatchWith: (BitString *)anItem — Returns the number of bits with the same value in this bitstring and that in the argument. Both bitstrings should be of the same length.
- –(void)printToFile: (FILE *)fp — Prints the bitstring to the specified file pointer.
- –(void)printToString: (char *)aBuffer — Prints the bitstring to the buffer.
- –print — Prints the bitstring to stdout followed by a new line.

The following methods may be used to modify the contents of the bitstring. (The above warning applies: only use these methods on *copies* of bitstrings that you have got from model objects.)

- –(void)setBit: (unsigned)n to: (int)value — Sets the nth bit to the specified value (which should be 1 or 0).
- –(void)toggleBit: (unsigned)n — Toggles the nth bit in the bitstring — if it is 1 set it to 0, if 0 set it to 1.
- –(void)setToParityOf: (BitString *)bitString1 and: (BitString *)bitString2 — sets the contents of this bitstring to the result of the bitwise parity of the two arguments. Both arguments should have the same length as this bitstring.
- –(void)setToOROf: (BitString *)bitString1 and: (BitString *)bitString2 — Bitwise OR, as parity.
- –(void)setToXOROf: (BitString *)bs1 and (BitString *)bs2 — Bitwise XOR, as parity.