Simulation - grass, rabbits and foxes

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This is a spec for a (relatively) simple simulation of digital life, neural networks and evolution on a flat, hexagonal grid. This is based on the classic "grass, rabbits and foxes" that students have been simulating for 50 years, although these creatures (which I call "Sims") are more like simple insects than mammals, inasmuch as their neural networks do not learn, but are hard-wired at birth based on inherited genes.

Basic Principles

Initially, I aim to keep the simulation as simple as possible (I can always add stuff later). This simulation will include:

1. energy
2. behavior
3. senses
4. neural networks
5. genes
6. mutations
7. simple "rules of engagement" for how this world works

My goal is to make this (almost) as simple as Conway's "Life".

Grass

1. **Growth**:

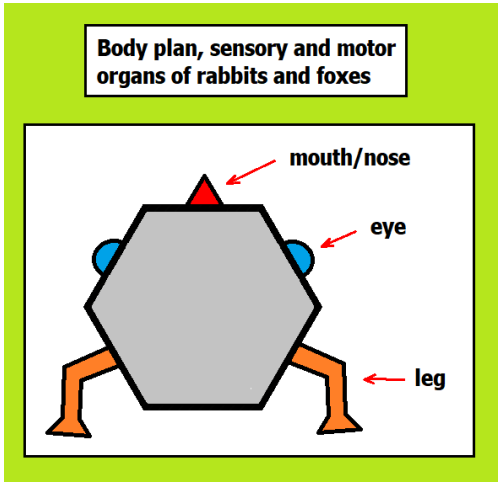
   Each cycle, every grass sim will receive 100 units of energy from the sun (which will accumulate)

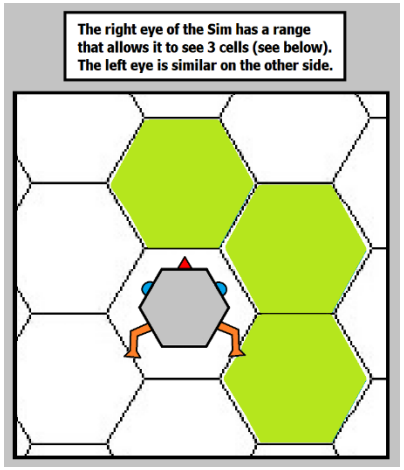
2. **Reproduction**:

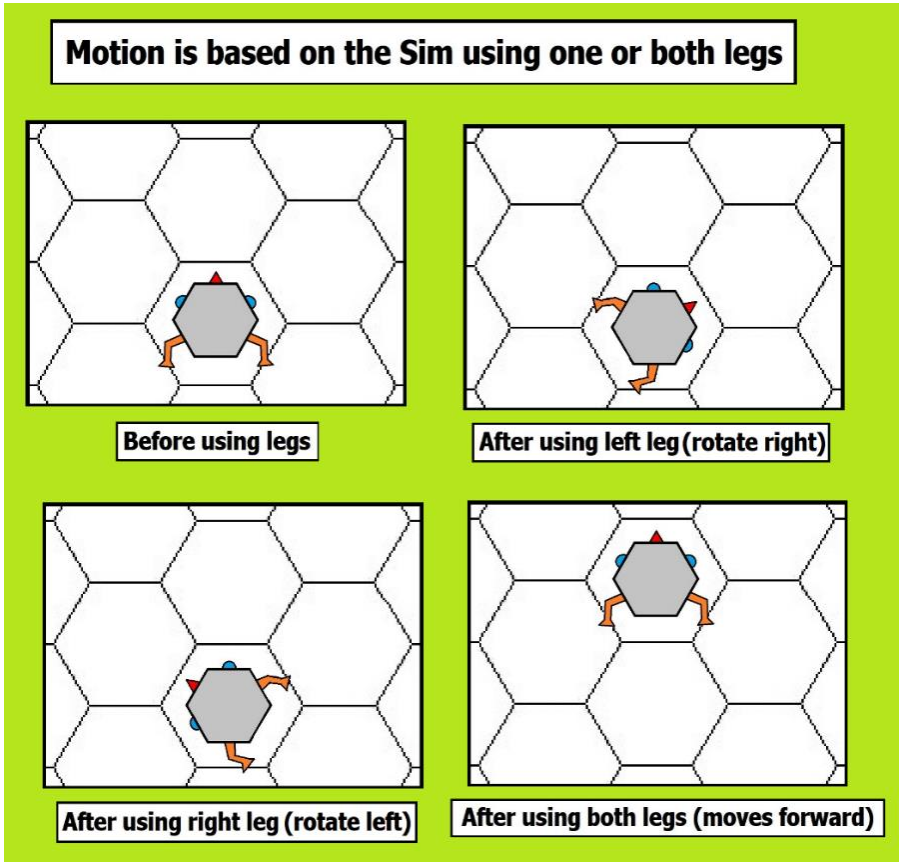
   When the energy level of a grass sim reaches 1000 units, then:

   (a) the grass sim will send out 5 seedlings (random walk, 10 steps) each of which will initiate a new grass sim if they land on an empty cell (ie: where there is not already a grass sim)

   (b) the original sim will then have its energy level decremented to 500 and the 5 seedlings will each be given an energy level of 100.







Rabbits and Foxes

1. **Body plan**: Rabbits and foxes will each have two eyes, one nose, and two legs (see basic body plan diagram)

2. **Motion** is based on the legs. Using only the right or left leg will cause the sim to rotate 60 degrees (see diagram). Using both legs will move the sim forward one cell.

3. **Vision**: Each eye has a range of only 1 cell. This means that the right eye and the left eye can each see what is in the 3 cells that are closest to it (see diagram). These are quite simple eyes. During each cycle, each eye will send messages to the sim brain indicating whether a fox, a rabbit, or grass has been seen.

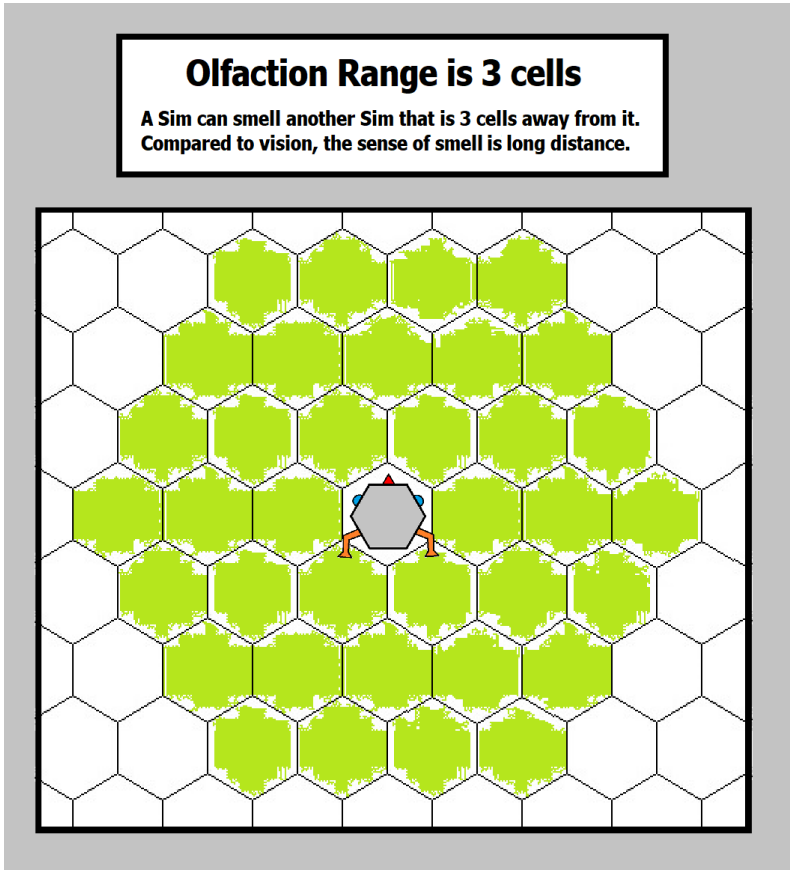
4. **Olfaction**: Each Fox or Rabbit can smell another fox or rabbit that is up to 3 cells away. The Sim nose will send a message to the brain indicating whether a fox or a rabbit is within that range.

5. **Energy level**: Foxes and Rabbits also have cells in their neural network indicating their internal energy level and whether (for example) they are close to starvation or ready to reproduce (see chart for neural network cells).

Energy

1. **Rabbits eat Grass**
At the end of each cycle, if a Rabbit ends up on a cell with a Grass Sim (and the cell has no other rabbits or foxes) then the Rabbit eats the grass sim. The grass sim is eliminated, and **half** of the energy units go to the Rabbit while the other half are lost to entropy.

2. **Foxes eat Rabbits**
At the end of each cycle, if a Fox ends up on a cell alone with a Rabbit -- then the Fox eats the Rabbit and half of its energy goes to the fox.



3. **Starvation**
Each cycle of life for a Fox or Rabbit requires 1 unit of energy. If, at the end of each cycle, the energy level of a sim is zero--then it is dead.

4. **Movement costs energy**
Foxes and Rabbits consume energy when they use their legs. Each time they use their left or right leg--it costs them 1 unit of energy. So moving forward (which requires both legs) costs 2 units of energy.

Collisions

As noted, if a Rabbit ends up on a cell with Grass, or if a Fox ends up on a cell with a Rabbit, then one sim eats and the other is eaten. But there are two other possibilities:

(a) If multiple Rabbits end up on the same cell at the end of a cycle (and if there are no foxes on that cell) then (1) all of the Rabbits lose 10 percent of their energy and (2) no Grass will be eaten even if the cell contains a grass sim.

(b) If multiple Foxes end up on the same cell (regardless of whether there are Rabbits involved) then only one fox survives. The odds of survival are proportional to the energy levels of each fox.

Reproduction of Foxes and Rabbits

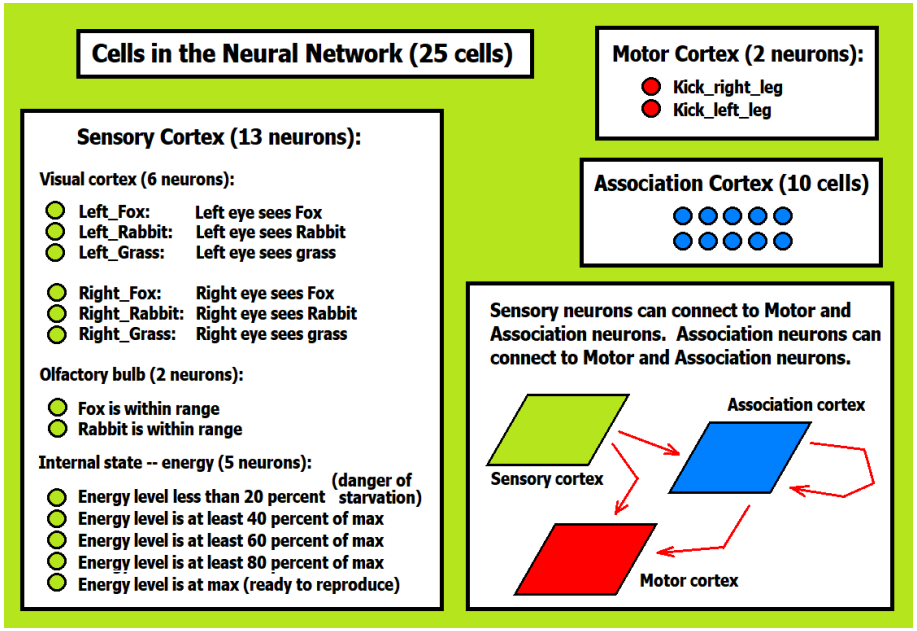
If a Rabbit or Fox reach the maximum energy level (which is 500 for a Rabbit and 1000 for a Fox) then the Sim splits (and the energy is divided) with one Sim getting ejected into the cell that the Sim is facing, and the other Sim getting ejected into the other direction.

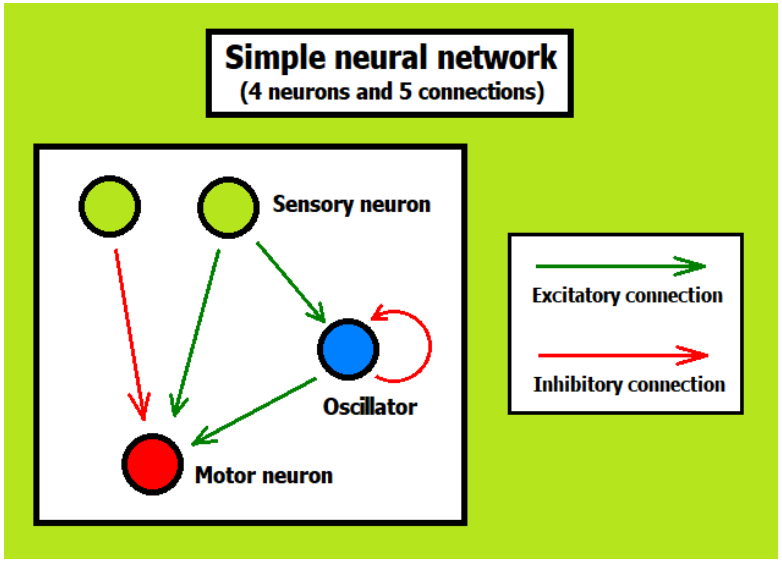
The "Brain" of each Sim

The neural net runs 6 internal cycles for each "real world" external cycle. This should allow for multipath signal propagation effects.

The connections between neurons are determined genetically--each gene specifies a single connection. This means that each gene will specify a "source" neuron, and a "destination" neuron, and a connection strength. Negative numbers for connection strength represent inhibitory connections.

Each neuron fires with a strength of 1 (to keep things simple) during each internal cycle or does not fire at all. If neuron A fires during internal cycle 1, then the connection from neuron A to neuron B will deliver a signal to neuron B at the beginning of internal cycle 2. Neuron B will then simply add up the connection weights of all the signals it has received and--if the result is more than zero--will fire at the end of internal cycle 2. This means that (for example) a neuron that connects to itself with an inhibitory connection (see chart) could function as an oscillator.





Sensory neurons will have the identical firing pattern during all internal cycles (ie: nothing outside the Sim changes). If a motor neuron fires during any of these internal cycles--then the corresponding leg will be regarded as having "kicked".

Genes and Mutations

Each gene consists of 3 parts:

(a) **Source neuron** -- which of the 23 neurons in the Sensory (13 neurons) or Association (10 neurons) cortex sends a signal
(b) **Destination neuron** -- which of the 12 neurons in the Motor (2 neurons) or Association (10 neurons) cortex receives the signal
(c) **Connection strength** -- representing one of the 10 possible values (ie: 1, 2, 3, 5, 8 or -1, -2, -3, -5, -8).

Each of the 3 parts of the gene is specified by 8 bits (which creates a number from 0 to 255). Modulo arthmetic is used to reduce the 8 bits to a number between 0 and 22 (for the source neuron) or between 0 and 11 (for the destination neuron) or between 0 and 9 (for the 10 possible values of connection strength).

When a Fox or Rabbit reproduces--each gene copies itself. Since a Rabbit has 10 genes, and creates 2 copies of each when it splits, an act of reproduction would consist of 20 gene-copy events. With an error rate of one out of a hundred gene-copy operations, this means that once every 5 times a rabbit reproduces--one of the genes for one of the two rabbits that result will have a flipped bit.

Comments on potential future development

Simulation will eventually attract the attention of larger numbers of amateur hobbyists, so some notes on future development may be appropriate.

The essence of an interesting simulation is to *ruthlessly* abstract away or leave out all non-essential features--in order to leave more bandwidth for hardware cycles and the attention of human programmers and hobbyists. For example, John Conway's "Game of Life" captured attention because it was based on the maximal simplification of earlier work by John von Neumann.

The most obviously interesting potential features (in my opinion) that would be good to add to a similuation like this include:

(a) Adding a third dimension

(b) Allowing the body plan itself to be subject to evolution, so that (for example) compound (ie: insect-like) eyes can evolve,

(c) Sexual reproduction (so genes can be efficiently shuffled)

(d) A neural network that can learn (ie: "neurons that fire together, wire together") with operant conditioning, a reward center, and habit formation, habit chaining and habits as subroutines for other habits.

(e) Making it possible for the Sim to internally simulate the results of alternate potential actions it may be considering. This would mean that our simulation would simulate creatures that do their own simulations (ie: such as most animals do) in order to plan their actions. If this has not already been done--then some sort of special recognition needs to go to the first person or team which creates such a 2-level simulation.

(f) The development of two emotional clusters of neurons (ie: "fight or flight" and "rest and digest") corresponding to the (more externally focused) sympathetic and (more internally focused) parasympathetic nervous sytems.

Related to this, it will be useful to model the division of labor between the more object and task-oriented functions associated with the left hemisphere and the greater situational awareness and holistic integration of large volumes of complex information associated with the right hemisphere.

(g) Generally a more complex environment with different niches favoring the evolution of body plans, behavior and brains.

Parameters used:

The biology, chemistry and physics of this simulated world are based on the following parameters--which I will adjust in order to create a world that is "interesting".

Parameter	Value
Units of energy sun gives to grass each cycle	100
Grass reproduction energy level	1000
Length of grass seedlings random walk	10
Number of grass seedlings	5
Amount of energy grass gives to seedlings	half
Number of eyes	2
Number of legs	2
Range of vision	1
Range of olfaction	3
Number of cells in Association cortex	10
How many Energy levels monitored by neural net	5
How many internal neural net cycles per external cycle	6
Energy loss when one sim eats another	half
Rabbit reproduction energy level	500
Fox reproduction energy level	1000
Number of genes for each Rabbit	10
Number of genes for each Fox	25
Mutation rate (inverse) per gene during reproduction (ie: the average number of gene-copy operations needed for a bit to get flipped in error)	100
Size of hexagonal grid representing world	30x30
Geometery of world	toroid

(Only integer arithmetic is used in this simulation in order to keep things simple and reproducible across different hardware and programming platforms. For example, if a Rabbit has an energy level of 27 and loses 10 percent of its weight -- then it will lose 3 units of energy.)