PS Einführung in die Bioinformatik
Project Overview

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1 Introduction

The goal is to write a program similar to Vaario's in [1]: Some simulated creatures populate the artificial world and fight for survival. Each creature has an artificial brain which processes the incoming information and controls its bahaviour. This brain is modelled as an ANN with a fixed number of neurons, input cells and output cells but the connections between them grow on a biological plausible basis.

2 External World

The external world is a bounded plane. Obstacles are spread out over the world. When a creature crashes into an obstacle or into the boundary it receives a penalty. On the other hand food is initially placed on the plane. If a creature "eats" some food it gets a bonus.

3 Connection between External and Internal World

Each creature has a fixed set of sensors for food detection("Eyes") and obstacle detection("Whiskers"). The strength of a stimulus from a food detecting sensor depends on the distance and on the angle to the target food. Obstacle detection works a bit different: Each sensor has an area of influence and the strength of a stimulus depends on how much of this area is occupied by obstacles similar to Vario's approach in [1].

3.1 Sensors

The two types of sensorrs are modelled similarly. Both check the squares in front of the creature by calculating concentric arches as shown in the pictures below. Only the action on finding something differs. The "eyes" (see figure 1) search for the closest food and return a stimilus depending on the distance to this food. The "whiskers" (figure 2) simply count how many of the squares in their range are blocked by obstacles. Their resulting stimulus is dependend on the ratio of blocked to non blocked squares.

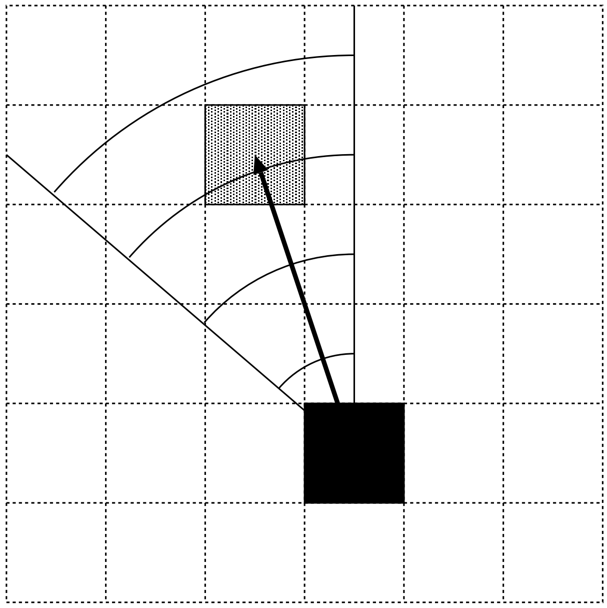


Figure 1: An "eye" searches the nearest food square.

3.2 Movement

To move in the virtual world each creature has two wheels. Velocity and change of direction of a creature are computed based on the strength of the signals both wheels receive.

If the way both wheels move is the same ($v_r = v_l$), then

$$\begin{aligned} \Delta_\alpha &= 0 \\ \Delta_y &= v_r = v_l \\ \Delta_x &= 0 \end{aligned}$$

otherwhise

$$\begin{aligned} \Delta_\alpha &= \frac{v_l - v_r}{d} \\ r &= \frac{v_r}{\Delta_\alpha} + \frac{d}{2} \\ \Delta_y &= r \cdot \sin(\Delta_\alpha) \\ \Delta_x &= r \cdot (\cos(\Delta_\alpha) - 1) \end{aligned}$$

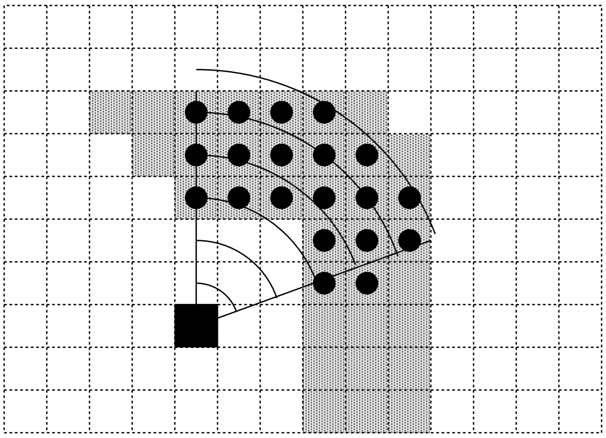


Figure 2: A "whisker" counts the number of blocked squares

where d is the constant distance from one wheel to the other, v_r and v_l is the way each wheel moves, Δ_α is the change of direction of the creature. Δ_x and Δ_y represent the change of position of this creature in this turn.

and finally

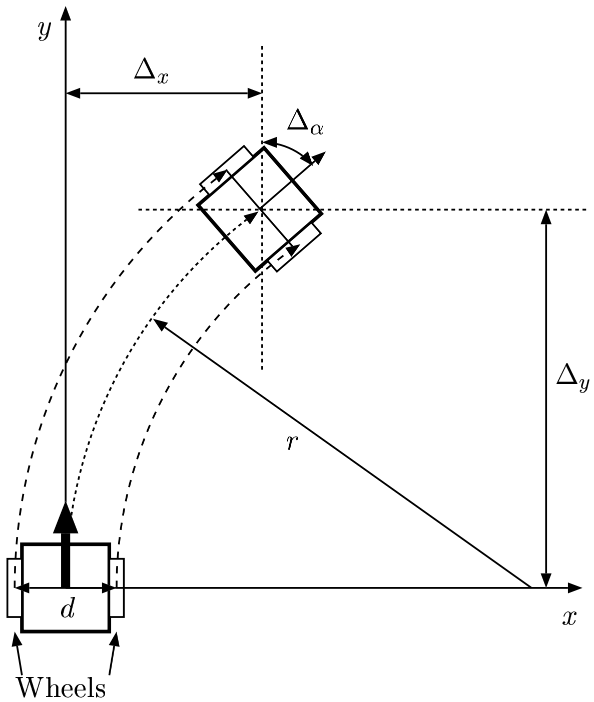
$$\begin{aligned}\Delta_X &= \cos(\alpha) \cdot \Delta_y + \sin(\alpha) \cdot \Delta_x \\ \Delta_Y &= \cos(\alpha) \cdot \Delta_x - \sin(\alpha) \cdot \Delta_y\end{aligned}$$

where Δ_X and Δ_Y are the distances the creature moved in the world with it's original heading of α.

4 Internal Word

The internal world is a cube with the sensors and wheels on fixed positions. Several neurons and guidance cells are scattered in space. From sensors and neurons axons grow guided by "chemical" gradients. Every neuron, guidance cell, and wheel produces one of several substances that may attract axons. Each axon has a list of substances which it follows consecutively. When the concentration of the substance the axon is following exceeds a certain threshold the axon "switches" to the next substance in it's list. After reaching the treshold of the last substance in the list the axon stops growing.

After the connections have grown during development of the phenotype the "brain" is abstracted to an ANN. The length of a connection in the brain and the distance of an axon's end to a cell determine a connection weight for the ANN.



5 Growth

5.1 Building the concentration grid

Since the axon's growth is guided by chemical gradients we have to built a "concentration grid" first in which the gradients for the various chemicals are stored. A grid cell's concentration value is determined by the formula

$$C_{x,y,z,s} = \sum_{\varphi \in \Phi_s} \frac{1}{\sqrt{(\varphi_x - x)^2 + (\varphi_y - y)^2 + (\varphi_z - z)^2}} \cdot \varphi_c \qquad (1)$$

where x, y, z are the grid cell's coordinates, Φ_s is the set of all axon attracting cells which send out the substance s and φ_x, φ_y, and φ_z are φ's coordinates. $varphi_c$ is the initial concentration of the substance the cell produces. If $(\varphi_x - x)^2 + (\varphi_y - y)^2 + (\varphi_z - z)^2$ equals 0 then the value of the fraction becomes 1.

5.2 Axongrowth

The axonheads get a chance to grow consecutively. For each directly adjacent grid cell that is not yet occupied by an axon the chance that the axon

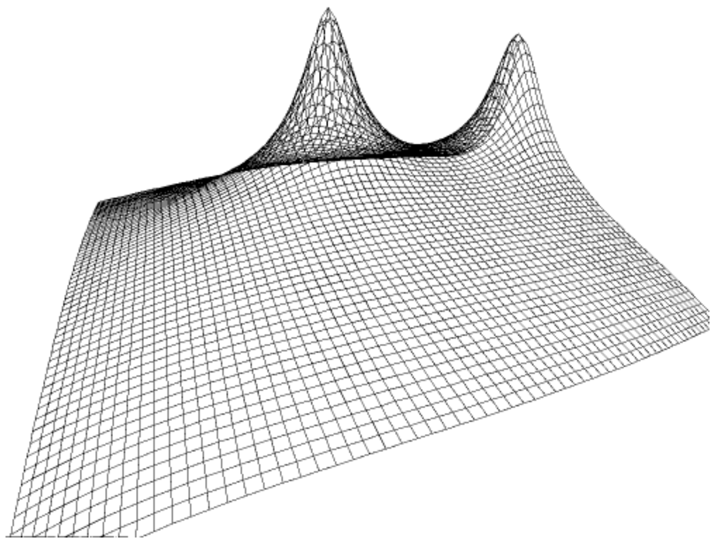


Figure 3: The concentration landscape of one plane in the cube. In this example the concentration is made up of two substance-emmitting cells.

grows into this grid cell is calculated with the formula

$$P_{x,y,z} = \frac{(C_{x,y,z,\psi_s} - \min C_{\Theta,\psi_s})^{\psi_\eta}}{\sum\limits_{\theta\in\Theta} (C_{\theta_x,\theta_y,\theta_z,\psi_s} - \min C_{\Theta,\psi_s})^{\psi_\eta}} \cdot \left(p_b - \frac{1}{e^{\sum_{\theta\in\Theta} C_{\theta_x,\theta_y,\theta_z,\psi_s}}} \right) \quad (2)$$

where $x, y.z$ are the coordinates of the grid cell in question. C_{x,y,z,ψ_s} is the concentration of the substance the axon ψ is following at this time. Θ is the set of all directly adjacent grid cells not occupied, and $\min C_{\Theta,\psi_s}$ is the smallest concentration in Θ. ψ_η is the axon's connectivity parameter, and p_b determines the minimum probability a cell has to grow.

The first part of formula 2 calculates the normalized, relative concentrations of the adjacent grid cells to determine the probabilities that the axon is growing in a certain direction. The second part modifies these values in respect to the absolute amount of the substance ψ_s. If this part becomes greater one it is assumed to be one.

If the concentration of the substance the axon follows exceeds a certain inherited threshold the axon changes to the next substance in an also inherited list.

The growth terminates when the axon did not grow for a certain number of turns. This number is the same for all the axons of one cell and is stored in the cell's genome.

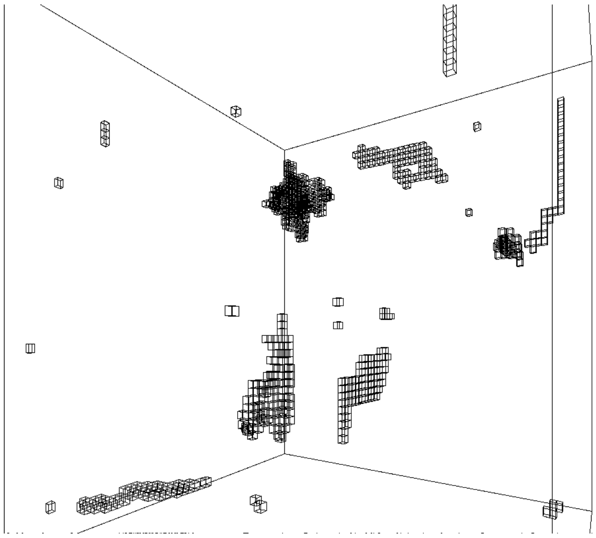


Figure 4: A "brain" after several turns of growth.

5.3 Building up the ANN

After all axons finished growing the conections grown are abstracted into weights useable in an ANN. A cell's s influence $I_{s,d}$ on another one d is computed with

$$I_{s,d} = \sum_{\psi \in \Psi_{s,d}} (-1)^{\psi_\kappa} \cdot (\chi \cdot \rho) \tag{3}$$

with

$$\chi = \begin{cases} 1 - \overline{\sigma\psi} \cdot \alpha & \text{if } \overline{\sigma\psi} \cdot \alpha \leq 1, \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

$$\rho = \frac{1}{\sqrt{(\delta_x - \psi_x)^2 + (\delta_y - \psi_y)^2 + (\delta_z - \psi_z)^2}^{\,3} \cdot \beta} \tag{5}$$

where $\Psi_{s,d}$ is the set of all axonheads from cell s that are in d's vicinity, ψ_κ is either 0 or 1 depending on whether the synapse is inhibitory or excitatory, $\overline{\sigma\psi}$ is the length of the axon, and α and β are constants.

Those weights are stored as a graph in an adjacency matrix.

Incoming stimuli are added up at neurons and if the sum does exceed a certain threshold it propagates a stimulus of a ceratin strength which is independent from the incoming stimuli. If the threshold is not exceeded the level of excitement is stored in the neuron and added to the incoming stimuli in the next cycle. (Pulse coded)

In one clock cycle information is only propageted from one cell to its direct successors. So it is no problem if a recurrent network develops.

6 Genetic Coding

The genome is stored in a bitstring. Values are directly encoded binary numbers.
The following data is stored for every axon-growing cell (sensors, neurons):

- Substances which the axon follows and threashold values from which concentration on this substance is ignored.
- A propability whether this cell has an inhibitory or excitatory influence on other cells.
- Connectivity parameter: the degree of "hairiness" of axons.
- A number determining after which number of inactive turns this cell's axons stop to grow.

Data for axon attracting cells (guidance cells, neurons, wheels):

- A Substance to produce and its initial concentration.

Data for free placed cells (guidance cells, neurons):

- X, Y, Z coordinates which define the position of the cell within the cube.

Additional data for neurons

- The threshold value which determines the strength a stimulus must exceed in order to be propagated

7 Evolution and Fitness

Every creature has a certain amount of energy which is reduced every turn. If the creature finds some food it gets extra energy; if it bumps into an obstacle it is injured and so loses some energy. As soon as a creature's energy gets less or eqal zero it dies and so is removed from the world. Since amount of food available decreases with time all the creatures finally die.

$$P_n = \sqrt[3]{\frac{10}{(n+10)}} \tag{6}$$

We are choosing the mating partners with a roulette selection mechanism. An agent with a high fitness (i.e. it survived for a long time) has a greater probability to get selected. Function 6 as can seen in figure 5 determines – after normalizing the sum of all P_i to 1 – the probabilities a certain

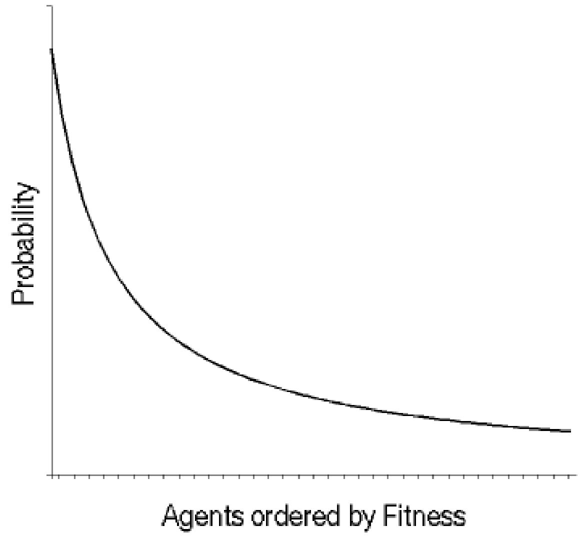


Figure 5: the probability distribution

creature is selected. In this formula n is 1 for the fittest agent, 2 for the second, etc. . After selecting two creatures we derive offspring using crossover and bitflip mutation operations each with a certain propability. We use 0.6 as a crossover probality and $1/l$ where l is the length of the genotype as a bitflip probability.

References

[1] Jari Vaario, Akira Onisuka and Katuso Shimohara. *Formation of Neural Structures.* Technical Paper, ATR Human Information Processing Laboratories.