Computing Science and Biology (3)

Artificial Life

Learning Goals

- understand some basic goals and concepts in *artificial life (AL)*
- become familiar with a simple example for an AL system: *Langton's ant*
- get acquainted with the concept of *emergent behaviour*
- encounter the idea of a *universal models of computation*

What is Artificial Life?

Fundamental goal of biology: understand life!

What is life?

- growth through metabolism
- ability to reproduce
- internal regulation in response to the environment

Can we build artificial systems that have these properties?

Note: This is different from building artificial intelligence!

Artificial Life: Research area that is concerned with

- the simulation of life
- the realisation of life

in some artificial environment, usually the computer.

Goals in artficial life research:

- build machines (or computer programs) that exhibit life-like behaviour, such as growth, replication, communication, ...
- identify (simple) formal principles underlying *all* life-like behaviour

Fundamental assumption:
"Life [is] a property of the organisation of matter, rather than a property of the matter which is so organised." *(Chris Langton)*

A Simple Example: Langton's Ant

- The 'ant' lives on an infinitely large, 2-dimensional grid.
- Each square in the grid can be black or white; you can think of these cells as pixels on a black-and-white display.
- At the beginning, all squares are white and the ant sits on one of them, *e.g.*, in the middle, and faces in one of the four main directions, *e.g.*, right.
- In each step, the ant follows these rules:
  1. If the ant is on a black square, it paints the square white, turns right 90 degrees and moves forward one square.
  2. If the ant is on a white square, it paints the square black, turns left 90 degrees and moves forward one square.

Langton's ant . . .

- was invented by computer scientist Christopher Langton, one of the founders of the field of artificial life, in the 1980s.
- is one of the simplest and most widely known artificial life systems.
- despite its simplicity, shows surprisingly complex behaviour.

Emergent behaviour of Langton's ant:

- For a long time, the pattern generated by the ant is complex and apparently random.
- After about 10 000 steps, the ant starts building an extremely regular structure: a diagonal 'road' consisting of a modules of 104 steps that are repeated indefinitely!
- The road building behaviour results from the interaction of the ants localised actions (defined by the rules) with its environment (the squares on the grid).

- Looking at the simple rules governing the ant's behaviour, the road building behaviour is unexpected.
- Such unexpected, complex behaviour of a simple system is also called *emergent behaviour*.
- We have seen other examples of emergent behaviour when we looked at the simple rules we used for creating self-similar images of plants.

Some generalisations:

- start with a non-empty grid, *i.e.*, some squares set to to black
- use a finite grid
- use different grid geometries (*e.g.*, hexagonal), or dimensionalities (*e.g.*, three-dimensional)
- allow more than two colours
- give the ant more memory, allow more complex rules
- use multiple ants on the same grid

Related systems:

- Langton's ant is closely related to a simple and well-known formal model of computation called a *Turing machine*.
  - Turing machines are *universal models of computation*, *i.e.*, they can simulate any real computer and run any given algorithm.
  - Because Turing machines are much simpler to analyse than real computers, they are often used in theoretical computing science, *e.g.*, in the analysis of the hardness of computational problems.

- Langton's ant can also be seen as a special case of a type of formal system called a *cellular automaton*.
  - Like Turing machines, cellular automata are a universal model of computation.
  - As seen in the case of Langton's ant, cellular automata often achieve surprisingly complex behaviour on the basis of very simple rules.
  - Cellular automata like Langton's ant play an important role in the study of complex systems, emergent behaviour and artificial life.

Food for Thought:

- Can you think of other examples of systems that show emergent behaviour?
- What would we learn if we could build AL systems that accurately simulate interesting behaviour of biological systems?
- Could the universe be based on simple rules, not unlike Langton's ant?
- What is the difference between real life and a simulation?
- Could it be that we live in inside a simulation and simply don't know it?
- What is the Matrix? Would you take the red pill or the blue pill?

Resources

- Scientific American Mathematical Recreations column using Langton's Ant as a methaphor for a Grand Unification Theory: `http://www.fortunecity.com/emachines/e11/86/langton.html`
- Generation5 JDK Demonstrations (including Langton's ant and slime mold simulation): `http://generation5.org/jdk/demos.asp`
- Luis Rocha's course on Evolutionary Systems and Artificial Life: `http://informatics.indiana.edu/rocha/alife.html`
- Frequently asked questions from comp.ai.alife: `http://www.faqs.org/faqs/ai-faq/alife/`
- A nice collection of AL links: `http://felix.unife.it/++/ma-bio-alife`