Universiteit Leiden

Exam, Natural Computing

Prof. Dr. Thomas Bäck

Aug 22nd, 2012, 10:00 – 13:00, room 412

- Please write readable, and write your name and student identification number on every single sheet of paper for unique identification!
- Don't spend much time writing long stories – that's really not necessary. Don't panic! You ARE able to make it!
- Take a look at the whole exam first to get an overview, and do those assignments first which you feel are doable for you.
- Good success and all the best for your studies!

1. (**Natural Computing, total: 6**) To start with, please explain (briefly!) what we mean by complexity and emergence, and give two examples of real-world phenomena illustrating these terms.

2. (**Cellular Automata, total: 10**) Assume you have got a binary 2-D cellular automaton with von Neumann neighbourhood, radius r=1, and toroidal boundaries.

   a. How big is the rule space for this type of CA?
   b. What does it mean to say something like "rule 6" in this case?
   c. For a 3 x 3 CA with initial state: all cells zero except the center, which is one, simulate the dynamics of rule 6 for one step. Please observe that you need to introduce a neighbourhood indexing convention to do this. Suggestion: leftmost bit = upper cell, next bit = left cell, next bit = middle cell, next bit = lower cell, last bit = right cell.
   d. Explain what we mean by "inverse design" of CAs. How would you approach the inverse design problem?

3. (**Evolutionary Algorithms, total: 8**) Assume that you want to solve the travelling salesperson problem with an evolutionary algorithm.

   a. Propose a representation and mutation and crossover operators (one each) for your evolutionary algorithm.
   b. Propose a selection operator.

4. (**DNA Computing, total: 8**) For filtering algorithms in DNA computing, we introduced the so-called test tube programming language.

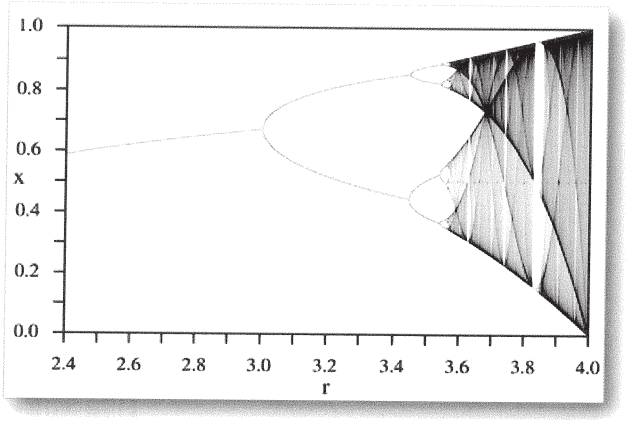
   a. Explain the four operators of the test tube language.
   b. Explain the basic principle and the fundamental limitations of the filtering approach.

5. (**Swarm Intelligence, total: 10**) Many natural computing algorithms rely on some concept of moving the "population", "swarm", or other solution representations towards better and better solutions as the search proceeds. This requires some kind of selection method. Explain how this process of "selection" works in the following algorithms:

   a. Simulated Annealing.
   b. Genetic Algorithms.
   c. Particle Swarm Optimization.
   d. Ant Colony Optimization.
   e. Explain whether you see any fundamental difference in the approach between the first two and the second two methods.

6. (**Nonlinear Dynamics, total: 14**) Given the map f(x) = ax(1-x), answer the following questions:

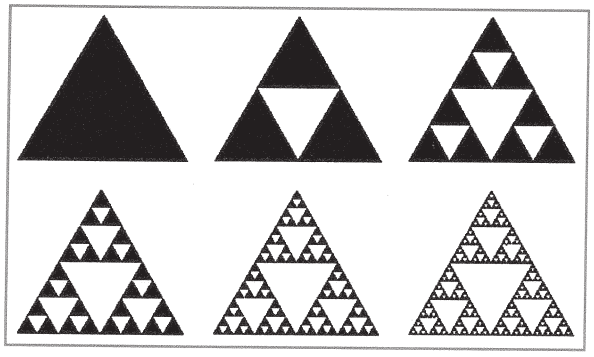
   a. What is an orbit? What is a periodic orbit of period 6?
   b. What is a fixed point? Give its definition. Give a graphical interpretation of a fixed point.
   c. Give an equation for all fixed points of f(x).
   d. Define, in your own words, what a sink and a source is.
   e. Give a fixed point of f(x) = 3x(1-x). Is this a sink or a source? How do you get to your result?
   f. Explain the meaning of the following diagram:



   g. Explain the so-called Feigenbaum constant by referring to the diagram.

7. **(Fractals, total: 12)** Explain the main characteristics of fractals, and explain the difference between a fractal occurring in nature and the mathematical abstraction of a fractal.

   1. The Sierpinski triangle, shown below, is a typical example of a mathematical fractal. Calculate the self-similarity dimension of the Sierpinski triangle. You might find the small table of logarithms useful for calculating the self-similarity dimension. Explain how this dimension is calculated.



n	Log(n)
2	0,301
3	0,477
4	0,602
5	0,699
6	0,778
7	0,845
8	0,903
9	0,954

   2. **(5)** Now, let's get to 3D-fractals, such as the one shown below. Let's call it the Sierpinski tetrahedron. Again, calculate the self-similarity dimension. If you find a surprising result, do not worry.

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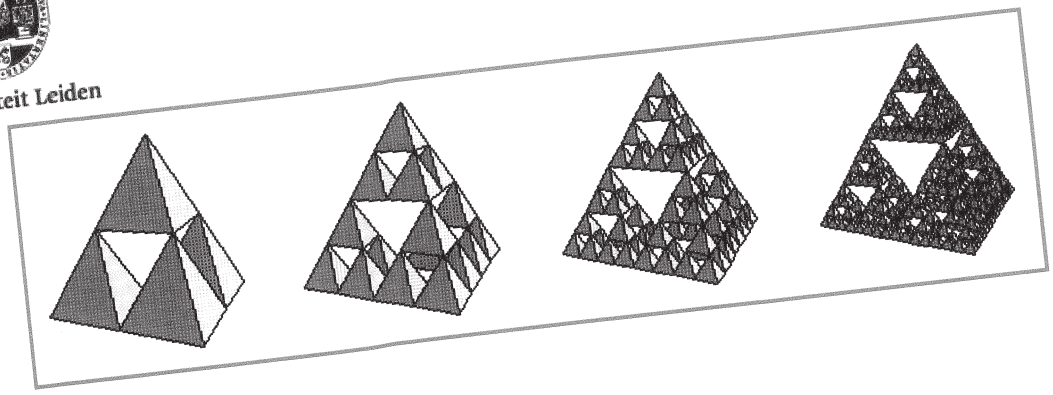

8. (**Particle Swarm Optimization, total: 10**) One of the algorithms for swarm-based optimization is called particle swarm optimization.

   a. Give a short general outline of the working mechanism of a PSO.
   b. What is meant with neighbourhood topology or communication network topology?
   c. Which communication network is commonly used in a Fully Informed Particle Swarm (FIPS) algorithm?
   d. Give for a certain particle at position $\mathbf{x}$, with velocity vector $\mathbf{v}$, its neighbourhood's best $\mathbf{x}_g$, and its personal best $\mathbf{x}_p$, a possible update rule for the velocity and position, each.
   e. What is meant by the inertia weight, and how does it affect the velocity update?

9. (**Swarm-based optimization, total: 10**) In the lecture, three types of communication were discussed: Point-to-point, broadcast-like, and indirect.

   a. For the following meta-heuristics, determine which communication type is used, and explain your answer: ACO, PSO, CA, firefly systems, SA.
   b. Which of these communication types is also known as stygmergy?

Total: 88 Points possible.