Introduction to Natural Computation

Lecture 1

Module Introduction and Examples\textsuperscript{1}

Xin Yao

\textsuperscript{1}Notes adapted from Intro to NC Year 2010.
Lecturers

Professor Xin Yao
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Other Teaching Personnel

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**Dr. Shuo Wang**  
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MSc and ICY students’ tutorials  
Time and place: TBA
Office Hours

Questions on the topics of the lectures:
- Come to see the corresponding lecturer.

Questions on exercises, marks, maths and programming:
- Come to see a teaching assistant.

Please, email the corresponding lecturer / teaching assistant before coming.
Lecture plan for the semester on the web site.

Two lectures per week:
- Wednesdays 9-10am, LT3 Sports and Exercise Science
- Thursdays 12-1pm, G15 Muirhead Tower

Lecture attendance: Required, but we won’t take a roll call.

Lecture notes:
- Available after each lecture.
- Lectures notes list keywords only, not to replace the required readings

Module web site: http://www.cs.bham.ac.uk/internal/courses/intro-nc
70% examination (1.5 hours closed book), 30% continuous assessment

Continuous assessment:
- Weekly exercises, total 18%
  - Released almost every Thursday
  - Deadline every Wednesday of the next week
  - Hand in to the CS reception before 12 noon
  - Mark zero for late submissions
  - If extension of deadline needed, email welfare
- Coursework, 12%
  - Released on 05/11
  - Deadline at noon on 03/12

Resit: 100% examination (1.5 hours closed book)

Pass mark: 40% for undergraduates, 50% for masters students
What’s So Unnatural About CS Now?

- Brittle and inflexible
- Doesn’t learn and never grows up
- Hopeless in dealing with noisy and inaccurate information
- Hopeless in dealing with uncertain environments
- ...

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Solution? Mother Nature
What Is Natural Computation?

It studies **computational systems** that get inspirations and borrow ideas from natural systems, including biological, physical, chemical, social and economical systems. It includes

- Evolutionary Computation,
- Neural Computation,
- Social Computation,
- Molecular Computation,
- Quantum Computation,
- ...
Borrowing Ideas from Nature...
Natural Computation = Nature Inspired Computation
Evolutionary Algorithms

Population of solutions

Select the best

Parents

Combine features of parents

Make some random changes (mutation)

Offspring

Replace the worst
Evolutionary Algorithms

Example: Factory Planning and Scheduling

i2 Technologies, USA: “The i2 Factory Planning and Scheduling solution...

- “... proven best practice templates used in 12+ industries and more than 800 installs ...”
- “... brings together the most advanced planning and scheduling engine, Factory Planner, and i2’s patented genetic algorithms for solving the most tedious scheduling problems ...”

Example: M&S Uses Genetic IT to Create Best Displays

High-street retailer Marks & Spencer is using genetic algorithm technology to transform its in-store displays and improve stock management.

(ComputerWeekly, Tuesday 17 February 2004)
http://www.computerweekly.com/Articles/2004/02/16/200284/Mamp%3BS-uses-genetic-IT-to-create-best-displays.htm
Artificial Neural Networks

- Extremely simplified model of a brain
- Artificial “neurons” connected to each other
- Can learn and generalise
- Good at perception tasks
- Fault tolerant
- Noise resistant
Artificial Neural Networks

Example: Recognition, Classification and Prediction

- Object recognition
- Medical diagnosis
- Credit card assessment
- Fraud detection
- Churn prediction
- Water quality prediction
- Traffic flow prediction
Human beings in markets follow different strategies in a parallel, decentralised and asynchronous system.

- Yet, the resource allocation achieved is theoretically optimal

- Economists refer to this emergent behaviour as Adam Smith’s “invisible hand”

- Similar ideas can be used for any resource-allocation problem
Craig Reynolds demonstrated with his *Boids* that even very simple local rules and interactions can give rise to apparently complex global behaviour.

The rules applied in the simplest Boids world are as follows:

- **separation**: keep your distance from other boids,
- **alignment**: steer towards the average heading of other local boids
- **cohesion**: steer to move toward the average position (center of mass) of local boids

More complex rules can be added, such as obstacle avoidance and goal seeking.


Also see http://www.red3d.com/cwr/boids/
Swarm Intelligence

Example: Swarm Intelligence for Animation

- Flocking can be simulated in computers
- Flocking uses rapid short-range communication
- Behaviour governed by mutual avoidance, alignment and affinity
- Simple rules generate complex behaviour
Swarm Intelligence

Example: Ant Colony Optimisation

Technique for solving problems which can be expressed as finding good paths through graphs.

Each ant tries to find a route between its nest and a food source.

The behaviour of each ant is as follows:

- Wander randomly at first.
- If food is found, return to the nest laying down a pheromone trail.
- If pheromone is found, with some increased probability follow the pheromone trail.
- Once back at the nest, go out again in search of food.

Pheromones evaporate over time, such that unless they are reinforced by more ants, they will disappear.
Swarm Intelligence

Example: Ant Colony Optimisation

1. The first ant wanders randomly until it finds the food source (F), then it returns to the nest (N), laying a pheromone trail.

2. Other ants follow one of the four possible paths at random, also laying pheromone trails. Since the ants on the shortest path lay pheromone trails faster, this path gets reinforced with more pheromone, making it more appealing to future ants.

3. The ants become increasingly likely to follow the shortest path since it has the most pheromone. The pheromone trails of the longer paths evaporate.

Over the course of this module, we will look at:

- Cellular automata
- Coordination amongst fireflies
- Swarm intelligence
- Modelling the spread of diseases
- Artificial life
- Market-based control of computation systems
- Neural networks
- Evolutionary algorithms
- ...and more!
Why Natural Computation?

- **Flexible:** applicable to different problems.
- **Robust:** can deal with noise and uncertainty.
- **Adaptive:** can deal with dynamic environments through self-adaptation.
- **Autonomous:** can function without human intervention.
- **Decentralised:** without a central authority.
Further Reading