Genetic Algorithm

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Outline

- Background: Biological Genetics & GA
- Two Examples
- Some Applications
- Online Demos* (if the time allows)

Introduction

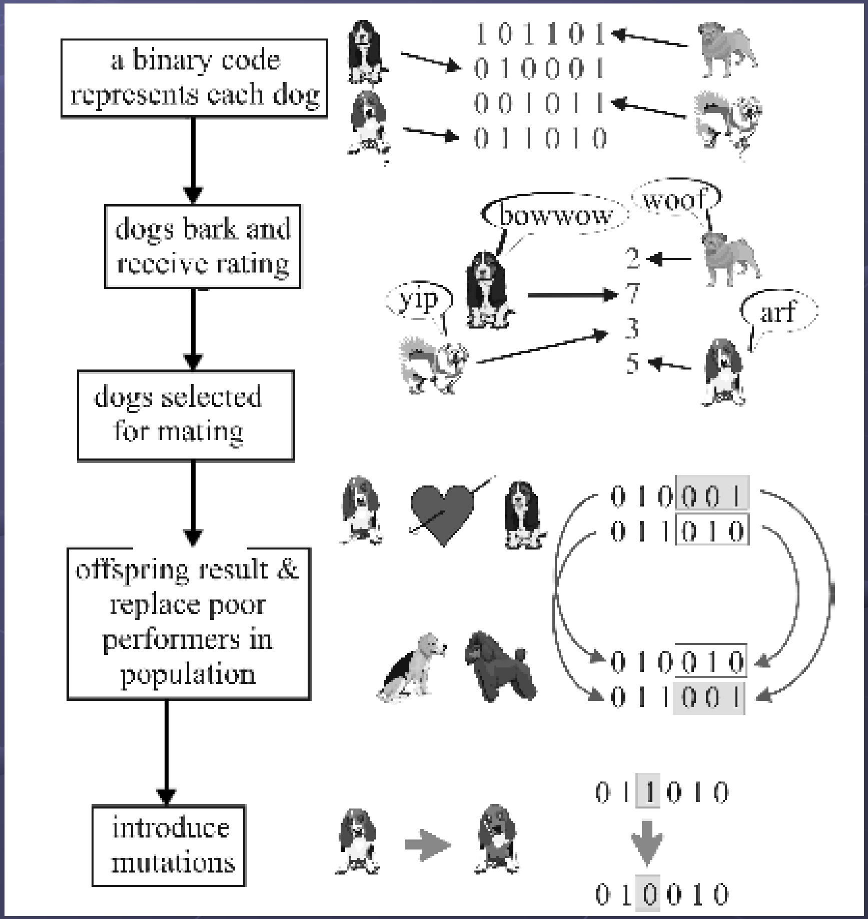
- What is Genetic Algorithms (GA)?
  - A search technique used in computing to find true or approximate solutions to optimization and search problems (Wikipedia).
  - Suitable for searching problems with extremely huge search space that are hard or even impossible to be solved by traditional analytical methods or minimum-seeking algorithms (i.e. exhaustive search or calculus based optimization method)
  - Inspired by Darwin’s theory of evolution and the study of genetics such as inheritance, mutation, selection, and crossover (also called recombination), etc.
  - Originally invented by John Holland from the University of Michigan in the early seventies(1975)

Biological Background

- Organism:
  - Cell – the basic part of all living organism
  - Chromosome – each cell contains the same number of chromosomes
  - Gene – a chromosome consists of genes, the traits are encoded in the form of DNAs or genetic codes
- Reproduction:
  - Inheritance – offspring inherits the traits (genetic code) from parents
  - Crossover – the portion of mother's and father's chromosomes
  - Mutation – a random change may occurs in the offspring's genetic code
- Natural selection & evolution (Darwin's theory)
  - Fitness – how successful is an individual fit for the environment, determined by genetic code.
  - Natural selection- higher fitness value means higher survive rate
  - Evolution – on the long run, the most recent survived generation intend to have a high fitness

GA v.s Biological Genetics

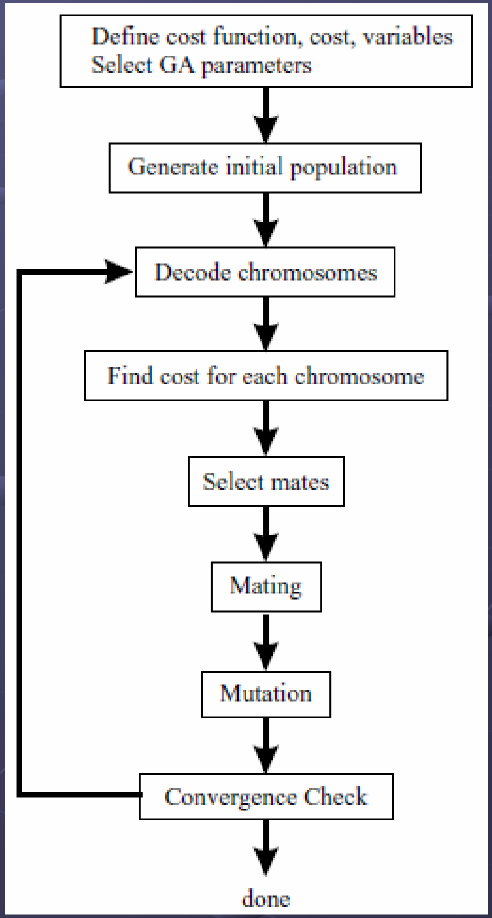
- GA is the simulation of the natural selection and evolution on a computer
- An intuitive analogy



[Haupt2004]

Flowchart

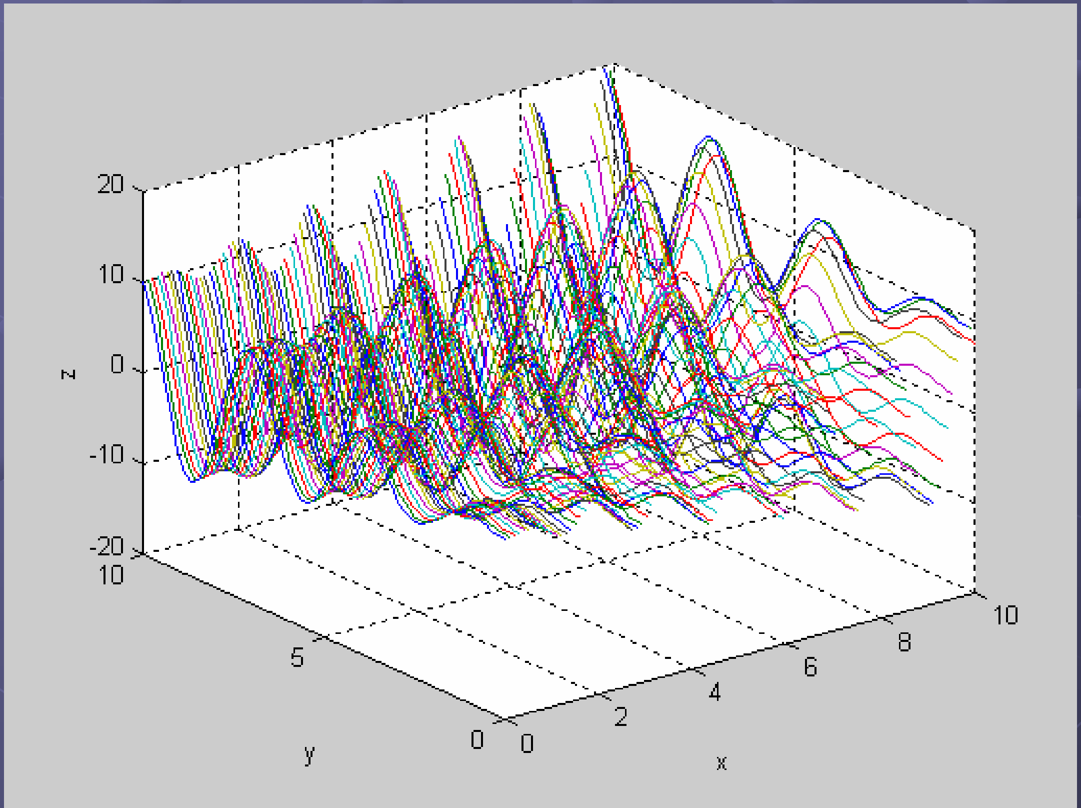
- The GA starts with an initial population that consists of a set of individuals, each individual is represented by a unique binary string or float-point value (chromosome).
- Individuals are evaluated (based on their fitness), selected, and mated
- New individuals are generated in the principles of inheritance and variation. Individuals with low fitness are discarded.
- The iteration continues until a convergence requirement is fulfilled



[Haupt2004]

A Basic Example

- Problem: find the global maximum point of the following surface (2D function):



$$f(x,y) = x\sin(4x) + 1.1y\sin(2y)$$

$$0 \le x \le 10, 0 \le y \le 10$$

GA Steps

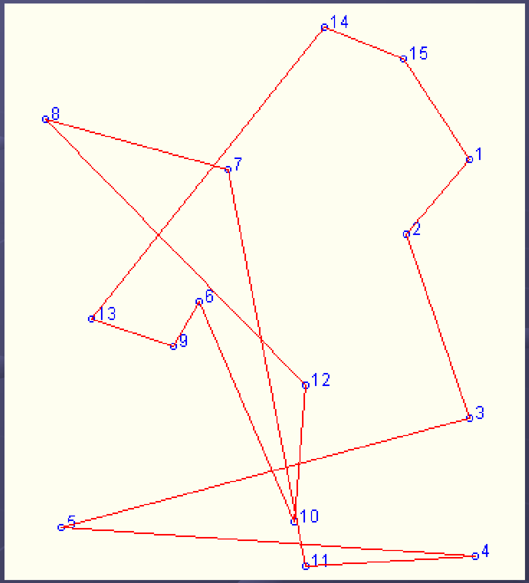
- Chromosome Encoding: chromosome = [x, y]
- Fitness Function: *fitness = x*sin(4*x)+1.1*y*sin(2*y)*
- First Generation: 16 random individuals (chromosomes)
- Selection: 8 most-fit chromosomes survive, others are discarded
- Pairing: 4 pairs of parents are randomly selected.
- Mating & Crossover: offspring is produced by parents:
  - blending method: p_child = b * p_pa + (1-b) * p_ma,
  - p is one of the variables (x or y), b is a random number between [0, 1], same or different b for each variable.
- Mutation: a few of randomly selected variables are replaced by uniform random numbers.
- New Generation: made up by survived parents and offspring
- Iteration: the above process is iterated until the global maximum is found, or the predefined iteration number is exceeded.

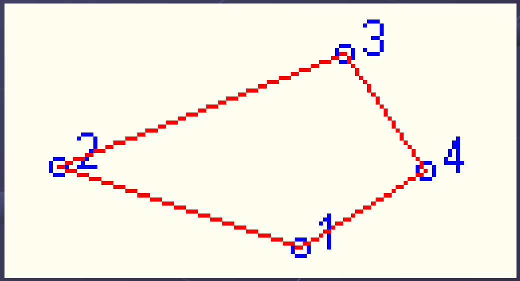
Parameters

- Elitism:
  - One or a few best chromosomes are copied directly to the next generation, without changes
- Crossover probability: between [0, 1]
  - 0%: all offspring is exact copy of parents (but the new generation is not necessarily the same!)
  - 100%: all offspring is made by crossover
- Mutation probability: between [0, 1]
  - 0%: no individual is changed
  - 100%: all individuals are changed (random searching)
- Population Size:
  - Too small: the search space is limited
  - Too large: slows down

A Classical Example

- Traveling Salesman Problem (TSP):
  - Randomly located cities, the traveling salesman has to minimize the traveling distance while visit all of the cities
  - Essentially an ordering problem: finding an optimal ordering for a sequence of N items
  - Other similar problem: scheduling, routing, resource allocation, assignment
- A “natural” encoding method might be problematic!
  - The simplest case: four cities: 1, 2, 3, 4 – each with a unique bit-string encoding
  - Considering two individuals: 3-2-1-4, and 4-1-2-3
  - A crossover between the parents may produce wrong offspring, i.e. 3-2-2-3!
- “Random-key” encoding method [Forrest1993].
- In fact, for each specific GA problem, designing the encoding method is an important issue, so do the
  - crossover and mutation methods.
  - selection and pairing methods.
  - Refer to: http://cs.felk.cvut.cz/~xobitko/ga/cromu.html





Random-key Method*

- The chromosome is encoded by a bit string, which is divided into N segments of k bits [Forrest1993]
  - N is the same as the cities number
  - $2^k >> N$
- For example: N = 4, k = 4 (16 bits for each chromosome)
- A randomly generated chromosome: [0101 0011 0001 1001], interpreted as decimal numbers: [5-3-1-9]
- City numbers are encoding as the segment position, sequence of traveling route is up to the relative value of each segment.
  - Segment 3 has the smallest value 1, so city 3 is the first.
  - Segment 2 has the second smallest value 3, so city 2 is the second, and so on and so forth
  - Thus, pattern [5-3-1-9] represents the tour [3-2-1-4]
- The offspring’s legality is guaranteed, no matter what “strange” chromosome (bit string) is produced via crossover and/or mutation
- Also called permutation encoding

Online Demos*

- Global Maximum of 1D Function:

  http://cs.felk.cvut.cz/~xobitko/ga/example_f.html

- Global Maximum of 2D Function:

  http://cs.felk.cvut.cz/~xobitko/ga/example3d.html

- TSP:

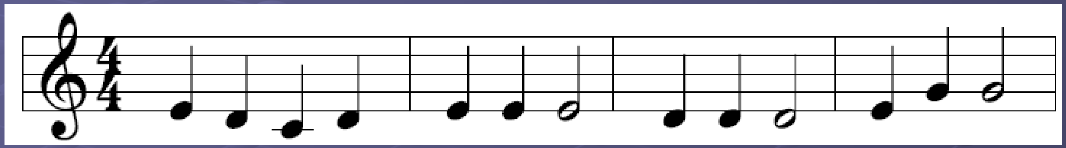
  http://cs.felk.cvut.cz/~xobitko/ga/tspexample.html

Examples in Music Tech

- Granular Synthesis Regulation [Fujinaga1994]
  - Each grain's parameters (freq, amp, etc.) mapped to a chromosome's bit string
  - GA parameters (crossover rate, mutation rate, etc.) control the change in the grain population
- FM Synthesis Parameters Optimization [Lai2006]
  - FM parameters (carrier freq, mod freq, amp) mapped to a chromosome’s bit string
  - Spectrum similarity of target sound and synthesized sound is evaluated as fitness
- Automatic Generation of Sound Synthesis [Garcia2000]
  - Not only the parameters of synthesis, but the synthesis building block are regarded as genes
  - Generates new topologies and synthesize the target sound
  - Genetic Programming
    - Tree coding
    - Lisp Implementation [Forrest1993]

Examples in Creativity

- Music Searching:



- Encoding:
  - One gene (3 bits) for each beat
  - 000 for hold, 001 – 111 mapping to A to G
  - Chromosome: [EDCDEEEholdDDDholdEGGhold]
  - Encoded as [101 100 011 100 101 101 101 000 100 100 100 000 101 111 111 000]
- Fitness Function:
  - Objective:

$$cost = \sum_{n=1}^{48} |answer[n] - guess[n]|$$

  - Subjective: Interactive ranking by ear
- Extension of this INTERACTIVE idea:
  - GA composing and other genetic art
  - New product design

Applications List

- General
  - Optimization (strategy planning, robot trajectory, sequence scheduling)
  - Modeling dynamic systems (ecologic systems, immune systems, genetic systems, social systems)
  - Evolving LISP programs (genetic programming)
  - Etc.
- Music Engineering / Composing
  - Synthesis system design
  - Synthesis parameters optimization
  - Sound synchronization, animation
  - Timbre recognition
  - Fugue generation
  - Jazz solos generation
  - Waveform evolving
  - Etc.
- Many others up to your imagination

References

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Questions?

- Please ask…