CSE/ECE 848 Introduction to Evolutionary Computation

Module 2, Lecture 5, Part 2
From Evolution to Evolutionary Computation

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(Many of the original slides were authored by Prof. Wolfgang Banzhaf)

Scientific Motivations for Evolutionary Computation

- EC as a scientific tool (to *study evolution*):
- Can use to test hypotheses (e.g. models) in biology, sociology, etc.
- For example, EC might give answers to the following questions:
  - Why homologous chromosomes?
  - Advantages of sexual reproduction?
  - Functions of unexpressed genes and codons?
  - How does altruism evolve?

Engineering Motivations for EC

- Can use for (some examples):
  - Function optimization
  - Combinatorial optimization
  - Machine learning
  - Engineering design
  - Fitting models/choosing model architectures
  - Feature selection in clustering/classification
- Fitness function often involves:
  - Simulation software executed for each individual (finite element, circuit simulation, MatLab, CFD, computational electromagnetics, etc.) to determine its fitness, or suitability for THIS application
  - Analysis software (e.g., Mathematica)
  - Compilers (for evolving bug fixes, etc.)
  - Artificial (deep) neural nets or other ML codes

How to Apply EC to Solve a Problem

- Uses the evolutionary analogy, "survival of fittest"
- To harness evolution as a search tool, we must provide an *environment structured* so that the fittest individual IS the desired outcome of our search—the solution to our problem! We must define:
  - Representation (of the genome)
  - Operators (genetic—crossover, mutation, etc.)
  - Fitness function (maps genotype to phenotype, subjects the phenotype to the environment, assigns it a fitness score

How Applicable is EC, Anyway?

- If a deterministic algorithm can solve the problem, and scales well enough to accommodate the problem to be solved, it's usually faster!
- BUT many deterministic algorithms do NOT scale well, so become useless as problem size grows
- EC is not *fast* in some sense; but can usually be made to scale relatively well, so can often approximate optimal solutions not otherwise obtainable—i.e., USEFUL solutions!
- EA's are stochastic – use random numbers, can get different answers on each run! But are *not* random search and are not Monte Carlo methods

What constitutes EC?

A few approaches considered part of the EC family:

- genetic algorithms
- genetic programming
- evolutionary strategies
- evolutionary programming
- classifier systems
- complex adaptive systems
- artificial life

The EC metaphor

- A population of individuals exists in an environment with limited resources
- Competition for resources causes selection of fitter individuals better adapted to the environment
- Individuals are progenitors for the next generation through recombination and mutation (or perhaps other operators)
- The new individuals have their fitnesses evaluated and compete (possibly with parents) for survival
- Over time, Natural Selection raises population fitness (degree of adaptation to present environment)

EC, the basics recapped:

- Most Evolutionary Algorithms (EA) are based on a combination of Darwinian Evolution and Mendelian Genetics
- Evolution: optimization and robust search for "good behavior" via "generate & test" of candidate solutions
- Genetics: encoding of behavior that must be "expressed", using a fairly simple alphabet
- EC usually represents all genetic material on a SINGLE chromosome, as a simplification—NOT even diploid, but a single DNA molecule, like a bacterium has
- Process is opportunistic and can only work within the framework of present individuals—i.e., the current population of solutions captures all you have learned so far about solving the problem

More on the Metaphor

- EAs fall into the category of “generate and test” algorithms
- They are stochastic, population-based algorithms, but NOT RANDOM SEARCH nor Monte Carlo
- Variation operators (such as mutation and recombination) create the necessary diversity and thereby facilitate novelty
- Selection reduces diversity and acts as a force pushing quality

The Fundamental EC Tension

- There is a tension: diversity vs selection
- Diversity is required to maintain novelty, but slows progress towards a/any solution
- (Diversity is associated with *exploration*, ability to search broadly in the domain)
- Selection is used to push progress but necessarily reduces diversity
- (Selection is associated with *exploitation* or *convergence*)
- **Managing this tension is the key to EC!!!**

Some Terms

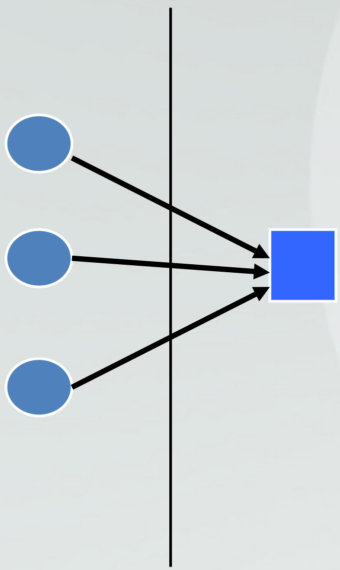
- Phenotype: Expressed behavior or solution, that which is optimized by evolution
- Genotype: Underlying representation, that which is manipulated by evolution (through operators like crossover or mutation)
- Genome (Chromosome): string representing the genetic representation for the problem
- Gene: subpart of genome (chromosome) that maps to a particular feature/behavior in the phenotype

More Terms

- Allele: a particular feature value of the gene
- Locus: position in the chromosome
- Deme: isolated, reproductive subpopulation, usually implying interaction with other subpopulations
- Epistasis: nonlinearity between genotype and phenotype caused by non-additive interaction of genes

More Terms (2)

Causes of nonlinearity

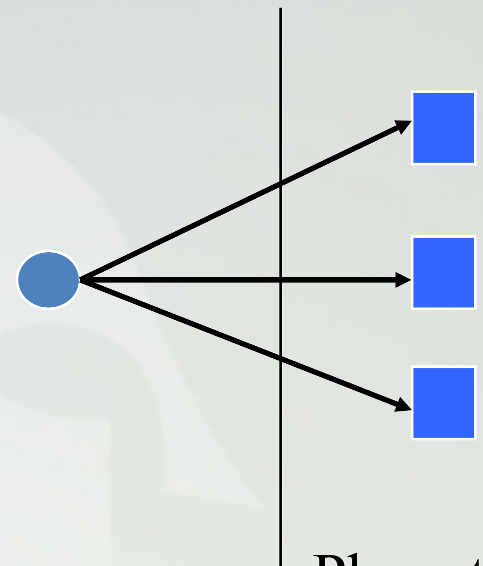


Genes Phenotypic trait

Polygeny

Polygenic interaction

Multifactorial trait



Gene Phenotypic Traits

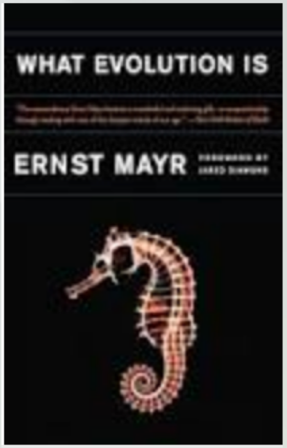
Pleiotropy

Paradigm: NeoDarwinism

- Life can be accounted for by physical processes operating on populations
- The main processes are:
  - reproduction
  - mutation/crossover (either error or variation)
  - competition (assuming limited resources)
  - selection (i.e., competitive replication)
- Sometimes summarized as VSI—Variation, Selection, and Inheritance—as the essential ingredients of evolution

More NeoDarwinism

From Mayr, "What Evolution Is":



- Individual is the primary target of selection
- Genetic variation is intrinsically stochastic
- Recombinant variation is dominant over mutation
- Evolution is gradual, however, with discontinuities
- Natural selection is not the only source of phenotypic variation
- Selection is probabilistic

How Natural Selection Works

- The individuals of a population which are fitter with respect to their environment tend to survive longer and reproduce more
- Their characteristics, encoded in their genes, are transmitted to their offspring and tend to propagate into new generations
- In sexual reproduction, the chromosomes of the offspring are a mix of those of their parents, with some chromosomes crossed over, so partly from one parent and partly the other
- An offspring's characteristics are partially inherited from its parents, and partially the result of new gene combinations created during reproduction

Next Up:

Prof. Banzhaf will talk about evolution in the context of the often-discussed Blind Watchmaker example argument