Biologically Inspired Computing

Solving Difficult Problems by Emulating Biological Systems and Other Real-World Phenomena

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Mathematical Approaches

- Differential Calculus
  - Best for smooth objective functions, solvable analytically.
- Steepest Descent
  - Best for smooth, well-behaved objective functions, not (practically) solvable analytically.
- Conjugate Gradient
  - Best for smooth – but not necessarily well-behaved – objective functions.
- Simplex method
  - Used for linear functions, linear constraints.
- …

Linear Surface

- Smoothest/simplest possible surface for finding solutions.
- Objective function is linear combination of input variables.
- Optima found on boundary points of feasible region.

Non-linear Continuous Surface

- Unbroken surface, but may have sharp bends.
- Objective function includes non-linear contributions from input variables and interactions between them.
- Optima at peaks/low points or boundaries.

Discontinous Surface

- Surface broken up into many separate regions (or even individual points).
- Objective functions are combinations of discontinuous input variables.
- Subject to “combinatorial explosion” in solution possibilities.
- Optima could be located virtually anywhere in the solution space.
- It may be acceptable to find a “good enough” solution, instead of the true optimum.

Biological Examples

- Stochastic hill climbing and random search
- Pheromone trails
- Colony communication and consensus
- …
- Evolution

Solution Techniques

- Stochastic search and hill climbing
- Simulated annealing
- Environmental reinforcement
- Swarm search
- Evolutionary algorithms

Stochastic Search & Hill Climbing

- On a real world solution surface, movement that exclusively follows the slope, or that stays in the vicinity of previous successful searches, is susceptible to settling quickly on local optima (solution points that are better than any others in the local neighborhood) that are not global optima.
- To succeed in these conditions, random movement is mixed with local "greedy" behavior, to search for global optima.
- If the slope or gradient (generalized rate of increase in objective function) isn't available for a given problem type, other local search behavior is interspersed with random movement.

Simulated Annealing

- Not biologically inspired, but similar in many respects to stochastic hill climbing.
- Solution process uses a “temperature” parameter that is progressively lowered (“cooled”) as the solution progresses.
- New solution candidate usually constructed by a random step from current solution.
- Temperature controls willingness to move from a current solution to a worse candidate: higher temperature = greater willingness.

(See attached `butterfly-3-sa.nlogo` for an example.)

Environmental Reinforcement

- Value of decisions taken in candidate solutions are stored in the environment (like pheromone trails), with strength scaled according to the overall value of the solution.
- New solution candidates weigh the apparent value of immediate decision alternatives vs. the "remembered" value from previous solutions.

(See attached `TSP Ants.nlogo` for an example.)

Swarm Search

- Many searches for optimal solutions running in parallel, with communication between searches.
- The path followed by an individual search is updated from step to step, with the motion "pulled" toward the best solution found so far by the swarm.
- There are similar approaches that are not biologically inspired – e.g. emulating the movement of charged particles in an electromagnetic field.

(See "Particle Swarm Optimization" model, in NetLogo Models Libary, for an example.)

Evolutionary Algorithms

- Candidate solutions survive and reproduce according to fitness (i.e. solution value): better solutions are more likely (but not guaranteed) to survive and reproduce.
- Genomes of new solutions are created by inheritance from one or more (usually two) parent solutions; copying errors (mutation) may be introduced.
- In some variants, the genotype of an individual solution may be an encoding of the decision variables (genetic algorithms) or an actual problem-solving/goal-seeking program (genetic programming).
- Other variants focus on phenotype and species-level attributes, rather than genomic encoding.

Challenge: Optimizing Butterfly Hill Climbing

- Rewrite the model design document for the purpose of optimization.
  - Select an appropriate optimization objective (e.g. minimize time for all to reach the highest point, maximize number reaching highest point).
  - Assume a stochastic hill climbing approach.
  - What new measures (if any) are needed?
  - What new agents, behaviors, and attributes (if any) should be included?
- How would your model design change if you were given
  - total number of local/global maxima?
  - height of local maxima vs. global?
  - degree of "flatness" of the terrain?
- Alternative models for optimization
  - What other biological models do you think would be effective in the butterfly hill climbing problem?
  - Would any be more effective than stochastic hill climbing?

Optimization in the Real World

- What problems do you see on a regular basis that could be treated as optimization problems?
- Are there any real world situations you see on a regular basis that you suspect are not addressed as optimization problems, but should be?

Resources

- Optimization materials from 2011 kickoff
  - "Optimization or Computational Solution Techniques for Mathematical Programming Problems", Bennett, Robey, Robey, Brown (http://supercomputingchallenge.org/kickoff/classes/Optimization.pdf)
- Recent Supercomputing Challenge finalist projects involving optimization
  - 2012
    - "Optimizing Community Detection", Team 56, La Cueva High School (http://supercomputingchallenge.org/archive/11-12/finalreports/56.pdf)
    - "ExcellAnts", Team 66, Los Alamos High School (http://supercomputingchallenge.org/archive/11-12/finalreports/66.pdf)
    - "Detection of Alzheimer's Disease Plaques", Team 82, Manzano High School (http://supercomputingchallenge.org/archive/11-12/finalreports/82.pdf)
    - "Ant Colony Conundrum", Team 118, Sat. Science & Math Academy (http://supercomputingchallenge.org/archive/11-12/finalreports/118.pdf)
  - 2011
    - "BrilliAnts", Team 56, Los Alamos High School (http://supercomputingchallenge.org/archive/10-11/finalreports/56.pdf)