Computational Intelligence

Unit # 1 - Introduction

Information

- Course wiki
  - http://cse659ci-f2014.wikispaces.com/
- Text/Reference Books
  - Andries Engelbrecht, Computational Intelligence: An Introduction, 2007
  - Daniel Ashlock, Evolutionary Computation for Modeling and Optimization, 2005
  - Gusz Eiben and Jim Smith, Introduction to Evolutionary Computing, 2007
  - Kenneth DeJong, Evolutionary Computation A Unified Approach, 2006

Marks Distribution

• Midterms	= 2 x 15 =	30%
• Final		40%
• Assignments (3-4)		15%
• Project		15%

Acknowledgement

- The slides of this lecture have been taken from the lecture slides of “CSE659 – Computational Intelligence” by Dr. Sajjad Haider.

Tentative Outline

- Evolutionary Algorithms
  - Genetic Algorithms
  - Evolutionary Strategies
  - Evolutionary Programming
- Swarm Intelligence
  - Ant Colony Optimization
  - Particle Swarm Optimization
- Artificial Neural Networks
- Reinforcement Learning
- Fuzzy Logic
- – Artificial Immune Systems
- Simulated Annealing
- Tabu Search
- Hybrid Techniques
- Other Algorithms (depending upon availability of time)
  - Harmony Search, Co-Evolution, Honey Bee Optimization, Artificial Life

Definition (Source: Wikipedia)

- Computational intelligence (CI) is a *set of Nature-inspired computational methodologies and approaches to address complex problems of the real world applications to which traditional methodologies and approaches are ineffective or infeasible.*
- It primarily includes Fuzzy logic systems, Neural Networks and Evolutionary Computation.
- In addition, CI also embraces techniques that stem from the above three or gravitate around one or more of them, such as Swarm intelligence and Artificial immune systems which can be seen as a part of Evolutionary Computation.

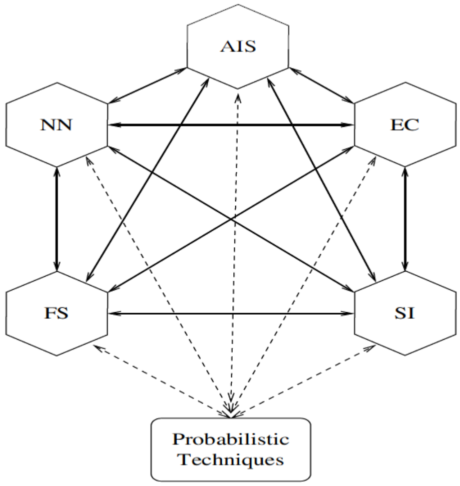
IEEE Computational Intelligence Society's Scope

- The Field of Interest of the Society shall be the *theory, design, application, and development of biologically and linguistically motivated computational paradigms emphasizing neural networks, connectionist systems, genetic algorithms, evolutionary programming, fuzzy systems, and hybrid intelligent systems in which these paradigms are contained.*

Excerpts from Engelbrecht's Book

- It is necessary to state that there are different definitions of what constitutes CI.
- This book reflects the opinion of the author, and may well cause some debate. For example, swarm intelligence (SI) and artificial immune systems (AIS) are classified as CI paradigms, while many researchers consider these paradigms to belong only under Artificial Life.
- However, both particle swarm optimization (PSO) and ant colony optimization (ACO), as treated under SI, satisfy the definition of CI given above, and are therefore included in this book as being CI techniques. The same applies to AISs

Computational Intteligence



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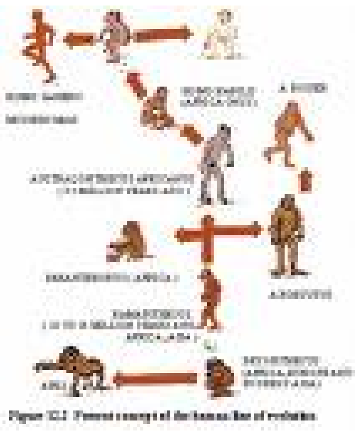
Evolutionary Algorithm (Source: Wikipedia)

- **Evolution** (also known as biological or organic evolution) is the change over time in one or more inherited traits found in populations of organisms.
- In artificial intelligence, an evolutionary algorithm (EA) is a parallel search scheme that is inspired by biological evolution.
- An EA uses some mechanisms inspired by biological evolution: reproduction, mutation, recombination, and selection.
- EAs have been used successfully for optimization problems in several fields



Swarm Intelligence

- The collective behavior that emerges from a group of social insects has been dubbed ***Swarm Intelligence***.
- Social Insects work without supervision.
- Their teamwork is largely self-organized, and coordination arises from the different interactions among individuals in the colony.
- Although these interactions might be primitive, taken together they result in efficient solutions to difficult problems.

Swarm Intelligence

- There are two popular swarm inspired methods in computational intelligence areas:
  - Ant colony optimization (ACO)
  - Particle swarm optimization (PSO)
- ACO was inspired by the behaviors of ants and has many successful applications in discrete optimization problems.
- The particle swarm concept originated as a simulation of simplified social system. The original intent was to graphically simulate the choreography of bird of a bird block or fish school. However, it was found that particle swarm model can be used as an optimizer.

Examples

MASON Demo

Artificial Neural Networks

- Artificial Neural networks are biologically motivated computing structures that are conceptually modeled after the brain.
- The neural network is made up of a highly connected network of individual computing elements (mimicking neurons) that collectively can be used to solve interesting and difficult problems.

Artificial Immune System

- Artificial Immune Systems (AIS) are a class of computationally intelligent systems inspired by the principles and processes of the biological immune system. The algorithms typically exploit the immune system's characteristics of learning and memory to solve a problem.

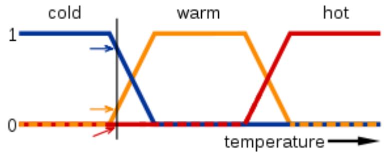
Reinforcement Learning

- An RL agent learns by interacting with its environment and observing the results of these interactions. This mimics the fundamental way in which humans (and animals alike) learn.

Fuzzy Logic

- **Fuzzy logic** is a form of reasoning that is approximate rather than fixed and exact.
- For example,
  - When you are at 10 meters from the junction start braking at 50% pedal level.

  Can be rephrased as:
  - When you are near the junction, start braking slowly.

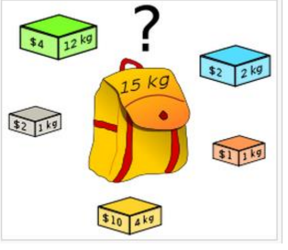


Ms Pacman Controller

What is Optimization?

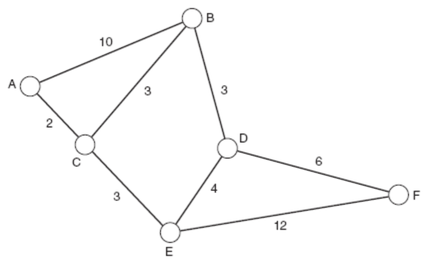
Knapsack Problem

- Given a set of items, each with a weight and a value, determine the number of each item to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible.



Travelling Salesman Problem

- Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once and returns to the origin city?



Profit Maximization

- An automobile manufacturer produces several kinds of cars. Each kind requires a certain amount of factory time per car to produce, and yields a certain profit per car. A certain amount of factory time has been scheduled for the next week, and it is desired to use all this time; but at least a certain number of each kind of car must be manufactured to meet dealer requirements.

Other similar problems

- Resource Allocations
- Scheduling Problems
- Shelf Placement
- Graph Coloring
- VLSI Design
- ....
- And many more combinatorial optimization problems

Search vs. Optimization

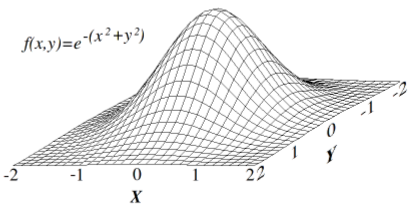
- The difference between optimization algorithms and search algorithms is that when performing a search algorithm, we know the element xi we are looking for and just want to find its position in a structured set.
- In global optimization algorithms on the other hand we do not even know the characteristics of the xi beforehand and are only given some criteria which describe if a given configuration is good or not.

Hill Climbing

- General Idea:
  - Start wherever
  - Always choose the best neighbor
  - If no neighbors have better scores than current, quit
- Why can this be a terrible idea?

Local vs Global Optimum?

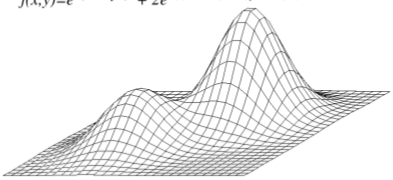
What is the optimum point?



Local vs Global Optimum?

What do you think about the optimum point now?

$$f(x,y)=e^{-(x^2+y^2)}+2e^{-((x-1.7)^2+(y-1.7)^2)}$$



Greedy Algorithm

(Source: Wikipedia)

- Greedy algorithms can be characterized as being 'short sighted', and as 'non-recoverable'. They are ideal only for problems which have 'optimal substructure'. Despite this, greedy algorithms are best suited for simple problems.
- **Greedy choice property**
- We can make whatever choice seems best at the moment and then solve the sub-problems that arise later. The choice made by a greedy algorithm may depend on choices made so far but not on future choices or all the solutions to the sub-problem. It iteratively makes one greedy choice after another, reducing each given problem into a smaller one. In other words, a greedy algorithm never reconsiders its choices.

Global Optimization

- Global optimization is the branch of applied mathematics and numerical analysis that deals with the optimization of single or maybe even multiple, possible conflicting, criteria.
- These criteria are expressed as a set of mathematical functions F = {f1, f2, . . . , fn}, the so-called objective functions.
- The result of the optimization process is the set of inputs for which these objective functions return optimal values.

Local Maximum and Minimum

Definition 2 (Local Maximum). A (local) maximum $\hat{x}_l \in X$ of an objective function $f : X \mapsto \mathbb{R}$ is an input element with $f(\hat{x}_l) \geq f(x)$ for all x neighboring $\hat{x}_l$.

If $X \subseteq \mathbb{R}$, we can write:

$$\hat{x}_l : \exists \varepsilon > 0 : f(\hat{x}_l) \geq f(x) \; \forall x \in X, |x - \hat{x}_l| < \varepsilon \quad (1.1)$$

Definition 3 (Local Minimum). A (local) minimum $\check{x}_l \in X$ of an objective function $f : X \mapsto \mathbb{R}$ is an input element with $f(\check{x}_l) \leq f(x)$ for all x neighboring $\check{x}_l$.

If $X \subseteq \mathbb{R}$, we can write:

$$\check{x}_l : \exists \varepsilon > 0 : f(\check{x}_l) \leq f(x) \; \forall x \in X, |x - \check{x}_l| < \varepsilon \quad (1.2)$$

Definition 4 (Local Optimum). An (local) optimum $x^\star_l \in X$ of an objective function $f : X \mapsto \mathbb{R}$ is either a local maximum or a local minimum (or both).

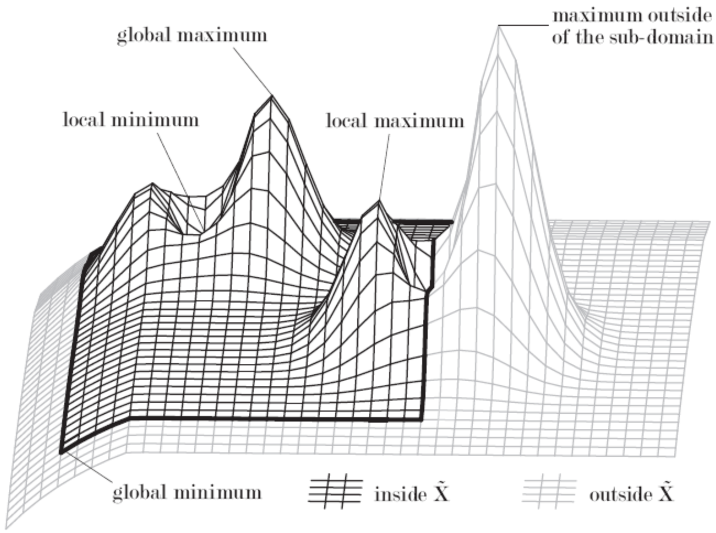
Global Maximum and Minimum

Definition 5 (Global Maximum). A global maximum $\hat{x} \in X$ of an objective function $f : X \mapsto \mathbb{R}$ is an input element with $f(\hat{x}) \geq f(x) \forall x \in X$.

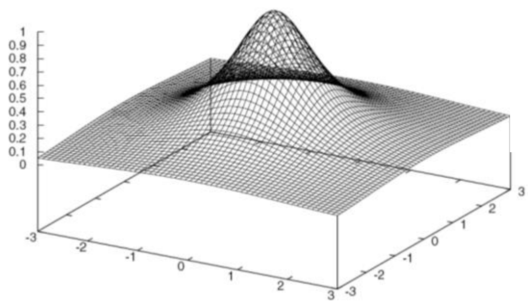
Definition 6 (Global Minimum). A global minimum $\check{x} \in X$ of an objective function $f : X \mapsto \mathbb{R}$ is an input element with $f(\check{x}) \leq f(x) \forall x \in X$.

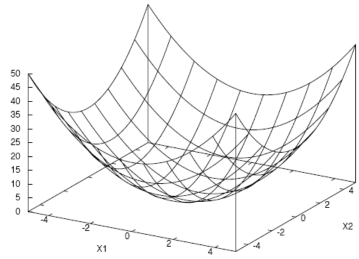
Definition 7 (Global Optimum). A global optimum $x^{\star} \in X$ of an objective function $f : X \mapsto \mathbb{R}$ is either a global maximum or a global minimum (or both).

Global and Local Optima

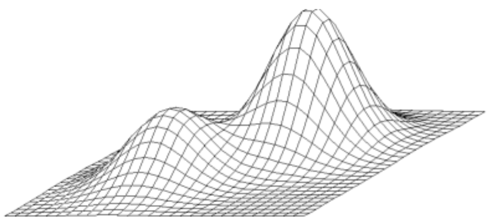


Simple Functions





Complex Functions



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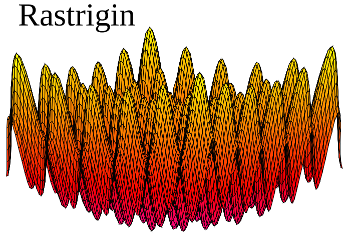

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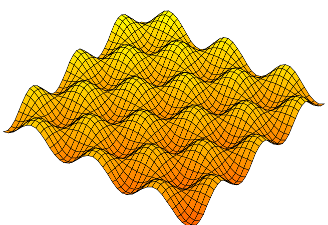

Rosenbrock