Crazy Ideas > Science > Engineering > Business

Science is to test crazy ideas — Engineering is to put these ideas into Business Lucky Students 😊

Red thread through this lecture

- 01 Examples of medical applications for EA
- 02 Nature-Inspired Computing
- 03 Ant-Colony Optimization
- 04 Collective Intelligence - Human-in-the-Loop
- 05 Multi-Agent (Hybrid) Systems
- 06 Neuroevolution
- 07 Genetic Algorithms

Reflection

Five Mainstreams in Machine Learning

- Symbolic ML
  - First order logic, inverse deduction
  - Tom Mitchell, Steve Muggleton, Ross Quinlan, ...
- Bayesian ML
  - Statistical learning
  - Judea Pearl, Michael Jordan, David Heckermann, ...
- Cognitive ML
  - Analogisms from Psychology, Kernel machines
  - Vladimir Vapnik, Peter Hart, Douglas Hofstadter, ...
- Connectionist ML
  - Neuroscience, Backpropagation
  - Geoffrey Hinton, Yoshua Bengio, Yann LeCun, ...
- Evolutionary ML
  - Nature-inspired concepts, genetic programming
  - John Holland (1929-2015), John Koza, Hod Lipson, ...
01 Applying Evolutionary computation to solve medical problems

Example Wisconsin breast cancer diagnosis

Feature selection with PSO together with ANN

Backpropagation ANN

Example for PSO: better results than “deep learning”

Open scientific issues and important research trends

- Whenever a decision is required, it is possible to find a niche for evolutionary techniques [1]
- Two relevant (and difficult!) questions:
  1) For a given problem: what is the best algorithm?
  2) For a given algorithm: what is the problem to solve?


02 Nature Inspired Computing

Why study Natural Computing?
- New forms of synthesizing and understanding nature
- Novel problem solving techniques
- New computing paradigms

Natural Computing Concepts are very useful for us
- Entity (agent)
- Parallelism
- Interactivity
- Connectivity
- Stigmergy (*)
- Adaptation
- Feedback
- Self-Organization
- No Self-Organization
- Complexity

(*) General mechanism that relates to both individual and colony behaviors – individual behaviors modify environment – Environment modifies behavior of other individuals – Indirect communication – Example: Ant workers stimulated to act during nest building according to construction of other workers

From Macrocosm to Microcosm (structural dimensions)
- Population: Collective Intelligence – Swarm Computing (Crowdsourcing HIL)
- Population: Individual – Artificial Life
- Population: Intra-Individual – Evolutionary Computing
- Individual: Neural Networks (Deep Learning)
- Individual: Intra-Individual – Immuno-Computing
- Molecules: Molecular Computing, Biocomputing
- Atoms: Simulated Annealing
- Subatomic: Quantum Computing

Example: Game of Life, John H. Conway (1970)

A brief overview of some nature inspired algorithms ...

http://www.naturalcomputing.com/issue/2010/10/10

Recommended Books

http://machinedlearningmastery.com/
Three of the more important swarm based approaches

- Particle Swarm Optimization (PSO)
  - based on social behaviour of bird flocks used as method for continuous optimization problems
- Artificial Bee Colonies (ABC)
  - Algorithms based on foraging of honey bee swarms used for continuous optimization problems
- Ant Colony Optimization (ACO)
  - Algorithms based on social behaviour of ants, used as metaheuristic for (hard) combinatorial optimization problems (e.g. for TSP-like problems)

Recommended Books

- Ant Colony Optimization
- Ant Colony Optimization and Constraint Programming
- Swarm Intelligence

Social insects show collective intelligence

Examples of social intelligent insects:

- Ants
- Termites
- Bees
- Wasps, etc

Some facts:

- 2% of all insects are social
- 50% of all social insects are ants
- Total weight of ants is about the total weight of humans
- Ants colonize world since 100 M years!!! humans only 5 M years...

Thanks to the UACS Natural Computing Group Leiden University

How to find good solutions?

- $\forall p, q \in \text{Population}: \text{dist}(p, g, q) \leq 2$
- Population
- Topological Neighbours

Ants are search machines

- Ants wander randomly and search for food
- If an ant finds food it returns home laying down a pheromone trail on its way back
- Other ants stumble upon the trail and start following this pheromone trail
- Other ants also return home and also deposit pheromones on their way back (reinforcing the trail) – when a path is blocked they explore alternative routes ...

03 Ant Colony Algorithms ACO

Ant colonies are extremely interesting ...

Ants as a inspiration for collective intelligence

- http://lifeconferenceANTS-2016
- http://www.darford.edu/bmgardiner/

Ant Colony Optimization (ACO) by Marco Dorigo

- Probabilistic optimization inspired by interaction of ants in nature.
- Individual ants are blind and dumb, but ant colonies show complex and smart behavior as a result of low-level based communications.
- Useful for computational problems which can be reduced to finding good paths in graphs.

Goal: Finding the shortest path (graph theory problem)

Reasons why ants find the shortest path (minimum linking model):
- 1) Earlier pheromones (the trail is completed earlier)
- 2) More pheromone (higher ant density)
- 3) Younger pheromone (less diffusion)

Soon, the ants will find the shortest path between their home and the food.

ACO-Pseudocode

initialize pheromones $\tau_{ij}$
for each iteration do
  for $k = 1$ to number of ants do
    set out ant $k$ at start node
    while ant $k$ has not build a solution do
      choose the next node of the path
    enddo
  enddo
endfor
update pheromones
endfor
return best solution found

What is the probability for selecting a particular path?

$$p_{ij} = \frac{[\tau_{ij}]^\alpha \cdot \eta_{ij}^\beta}{\sum_{l \in J_i} [\tau_{il}]^\alpha \cdot \eta_{il}^\beta}$$

- $p_{ij}$ - probability of ants that they, at a particular node $i$, select the route from node $i \rightarrow j$ ("heuristic desirability")
- $\alpha > 0$ and $\beta > 0$ - the influence parameters (the history coefficient $\beta$ and heuristic coefficient $\alpha$) usually $\alpha = \beta = 2 < 5$
- $\tau_{ij}$ - the pheromone value for the components, i.e., the amount of pheromone on edge $(i,j)$
- $\eta_{ij}$ - the set of usable components
- $J_i$ - the set of nodes that ant $k$ can reach from $i$ (tabu list)
- $\eta_{ij} = \frac{1}{\sum_{k=0}^m \Delta r_{ij}^k}$ - attractiveness computed by a heuristic, indicating the "a-priori desirability" of the move

ACO Basic Algorithm

initialize pheromones $\tau_{ij}$
for each iteration do
  for $i = 1$ to number of ants do
    build a solution by applying ($e-1$) times:
      at city $i$, choose the next city $j$ with probability given on next slide;
    endfor
  endfor
  eval the length of every solution build;
  if an improved solution is found
    then update the best solution;
  endif
endfor
update pheromones (slides 11&12);
for:
  return best solution found;
endfor

Step 1: Pheromone update

The pheromone on each edge is updated as:

$$\tau_{ij} = (1 - \rho) \cdot \tau_{ij} + \Delta \tau_{ij}$$

With:
- $\rho$ - the evaporation rate of the 'old' pheromone
- $\Delta \tau_{ij}$ - the 'new' pheromone that is deposited by all ants on edge $(ij)$ calculated as:
  $$\Delta \tau_{ij} = \sum_{k=0}^m \Delta r_{ij}^k$$
The pheromone that is deposited on edge \((i,j)\) by ant \(k\) is calculated as:

\[
\Delta r^k_{ij} = \begin{cases} 
Q / l_k & \text{if } (i,j) \in T_k \\
0 & \text{otherwise}
\end{cases}
\]

With:
- \(Q\): a heuristic parameter
- \(T_k\): the path traversed by ant \(k\)
- \(l_k\): the length of \(T_k\) calculated as the sum of the lengths of all the edges of \(T_k\)

### Use of heuristic information
- The attractiveness \(\eta_{ij}\) of edge \((i,j)\) is computed by a heuristic, indicating the a-priori desirability of that particular move.
- The pheromone trail level \(\tau_{ij}\) of edge \((i,j)\) indicates how proficient it was in the past.
- \(\alpha = 0\) is a greedy approach and \(\beta = 0\) represents the selection of tours that may not be optimal.
- Consequently, we speak of a “trade-off” between speed and quality.

### Excursus:
**Traveling Salesman Problem = hard**

### Dynamic Gamma Knife Radiosurgery is a TSP problem
http://www.dynaknarcancer.com

### Protein Design is a hard problem

### Protein Design is a big challenge and is important for PM

### Protein Folding is a TSP

### Travelling Salesman Problem (TSP) with ACO
- Desirability \(\eta_{ij} = \frac{1}{d_{ij}}\)
- The tabu-list contains all places (=“cities”) an ant has visited already.
- \(N = e\)
- Adding “elitary ant” with
- \(\alpha = 1, \beta = 5, \rho = 0.5, Q = 100, t_0 = 10^{-6}, b = 5\)

\[
\tau_{ij} = (1 - \rho) \cdot \tau_{ij} + \Delta \tau_{ij} + b \Delta \tau_{best}^b
\]

\[
\Delta \tau_{best}^b = \begin{cases} 
Q / l_{best} & \text{if } (i,j) \in \text{best} \\
0 & \text{otherwise}
\end{cases}
\]

### Advantages / Disadvantages
**Advantages:**
- Applicable to a broad range of optimization problems.
- Can be used in dynamic applications (adapts to changes such as new distances, etc.).
- Can compete with other global optimization techniques like genetic algorithms and simulated annealing.

**Disadvantages:**
- Only applicable for discrete problems.
- Theoretical analysis is difficult.
How to solve a problem with ACO? Not so easy!

I. Represent the problem in the form of a weighted graph, on which ants can build solutions
II. Define the meaning of the pheromone trails
III. Define the heuristic preference for the ant while constructing a solution
IV. Choose a specific ACO algorithm and apply to the problem being solved
V. Tune the parameters of the ACO algorithm

Example: ACO in health informatics

Simulated Annealing

- Simulated annealing presents an optimization technique that can:
  - (a) process cost functions possessing quite arbitrary degrees of nonlinearity, discontinuities,
    - and stochasticity;
  - (b) process quite arbitrary boundary conditions and constraints imposed on these cost functions;
  - (c) be implemented quite easily with the degree of coding quite minimal relative to other nonlinear optimization algorithms;
  - (d) statistically guarantee finding an optimal solution

Digression: Simulated Annealing

04 Ant’s and Collective Intelligence
Human-in-the-loop

Comparison Biological Ant Foraging and ACO Algorithm

- Biology (Ant Foraging)
  - Ant: Individual (agent) used to build (construct) a solution
  - Ant Colony: Population (colony) of cooperating individuals
- Pheromone Trail
  - Modification of the environment caused by the artificial ants in order to provide an indirect mean of communication with other ants of the colony. Allows assessment of the quality of a given edge on a graph.
- Pheromone Evaporation
  - Reduction in the pheromone level of a given path due to aging.
The Human Kernel Experiment (1/3)

http://functionlearning.com

Demos of experiments for The Human Kernel!

The page contains links to the demos described in the book "The Human Kernel".

- Part II: Estimating visual perception functions.
- Part IV: Estimating voice production functions.
- Part VI: Estimating phone production functions.
- Part X: Estimating moral judgment functions.


The Human Kernel Experiment (2/3)

Judgment 12 out of 31

Please call the system on your mind to predict the next 10 points as well as you can. Click the add button to add a point to the data set. Then select the point on the line. Hit the 'A' key to submit the point.


The Human Kernel Experiment (3/3)

Figure 2. "Pharaoh's ants, Monomorium pharaonis, form branching networks of pheromone trails. Here the network has been formed on a smoked glass surface to aid visualisation. (Image courtesy of Duncan Jackson.)"

Figure 3. The network has been formed on a smoked glass surface to aid visualisation. (Image courtesy of Duncan Jackson.)


Problem Solving: Humans vs. Computers

When is the human **5** better?

**5** Human intelligence/natural intelligence/human brain/human learning

- Natural Language Translation/Revision Machine cannot understand the context of sentences [3]
- Unstructured problem solving
- Without a pre-set of rules, a machine has trouble solving the problem, because it lacks the creativity required for it [5]
- NP-hard problems
- Processing times are exponential and makes it almost impossible to use machines for it, so humans still stay better [4]

When is the computer **5** better?

**5** Computational intelligence, Artificial intelligence

- Machine Learning algorithms
- High-dimensional data processing
  - Machines are very good at dimensional less or equal than 3, but computers can process data in arbitrary high dimensions
- Rule-based environments
- Difficulties for humans in rule-based environments often come from not recognizing the correct goal in order to select the correct procedure or set of rules [3]
- Image optimization
  - Machine can look at each pixel and apply changes without human personal biases, and with more speed [1]

Human Learning vs. Machine Learning

Human learning

- Categorization
- Causal learning
- Function learning
- Representations
- Language
- Experiment design

Machine learning

- Classification
- Density estimation
- Graphical models
- Nonparametric Bayes
- Probabilistic grammars
- Inference algorithms

Human Performance on Traveling Salesman Problems

Practical uses of the Ant Colony Optimization algorithm

- Drilling of circuit board
- Warehouse supply chain optimization
- Hospital Organization optimization
- Route planner
- DNA sequencing, Protein, etc.

Human in the Loop

- What are the problems with the Ant-Algorithm?
  - Wrong Initialization
  - What is the benefit of the interaction? How to measure the benefit?
  - Reduce of length
  - When is an interaction with the Human possible?
  - Change the ant's behavior

Ant-Algorithm

Initialisation:

Result of Ant-Algorithm

Source-Code: https://github.com/ dominant-knot/ants

Ant-Algorithm with iML

Bring in the Human
Sample Questions (1)

- Please explain the five mainstreams in ML!
- Why is it generally not easy to solve problems in health informatics?
- What is the model of a computational agent?
- Why is protein folding a hard problem?
- Explain why the study of human learning and machine learning can benefit from each other?
- What is a Pheromon and how does it work?
- In which areas are humans better than computers?
- What is the human kernel experiment?
- Why is simulated annealing interesting?
- Explain the Ant Colony Algorithm via pseudo code!
- Why should we study natural computing?

Questions

Thank you!

Appendix

"The contagion spread rapidly and before its progress could be arrested, sixteen persons were affected of which two died. Of these sixteen, eight were under my care. On this occasion I used for the first time the application of cold water in the manner described by Dr. Wright. It was first tried in two cases — [then] employed in five other cases. It was repeated daily, and of these seven patients, the whole recovered."

Currie (1798)

Medical Reports on the Effects of Water, Cold and Warm, as a Remedy in Fevers and Febrile Diseases
EVLKNNO: Future research in EAs [16]

- Testing of novel Evolutionary algorithms:
  - Intelligent Water Drops
  - Bacteria Foraging Search
  - ...

EVLKNNO crowdsourcing platform to implement and test new algorithms:
- Open Source data for Researchers to test algorithms
- Evaluate quality, reusability and efficiency of algorithms

Recommendable reading for further studies

Answers to the Quiz Questions (1/2)

- 1 = This is a chromosome - in computation we call it a sequence of information objects. Each cell of any living creature has blueprints in the form of this chromosomes, which are strings of DNA and blocks of DNA, called 'genes', are responsible for the manifestation of traits, such as eye color, beard, etc. Building blocks for chromosomes are proteins.

- 2 = This is a typical naive Bayes classifier: An example $E$ is classified to the class with the maximum posterior probability; $w$ = weighted naive Bayes, $V$ denotes the classification given by the web, and $I$ is the weight of the attribute; The naive Bayes classifier combines this model with a decision rule. One common rule is to pick the hypothesis that is most probable; this is known as the maximum a posteriori MAP decision rule.

- 3 = This is the famous finding of Charles Darwin's theory of life. Darwin used the tree structure in the context of his theory of evolution. Populations of individuals compete for limited resources; a fitness function is associated with each individual, which quantifies ability to survive; Parent populations reproduce to form offspring populations; and the traits of offspring are a combination of the traits of parents.