Computational Intelligence: Methods and Applications

Lecture 2
Problems requiring CI

Włodzisław Duch
SCE, NTU, Singapore
Google: Duch

Some non-algorithmizable problems

- Understanding meaning of sentences (queries), all problems related to natural language analysis.
- Perception: recognition of signals, phoneme recognition, olfactory signals – first step in robotics.
- Visual perception: face recognition, object recognition and many computer vision problems.
- Hand-written characters recognition for PDAs or security.
- Control and planning problems in robotics and control of non-linear complex systems with many degrees of freedom.
- Medical diagnostics, interpretation of medical images and biomedical signals (EEG, ECG ...), therapy planning.
- Playing complex games, like go or strategic war games.
- Solving untypical problems, or problems requiring creativity.

CI definition

- Many bad definitions have been proposed, listing computational methods used in CI; my working technical definition of CI is:

  Computational Intelligence (CI) is a branch of science dealing with problems that cannot be solved using effective computational algorithms (this does not mean that they cannot be solved using computations!).

- MIT Encyclopedia of Cognitive Sciences includes it among 6 main branches of cognitive sciences, aiming at understanding (natural science perspective), and creating (engineering perspective), animal-like (and human-like) cognitive systems.
- CS include philosophy, psychology, neurosciences, linguistics, CI, sociobiology (evolutionary perspectives on culture).

- In this course only engineering perspective is used.

Relations between CI, AI and CS

Cognitive Sciences includes both low and high-level processes:

Artificial Intelligence (AI) is part of CI that:
- is based on symbolic representation of knowledge;
- creates expert systems that help to reason;
- "knowledge engineering" is its most important branch.

- AI: is focused on higher cognitive processes, such as language, logic, reasoning, thinking, problem solving, sequential actions.
- CI: includes also basic sensory signal processing, low-level cognition, perception and control, senso-motoric behavior.
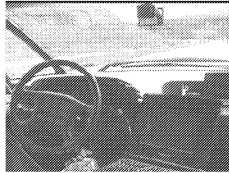
CI methods may help to discover knowledge hidden in data.
Only a few hybrid CI-AI systems exist, cognitive robotics needs them!
CI and AI conferences and journals have little overlap.

Pattern recognition problems

Classification, categorization, recognition of:

- images of all kinds, medical images;
- phonetic structure of speech signals;
- insects, birds, animals by their voices;
- biomedical signals, such as USG, fMRI;
- sonar, radar and other artificial signals;
- hand-sign speech and signals;
- machine and human intentions and behavioral patterns;
- chemical structures, QSAR (Qualitative Structure-Activity Relationships), rational drug design;
- biological structures, protein types, folding;
- silhouettes of cars and other vehicles, planes, ships;
- astronomical objects, recognition of types of stars and galaxies ...

Data mining problems
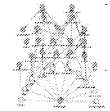
Data mining, or KDD, Knowledge Discovery in Data, aims at:

- understanding data, not just pattern classification;
- finding short explanation of data structure and association rules;
- discovering logical rules (classical and fuzzy) in the data;
- creating summaries of databases;
- Ex: discovering new rules in analytical chemistry, such as NMR spectroscopy rules;
- searching for knowledge in genomic and biological databases;
- automatically creating understandable models (theories) of data;
- creating causal models of processes, pathway databases in biological cells or hormone interactions in human body;
- using the knowledge discovered to reason in expert systems.

Selection of information
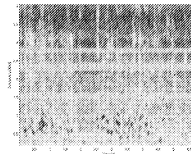
Attention allows to select relevant perceptual signals, without attention we could not function.

- finding relevant features in medical, biological, chemical, astronomical, technical, business and other data;
- finding a right person for the job – what is important?
- filtering junk mail by automatically discovering rules (~ 9 G$ losses in US + 2.5 G$ in Europe in 2002, according to CNN), ;
- aggregation of features in a linear or non-linear way;
- reducing dimensionality of the problem locally or globally;
- creating new, more relevant features and concepts that are useful in reasoning;
- separation of signals into interesting components, cleaning of signals, removing noise and artifacts, separating music from noise and pictures/video from dirt and scratches ...

Information Retrieval

IR and IE (info extraction): indexing documents, library keywords.

- semantic information retrieval;
- searching in large databases and in the Web;
- search engines discovering preferences of users;
- automatic annotation of Web documents, or going from HTML=> XML => DAML to create semantic Web;
- document clustering, categorization and visualization of relations between documents and keywords;
- constructing concept spaces from keywords;
- latent semantic analysis and other methods of dimensionality reduction of document search terms;
- NLP (Natural Language Processing) parsing + other techniques;
- automatic summarization of texts, dialog and chatter bot systems.

Decision support
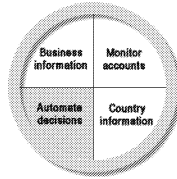
Intelligent decision support:

- support for business decisions, like pricing, upgrading, personalization of services;
- increasing response rates of advertising campaigns;
- support for medical diagnostics, evidence-based medicine;
- creating causal networks to explain inferences;
- models of customer and shopping behavior or service user behavior;

Andreas Weigend (www.weigend.com)
"Amazon.com might be the world's largest laboratory to study human behavior and decision making."

Control and planning
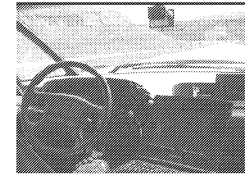
CI is needed in:

- quality control in industrial processes;
- tuning of complex equipment, automatic camera focus;
- driving a car or airplane without human intervention;
- controlling chemical factory;
- controlling mob behavior;
- controlling a robot with many degrees of freedom;
- planning robot actions, surviving in hostile environment;
- developing toy robots such as AIBO dogs
- planning large-scale constructions, such as highways, skyscrapers, power plants;
- optimization of organization structure and functions ...

Detection of regularities
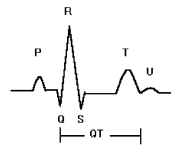
If we do not know what we are looking for:

- spontaneous, unsupervised learning;
- self-organization of feature detectors, automatic creation of elementary features;
- discovery and analysis of "interesting" clusters and structures in the data;
- detection of (ir)regularities in signals, for example in heart ECG;
- discovery of genes and other patterns in DNA strings;
- discovery of important active sites in proteins;
- use of the regularities discovered for construction of new features and new concepts, in the systematic reasoning.

Other problems
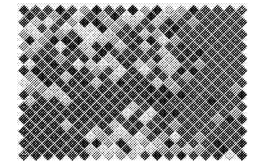
Many other problems require CI techniques for their solution:

- strategic games, learning from errors and successes;
- multi-criterion optimization problems (have no solution);
- determining missing features;
- discovering errors and outliers in the data;
- learning to solve simple sub-problems and generalizing to complex problems;
- combining data from many sources into one model, like consumer preferences and TV watching behavior;
- prediction of time series, stock behavior, Sun activity, weather, human decisions and intentions;
- understanding of human mind, results of psychological experiments, ways of reasoning, categorization, planning, learning, recognizing emotions.

CI inspirations
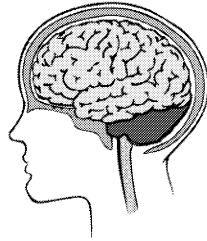
How to solve such problems?
Humans and many animals are quite good in solving them.
Although many specialized methods exist some adaptive
(learning) algorithms that have wide applications were discovered.
Biological inspirations help to formulate initial models.

- Neurobiological inspirations: how brains are solving such problems?
- Artificial Neural Networks (ANN) is a large field, many types of networks, from function mapping to hierarchical, self organizing, modular dynamical systems providing solutions to many problems.
- Some ANN models are close to statistics and pattern recognition.
- Some ANN models are inspired by specific brain structures, cf. CMAC (Cerebellar Model Arithmetic Computer); SDM (Sparse Distributed Memory); SOM (Self Organizing Maps).
- Computational Cognitive Neurosciences aim at models that are faithful to biology, results are compared with experiments.

Psychological inspirations

- How minds are solving such problems?

- Although mind is brain function, here instead of single neurons functions of larger brain structures (neural columns, modules, maps) are considered and used as inspiration.

- Connectionist models: networks of connected nodes, representing concepts, processing information in parallel distributed way, general graphical models and Bayesian causal influences networks.

- Learning through chunking, or hierarchical grouping of smaller units into more meaningful, complex structures replaced by a single symbol: from lines, curves, to letters, words, phrases and sentences to meaning; contrast that with neural learning (perceptrons).

Bio-medical inspirations

- How biology has solved the problem of species survival? Evolution leads to survival of the fittest, removing the weak.

- May be used for complex optimization problems: find parameters P that minimize some cost function $E(P)$.

- May help to learn optimal parameters of a complex adaptive system (such as ANN), but is evolution really the most efficient?

- Swarm algorithms: find optimal solution by creating many initial parameters $\{P_i\}$ and moving them in parameter space, using cost function $E(P_i)$ to determine interactions between "particles" $\{P_i\}$.

- Ant algorithms: interactions of many ants and pheromone traces helping to find optimal sets of parameters. Useful if the cost functions changes during the process (moving target problems).

- Immunological system: inspirations from medicine.

Inspirations from logic
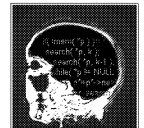
- Modern logic deals with uncertainty in the data.

Crisp logic: yes or no only, {0,1}, good for symbolic problems.
Q: Failed or passed? Teenager or not?

Fuzzy logic: degrees of truth [0,1] modeled by "membership function".
Q: old or young? So-so? Perhaps 0.6 old and 0.4 young?
Fuzzy = continuous generalization of multi-valued logic.

Rough logic is based on rough sets:
some objects certainly belong to a set, some certainly don't,
other objects maybe, to a degree determined by the data.

Dempster-Shafer theory of evidence represents our knowledge of the truth of sets of possibilities. Uncertainty theory is a large field ...

Math and statistics

- Probabilistic methods are the basis for inference and decision support.

  Object (sample) $X = \{X_i\}$ is a vector of features.

- Naive Bayesian classifiers treat all features as independent and are used for classification, estimating "a posteriori probabilities" $p(C|X)$, of assigning an object (sample) X to some category C.

- Bayesian networks include mutual influences of different features X_i using Bayes formula: $p(C,X) = p(C|X)\ p(X) = p(X|C)\ p(C)$

- Multivariate statistics has devised many classification and regression (approximation) methods.

- Clusterization and visualization methods also belong to statistics.

Machine learning and pattern recognition
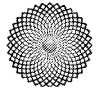
- Pattern Recognition (PR) is an engineering field has developed many classification and approximation methods.

- Most popular PR methods are based on the k-NN (k Nearest Neighbors) rule or decision trees, recursively partitioning data into smaller subsets.

- Machine learning (ML) is a part of AI, using inductive methods to find good symbolic rules that classify or approximate data.

- ML method usually deal with symbolic data only, covering samples from different classes to find best sets of rules.

- AI also uses memory-based methods similar to k-NN, calling it memory-based reasoning or case-based reasoning, that estimates similarity to memorized cases.

- We will be able to cover only few of these methods ...