# Computational intelligence: Introduction to basic concepts

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## What is human intelligence?

- product of brain activity, manifestation of mind (?)
- What are its characteristics?
  - Cleverness
  - Ability to solve novel problems
  - Foresight (insight)
  - Creativity
  - Making a guess that discovers a new underlying order
- Is universal definition possible?
- Quantitative or qualitative description?
- Test operationalization?



## Theories of intelligence

- Quantifiable (?) - IQ
- Various tests applied
- Theories:
  - General intelligence (Spearman's factor *g*) vs. specific abilities (Thorndike)
  - Multiple ability theories of intelligence (Thurstone)
    - Primary mental abilities – numerical ability, reasoning, verbal fluency, spatial relations, perception, memory, verbal comprehension
  - Triarchic theory (Sternberg) – analytic, practical, creative
  - Theory of multiple intelligences (Gardner)
  - ...



## Two example of definitions

- American Psychological Association in 1995:

  "Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought. Although these individual differences can be substantial, they are never entirely consistent: a given person's intellectual performance will vary on different occasions, in different domains, as judged by different criteria. Concepts of "intelligence" are attempts to clarify and organize this complex set of phenomena. Although considerable clarity has been achieved in some areas, no such conceptualization has yet answered all the important questions and none commands universal assent. Indeed, when two dozen prominent theorists were recently asked to define intelligence, they gave two dozen somewhat different definitions."

- "Mainstream Science on Intelligence", signed by 52 intelligence researchers in 1994:

  "A very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on", "making sense" of things, or "figuring out" what to do."

# Hallmarks of human intelligence

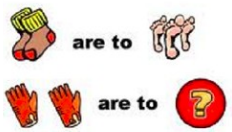
Object recognition

Speech recognition

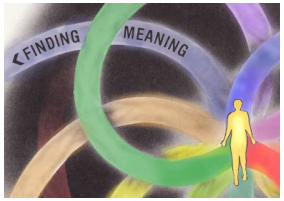
Language use


Movement

Analogies




Understanding






# Intelligent system is the one that ...

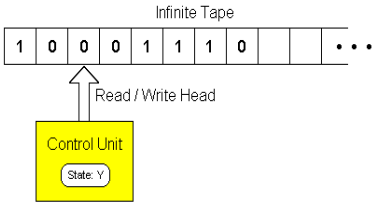
- acts humanly
  - Turing test
  - But not reproducible, constructive, or amenable to mathematical analysis
- acts rationally
  - doing the right thing: i.e. expected to maximize goal achievement, given the available information
- thinks humanly
  - During "cognitive revolution": information-processing psychology replaced orthodoxy of behaviorism
- thinks rationally
  - Laws of thought: prescriptive rather than descriptive
  - But not all intelligent behavior is mediated by logical deliberation

(Russell & Norvig, 2010)



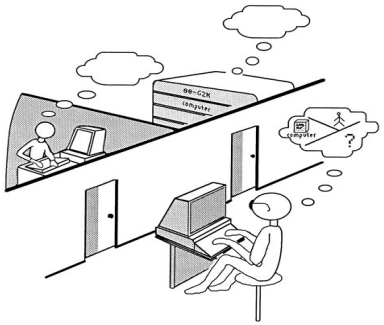
# Alan Turing

- Turing machine:




(1912-1954)

- Turing test:

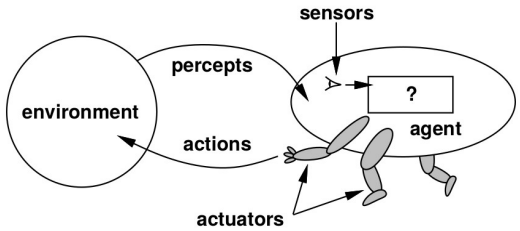


• Operationalized test of machine intelligence (imitation game)

"Softened Turing tests:"
• Deep blue (chess) 1997
• Watson (jeopardy) 2011



# Rational agents




Abstractly, an agent is a function from percept histories to actions:

$$f : \mathcal{P}^* \to \mathcal{A}$$

For any given class of environments and tasks, we seek the agent (or class of agents) with the best performance

Caveat: **computational limitations make perfect rationality unachievable**

→ design best program for given machine resources

(Russell & Norvig, 2010)

## What is “computation”?

- A. Turing (1936) – digital (binary) computation
  - basis of today's digital computers
- Different levels of description
- Levels of analysis (Marr, 1982):
  - computational, algorithmic, implementational
- Analog computation
- Do natural systems compute?
- Computations in artifacts
- Usefulness of computational approach in research
- building computational models (synthetic approach)



## Nature-inspired computation

- Biological organisms effectively function in their environments
- Each (more complex) organism (individual)
  - Is born with certain innate properties (evolution),
  - But it has to learn others (ontogeny).
- Processes standing behind behavior can be looked at as computations.
- Nature is an excellent source of inspiration.
- Current machines performance is still inferior compared to humans in certain complex tasks (vision, locomotion, language)
  - but the differences are diminishing, or becoming eliminated

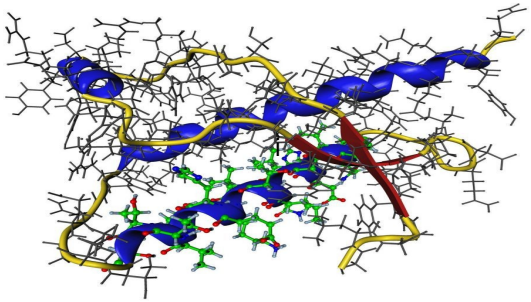


## Swarm intelligence



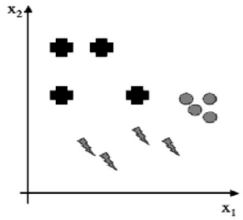
## DNA computing

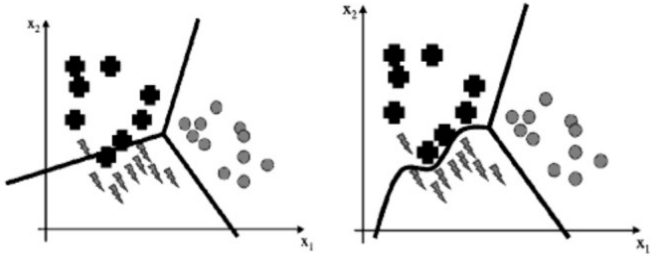
- Using DNA and molecular biology (instead of common computers) for solving complex tasks
- DNA codes genetic information
- Alphabet: 4 bases (molecules) - A, C, G, T.



# Task: Classification

| $x_1$ | $x_2$ | Class |
|---|---|---|
| 0.1 | 1 | 1 |
| 0.15 | 0.2 | 2 |
| 0.48 | 0.6 | 3 |
| 0.1 | 0.6 | 1 |
| 0.2 | 0.15 | 2 |
| 0.5 | 0.55 | 3 |
| 0.2 | 1 | 1 |
| 0.3 | 0.25 | 2 |
| 0.52 | 0.6 | 3 |
| 0.3 | 0.6 | 1 |
| 0.4 | 0.2 | 2 |
| 0.52 | 0.5 | 3 |



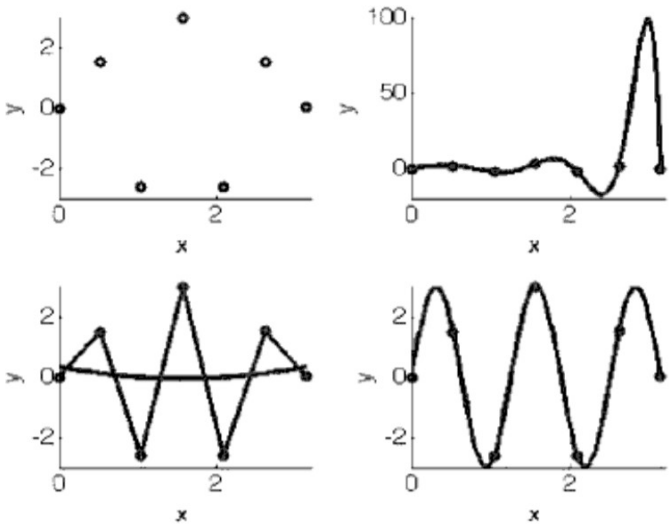






# Task: Feature extraction



# Task: Regression





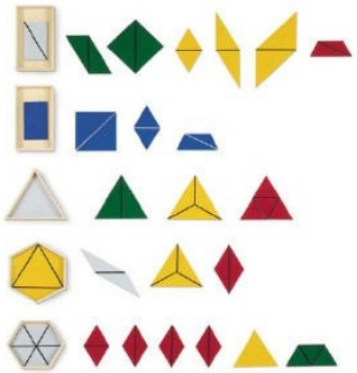

# Categorization

What is a cup ?

fuzzy boundaries, subjectivity

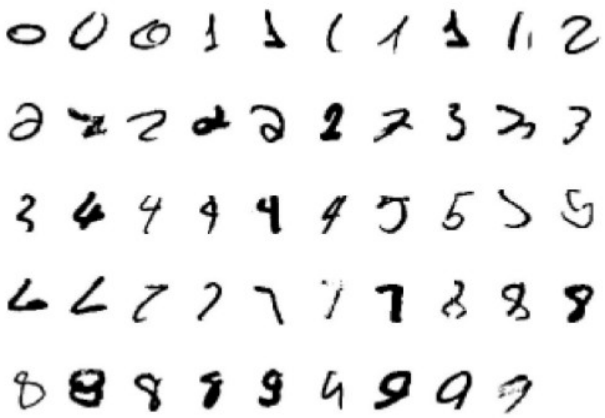
What is a triangle?

clear-cut boundaries, no subjectivity



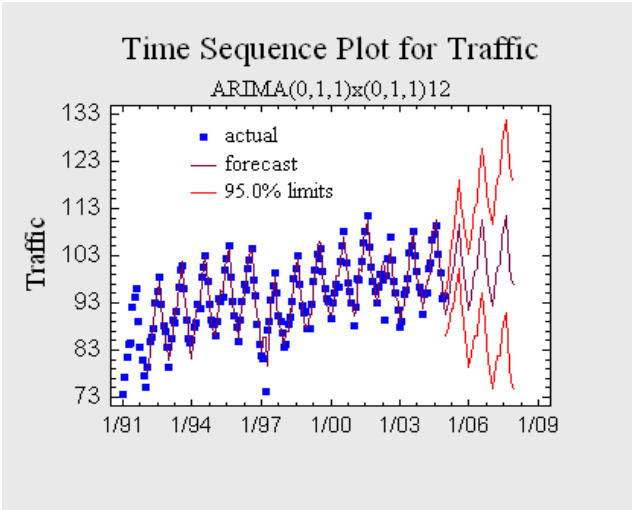
- feature theory (defining features)
- prototype theory (characteristic features); + exemplars
- synthesis (core + prototype)

## Seeking patterns in data



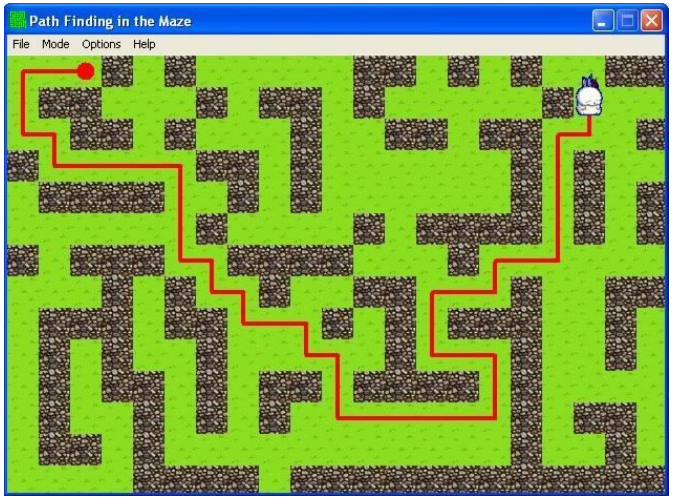


## Task: time series prediction






## Task: Path finding






## Artificial intelligence

- Born in 1950s in the US
- major framework – “crisp” logic (symbolic AI)
- focus: reasoning, knowledge, planning, learning, natural language processing (communication), perception
  - typically “weak AI” / narrow AI
- Approaches: statistical methods, computational intelligence (soft computing), and traditional symbolic AI.
- Artificial General Intelligence (AGI) introduced in 1997
  - “strong AI” ambition
- Computational intelligence – in 1990s.

## Views on main characteristics of CI

"... (strictly) computational systems depend on numerical data supplied by manufactured sensors and do not rely upon "knowledge"."

"It deals only with numerical (low-level) data, has a pattern recognition component, and does not use knowledge in the AI sense; and additionally, when it (begins to) exhibit (i) computational adaptivity; (ii) computational fault tolerance; (iii) speed approaching human-like turnaround, and (iv) error rates that approximate human performance."

(Bezdek, 1994)

"In summary, adaptation is arguably the most appropriate term for what computationally intelligent systems do. In fact, it is not too much of a stretch to say that *computational intelligence and adaptation are synonymous*." (Italics from Eberhart *et al.*)



## Views on main characteristics of CI (ctd)

"These technologies of neural, fuzzy and evolutionary systems were brought together under the rubric of Computational Intelligence, a relatively new field offered to generally describe methods of computation that can be used to adapt solutions to new problems and do not rely on explicit human knowledge."

(Fogel, 1995)

"Computational intelligence is the study of the design of intelligent agents. ... An intelligent agent is a system that acts intelligently: What it does is appropriate for its circumstances and its goal, it is flexible to changing environments and changing goals, it learns from experience, and it makes appropriate choices given perceptual limitations and finite computation."

(Poole et al., 1998)

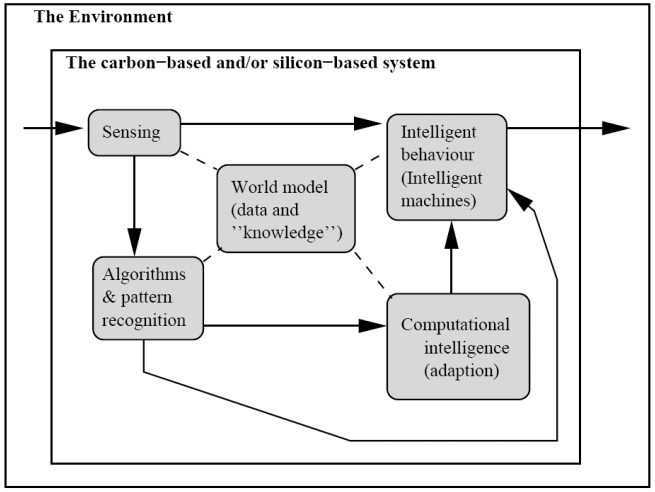


## Features of CI methods

- various methods in CI
- share the feature of being subsymbolic
- data-driven, where
- the structure (knowledge) emerges bottom-up
- rather than being imposed from above (pre-wired)
- directly draw on environment
- Relationship to AI?
  - subsumed field
  - any symbiosis possible?



## Relations among components of intelligent system



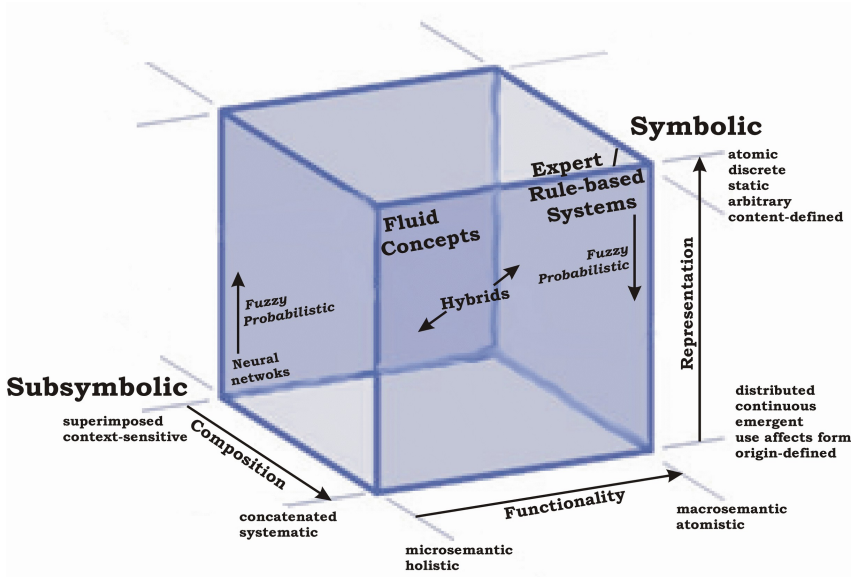

(Eberhart, 1995)

## Other issues (related to cognitive science)

- classical AI (computer metaphor of the brain) vs embodied AI
  - synthetic approach (understanding by building)
  - understanding the mechanisms behind intelligent behavior
- Chinese room problem (Searle, 1980) →
- Symbol grounding problem (Harnad, 1990)
- Enactive approach (environment–agent loop)
- Symbolic vs subsymbolic information processing
- Variety of cognitive architectures
  - Symbolic, hybrid, subsymbolic



## Symbolic-subsymbolic spectrum




(Vanschoren, 2004)

## What is computational intelligence?

- How does CI differ from Artificial Intelligence?
  - Successor, importance of machine learning
  - CI as a soft-computing subset of AI (Bezdek, 1994)
- only methods with nature-inspired computation?
- Proposed definition: "CI as a branch of computer science studying problems for which there are no effective computational algorithms." (Duch, 2007)
- CI society: "… the theory, design, application, and development of biologically and linguistically motivated computational paradigms..."