Computational Intelligence

Master in Artificial Intelligence

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Introduction to Computational Intelligence

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What the course is about

- The CI “primordial soup”:
  - Neural Computation
  - Evolutionary Computation
  - Fuzzy Computation
  - Swarm/Pack/Flock intelligence (ants, bees, wolves, birds, particles, ...)
  - Rough sets, Belief nets, ...

\- This is an introductory course

\- Hybridizations & advanced stuff are given in more depth in optional follow-up courses

Overview of today's topics

- What **is** Computational Intelligence?
- Overview of basic CI **techniques**
- **Challenges** for CI systems
- Important **notions** to bear in mind
- Application **examples** (past, present and future)
- **Non-CI examples** (the art of problem-solving)
- Take-home **messages**
- Course **information** (more will be given later)

What is Computational Intelligence (CI)?

CI is the field of computing that draws from the successes of natural systems to develop alternate ways of solving computational problems in the real world

[mine] “everything that produces a non-standard computational **solution** to a difficult problem”

CI = Computing + Nature: nature-inspired methods usually tolerate *incomplete*, *imprecise* and *uncertain* knowledge

(other commonly used names are *Natural Computing* and *Soft Computing*)

Example 1: parking a car
(difficult or easy?)

“Generally, a car can be parked rather easily because the final position of the car is not specified exactly. It it were specified to within, say, a fraction of a millimeter and a few seconds of arc, it would take hours of maneuvering and precise measurements of distance and angular position to *solve* the problem.”

Lofti Zadeh
(1921-2017)

Example 2: counting money
(difficult or easy?)

You go to a luxury boutique and decide to pay 3,000 € in 10 ¢ coins …

… that makes 30,000 coins. You are the cashier:

OPTION 1: manual counting
* COST: 2h + anxiety
* PRECISION: 100% (theoretically)

OPTION 2: approx. counting (how?)
* COST: 10s + smile
* PRECISION: 99.5%

Example 3: waiting for the bus
(difficult or easy?)

Assume you must attend a lecture at 15:00 … you usually take bus H12 … it is now 14:32 … your fav app says 5' wait

3' later it changes to 23' … what do you do?

You basically have 3 options:

1. Believe it and ...
2. Disregard it and ...
3. Doubt and … ask, wait (i.e., get more information)

On living intelligent systems

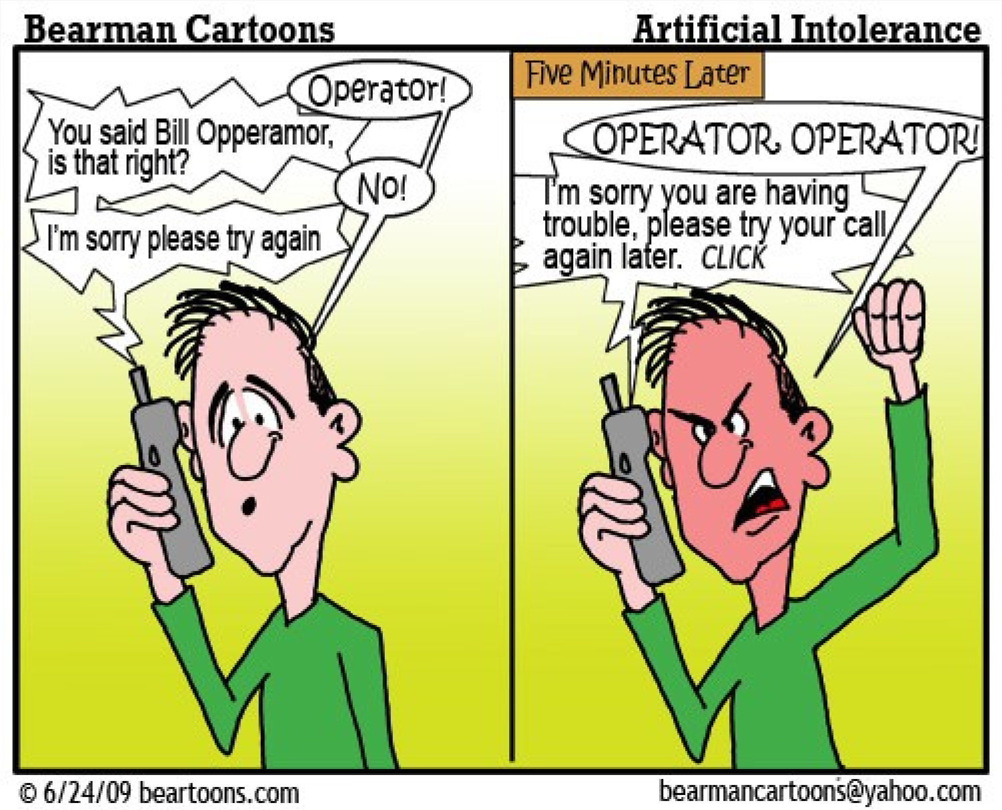
- What **is** intelligence? Don't know ...

- What is the **function** of intelligence?
 —to ensure survival in a given environment

- What are the **ingredients** of intelligence?
  * **Perceive** in a changing world
  * **Reason** under uncertainty, partial truth
  * **Plan** (and prioritize) dynamically
  * **Coordinate** several simultaneous tasks
  * **Learn** under noisy experiences

What CI is "not exactly": Artificial Intelligence

- Classical AI is the endeavor of making a machine <u>appear</u> intelligent (and most often in <u>human</u> tasks)



What CI is “not exactly”: Artificial Intelligence

A famous **AI success**: Deep Blue beating Kasparov in 1997. This system was essentially brute-force, highly pre-programmed, helped by an extensive (and external) human-knowledge base of partial games

6-game match (3½-2½): first computer system to defeat a reigning world champion in a match under standard chess tournament

A close cousin of CI: Artificial Life

- **ALife**'s ambition is to build “living” systems out of non-living parts
- Synthetic life-like system that could be classified as:
  - Life-as-we-know-it organisms
  - Life-as-it-could-be organisms

- Outcomes:
  - Increase the understanding of Nature
  - Get insight into possible artificial new lifeforms
  - Applications are usually left in the drawing board

What is <u>incomplete</u> knowledge?

“OECD says that half of the unemployed in Spain abandoned school at 14”

(yes, and finishing school did not bring a job for the other half)

“They first met last year”

(Who? How? Why? For how long? Where? What year is it?)

“You owe me 30 euros”

(yes, and *you* owe me 200!)

“Cuando se despertó, el dinosaurio seguía allí.”

(Augusto Monterroso's tiny story, a plethora of contexts)

What is <u>imprecise</u> knowledge?

“Quakers are pacifists, and Republicans are not.”
(What about Nixon?)

“Can you wait outside?”
(Do you have the ability to wait outside?)

“Mehr Licht!” (“More light!”)
(Goethe's famous last words; apparently asking for the shutters to be opened)

What is <u>uncertain</u> knowledge?

“75% of men shave daily”
(frequentist probability of a precise event + domain knowledge + truth)

“There is a 80% chance of a happy marriage”
(Bayesian probability of a fuzzy event + domain knowledge + truth)

“There is a majority of young people in this class”
(precise statement of a fuzzy event + truth)

“Pour one liter of water in the red bottle”
(rough statement + ambiguity)

Probability deals with **randomness**
Fuzziness deals with **ambiguity**
Roughness deals with **imprecision**

The key factors of CI systems

- **Design** non-complex mechanisms to produce acceptable solutions (rather than complex mechanisms for a close-to optimal solution)
- **Exploit** heuristics, approximations and surrogates
- **Deal** with (and exploit) imprecision, uncertainty, probabilistic dependencies and partial truths
- **Break** complexity into (many) smaller parts (subsystems that distribute and cooperate)
- **Improve** performance by exposure to a given (partially known) environment (learning)

Core techniques (I)

Evolutionary computation

- Genes and chromosomes contain the code for nature's designs
- A population of solutions competing/co-operating to improve over time

Neural computation

- Highly connected simple units working in parallel
- Robust, fault-tolerant, deals with probabilistic, noisy or inconsistent information; admits distributed representations

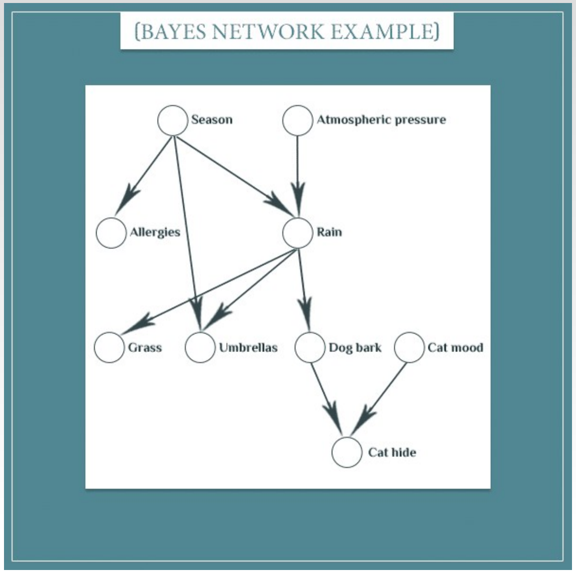
Fuzzy (possibilistic) computation

- Deals with event ambiguity or uncertainty
- Reasons with linguistic labels (e.g., “tall”, “cold”, ...)

Core techniques (II)

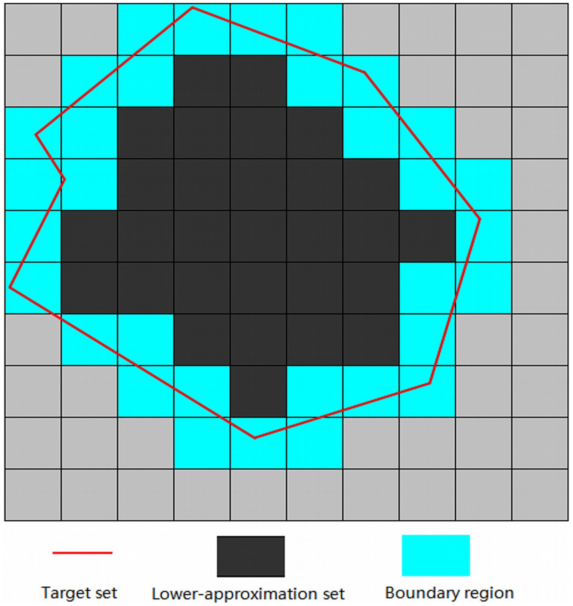
Probabilistic computation: belief networks

Able to estimate and propagate stochastic dependencies among random variables (in the form of causal structures)



Approximate computation: rough sets

Able to deal with the granularity in the domain, which causes uncertainty due to the lack of precision:



Other techniques:

Ant colony optimization (ACO) *(based on the behaviour of ants seeking a path between their colony and a source of food)*

Particle swarm optimization (PSO) *(particles are moved around according to the particle's position and velocity)*

Artificial immune systems (AIS) *(principles and processes of the vertebrate immune system)*

Gravitational search algorithms (GSO) *(based on the law of gravity and mass interactions)*

Cutting edge: {DNA, Quantum, Optical, Chaos} computing

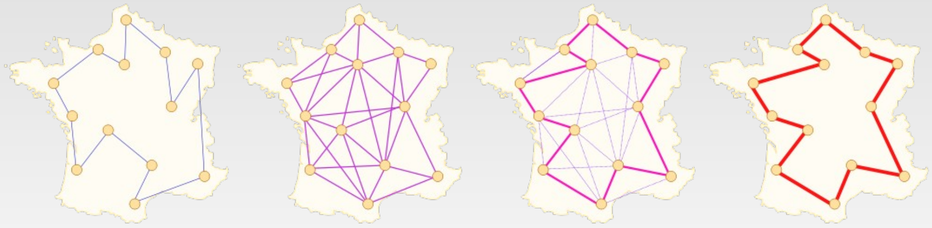
What are the challenges for CI?

1. Problem solving (search/optimization)
2. Sensoring/moving (sensorimotor coordination)
3. Learning (induction)
4. (Natural) Language Processing
5. Inference/reasoning (deduction, ...)
6. Emotion handling (plus ethics, conflicts, ...)

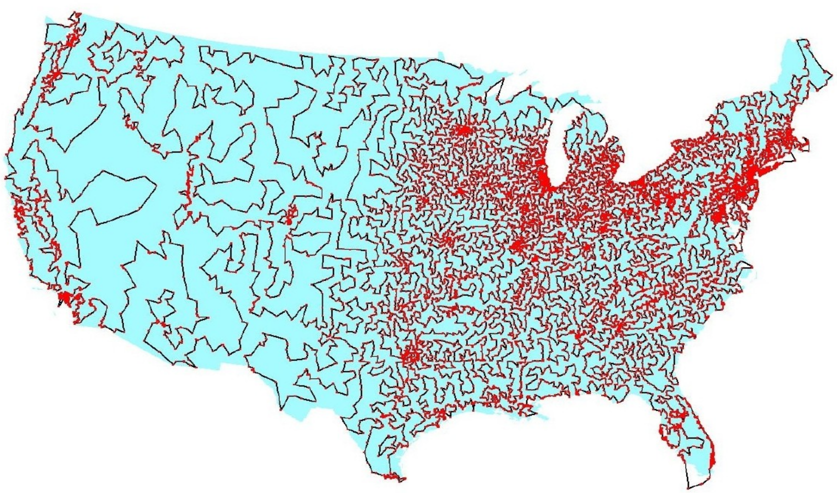
- How to put it all together ...
- Often in real time ...

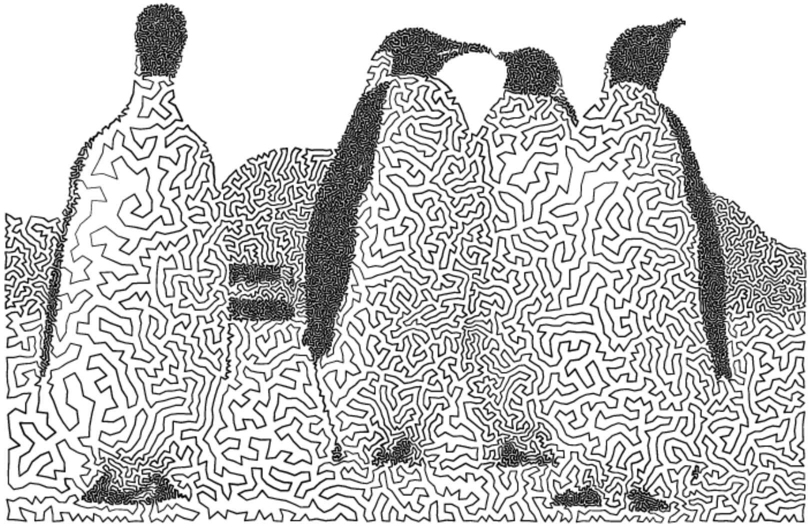
An example of problem solving (search/optimization): the TSP

- TSP: 10^5 cities,
  - accuracy within 0.75%, 7 months
  - accuracy within 1%, 2 days
- Compare
  - “absolute best for sure”
  - with
  - “very good with high probability”



1 2 3 4

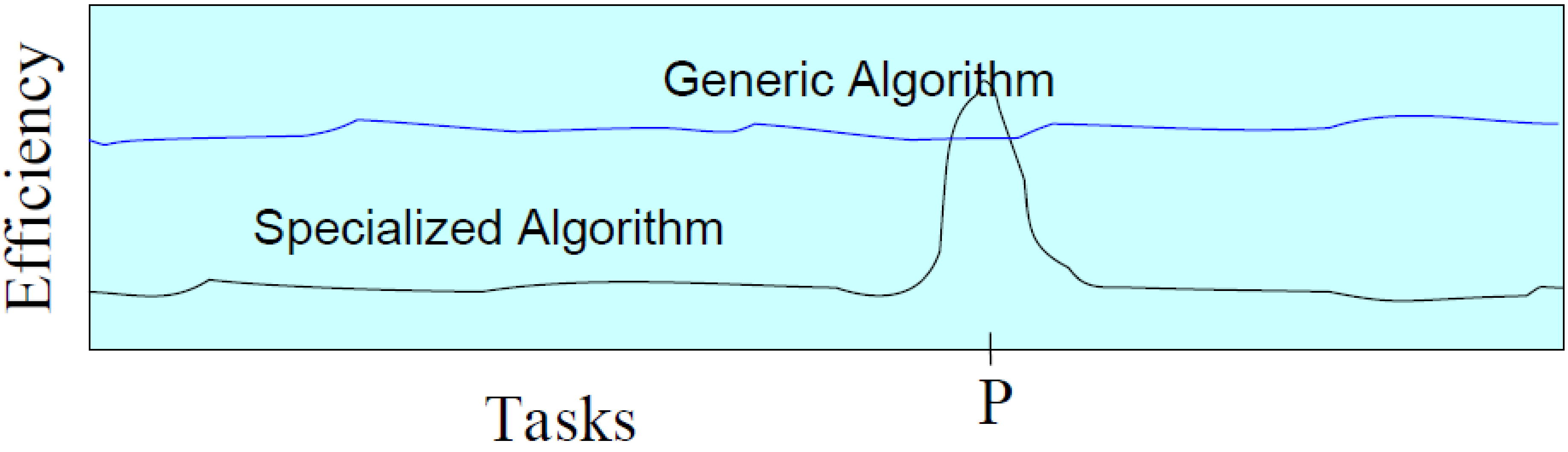




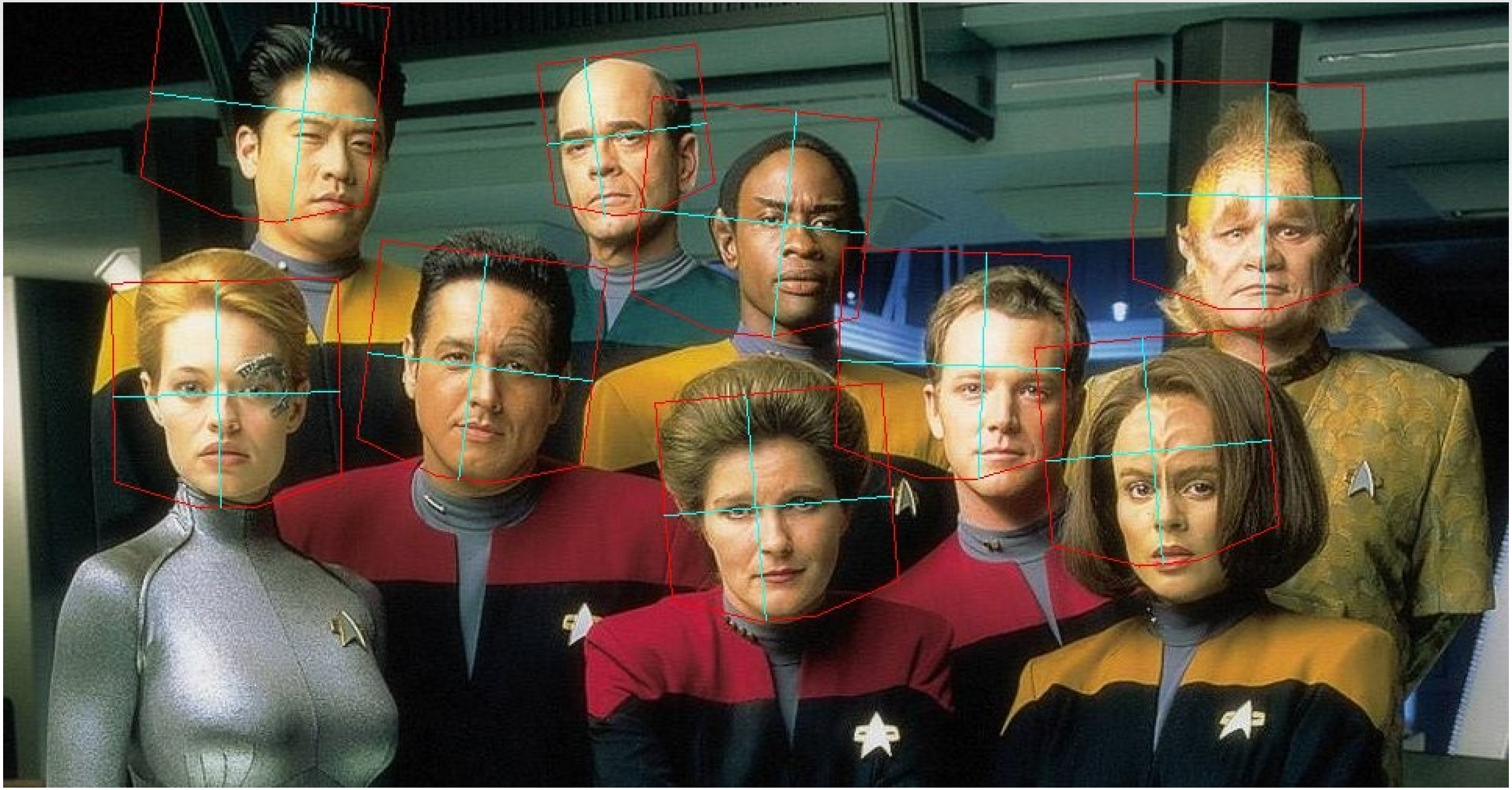
Kinds of algorithms (= solutions)

Specialized algorithms: best performance for special problems

Generic algorithms: good performance over a wide range of tasks



An example of sensing: face recognition



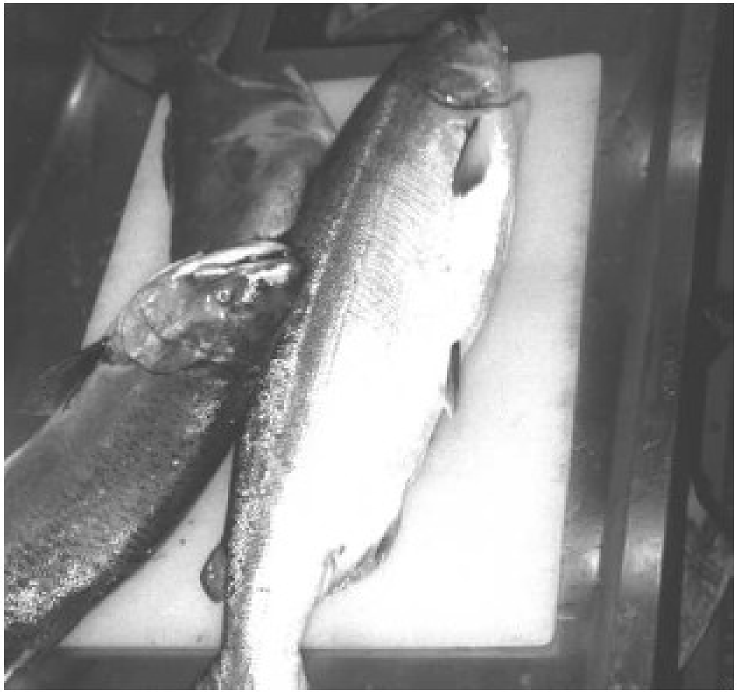
see website of Yann LeCun: www.cs.nyu.edu/~yann/research/face

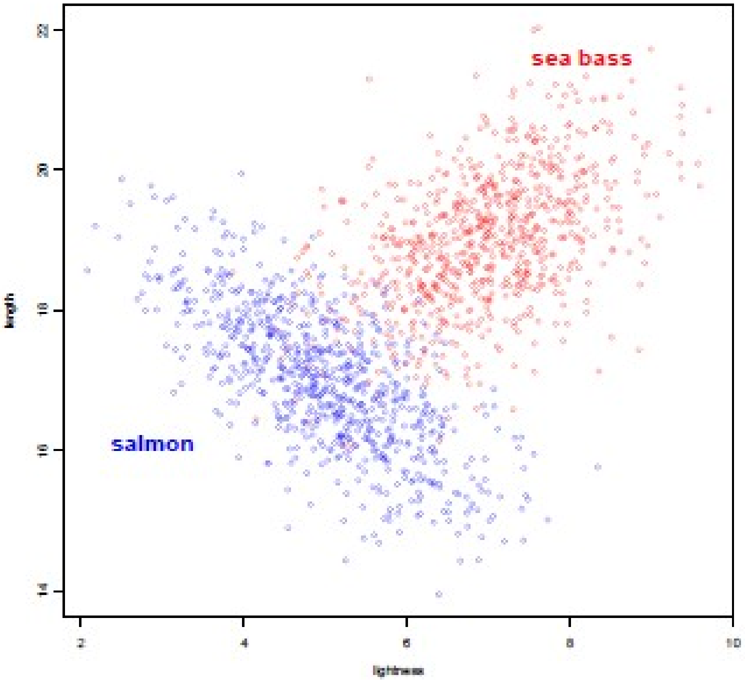
An example of moving: Atlas from BostonDynamics

youtube link https://www.youtube.com/watch?v=hSjKoEva5bg

An example of learning (induction)

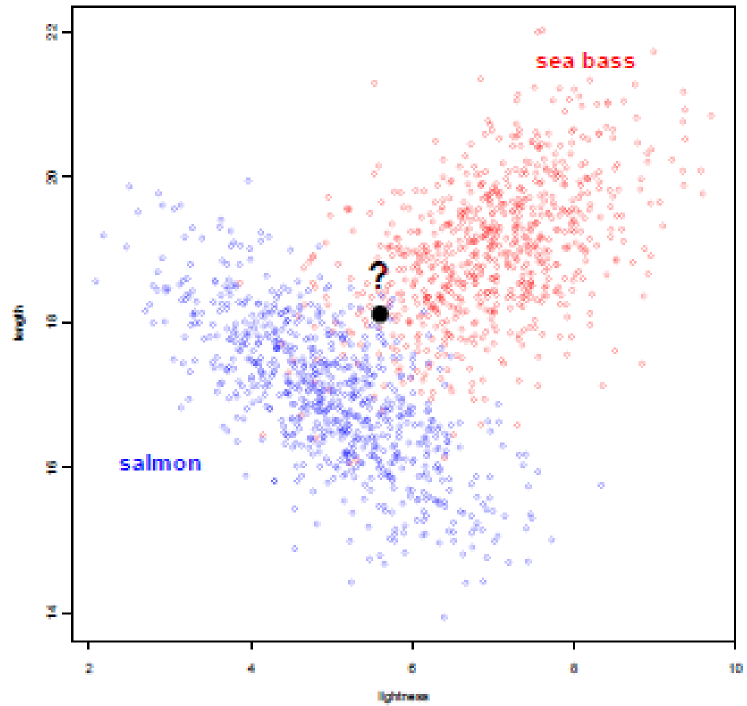
Suppose that a fishpacking factory wants to automate the process of sorting incoming fish (salmon and sea bass).





After some preprocessing, each fish is characterized by feature vector $\mathbf{x} = [x_1, x_2]$ (pattern), where the first component is the lightness and the second component the length.

An example of learning (induction)



Given labeled training data $(\mathbf{x}_1, y_1), \ldots, (\mathbf{x}_N, y_N) \in \mathbb{R}^d \times Y$ coming from some unknown probability distribution $p(\mathbf{x}, y)$. In this example, $Y = \{\text{salmon}, \text{sea bass}\}$ and $d = 2$. Unseen (unlabeled) pattern belongs to class salmon or sea bass?

An example of learning (induction)

“A day in Cairo” (attributed to Jim Alty, via B. Ripley)

JA was visiting Cairo and took a taxi with an English speaking driver
JA noticed that the taxi driver did not stop at red traffic lights
Later JA noticed that the driver did sometimes stop at red traffic lights and that these lights were also manned by a policeman
This spawned a new hypothesis:
“Taxi drivers in Cairo only stop at those red traffic lights which are manned by a policeman”
Later still the taxi drove through a red traffic light which *was* manned by a policeman
Now JA cannot fathom out the rule and asks the driver for an explanation

Ah! but that is obvious! --the taxi driver replies.

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Ah! but that is obvious! --the taxi driver replies. He is my brother!

Three basic forms of logical inference

Induction
We have a box of balls
We pick a ball from the box and the ball is black

All balls from the box are black

Deduction
We have a box of black balls
We pick a ball from the box

The ball is black

Abduction
We have a box of black balls
We have a black ball

The ball is from the box

An example of NLP
poetry translation

A voltes cau una cortina espessa damunt de tot, i tot esdevé estèril.

No és el silenci i és més que el silenci.

Floten els mots en una mar immòbil, tota la cambra és un parany i esclaten, inútilment, angoixes i projectes.

Res no distreu d'aquests instants terribles com tancar els ulls i imaginar una noia de cos propici al joc, a la baralla.

Sometimes a thick curtain falls above all, and everything becomes sterile.

It's not silence and it's more than silence.

Words float in an immobile sea, the whole room becomes a trap, while angers and projects burst, useless

Nothing distracts from these terrible moments as closing the eyes and imagining a girlfriend of a propitious body, for the game, for the quarrel.

Miquel Martí i Pol
(1929-2003)

No examples yet of emotion handling!

Daniel Goleman (1995) outlines five skills involved in **emotional intelligence**:

* being aware of one’s emotions

* managing those emotions

* motivating oneself

* empathizing, and

* relating well with others in a group

> “The psychological characters of an AI will have to await the advent of AI”
>
> Dubeck, Moshier, Bon
>
> *Science in Cinema*

peace, joy, love, happiness, gratitude   disappointment, anger, sorrow, grief, guilt

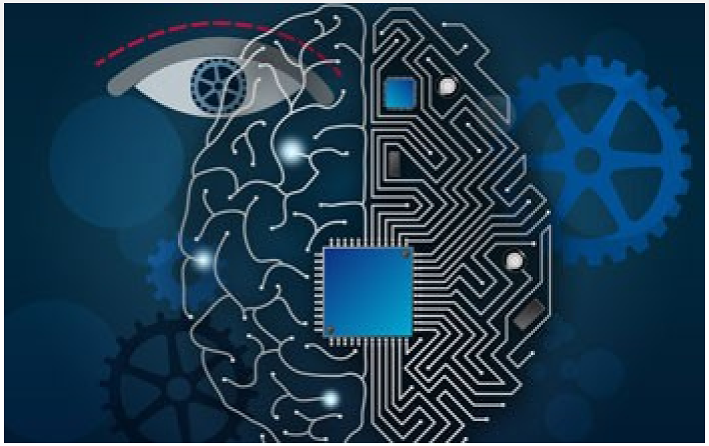
self-awareness, consciousness, sense of humor

“affective computing” A new field of computer science? http://affect.media.mit.edu/

What is CI? (revisited)

CI is what remains when other (traditional, standard) disciplines fail to give a (computational) solution:

- Logic
- Mathematics
- Probability
- Statistics
- Algorithmics
- Engineering



—Let's see some examples of problems solvable with purely non-CI techniques

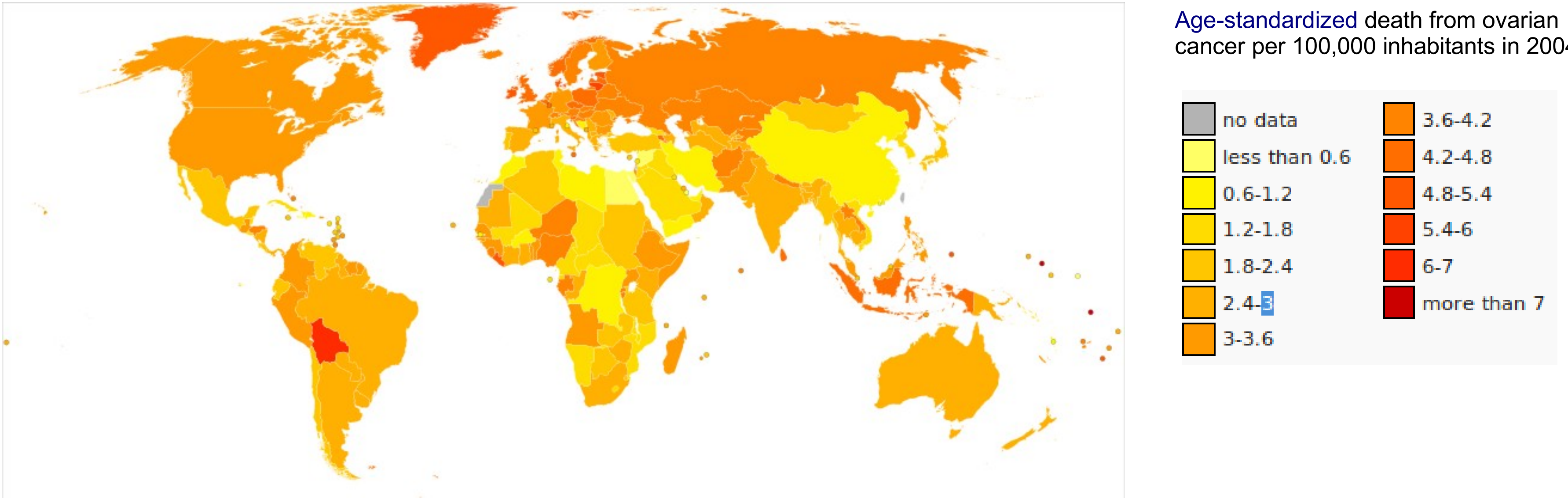
Problem 1
The taxi accident problem

In a certain city 85% of the taxis are painted blue and the rest are painted green. There is an accident in which one taxi is involved. An eyewitness says that the taxi was green. This eyewitness is 80% reliable.

What is the probability that the taxi was indeed green?

Problem 2
The ovarian cancer problem

- One in every 2,500 women aged above 35 who visit the doctor do have this cancer
- We have a wonderful **OC test**: it *always* detects OC when it is there
- When it is not, the test is negative in 63/66 cases
- How useful is the test?



Problem 3
The Crazy World problem

In a certain (crazy) world,

1. Algae wear red panties
2. Everything using deodorant plays sax
3. Everything that smokes uses deodorant
4. Nothing and nobody wearing red panties can play sax

Therefore, algae smoke.

TRUE or FALSE?

Please note that first-order logic (1-OL) is **undecidable** (though there are systems weaker than full 1-OL for which the logical consequence relation is decidable)

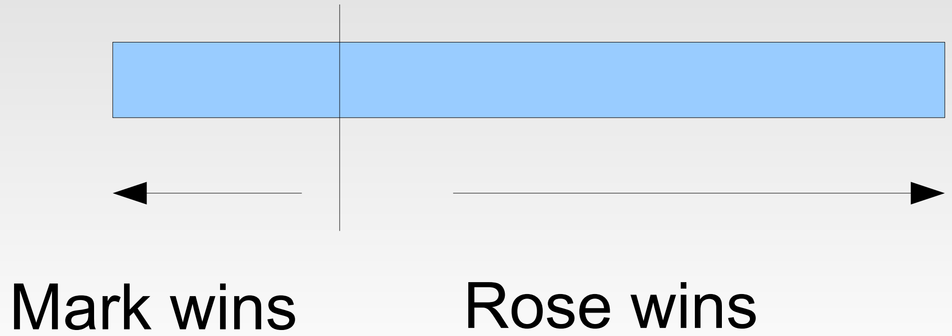
http://mclelun.deviantart.com

Problem 4
The celebrity party problem

The celebrity of an N people party is someone who does not know anyone in the party, but is known to everyone in the party.

Pierre-Auguste Renoir - *Luncheon of the Boating Party*

Problem 5
The child betting problem
(or the importance of the prior)



- Mark and Rose play a betting game
- An initial mark is fixed randomly and externally
- The mark position is never revealed to the players
- The first to get 6 points will win the game

Rose wins 5:3

What are fair betting odds for Rose to offer Mark?

Problem 6
The German tank problem

Statistical formulation

Suppose we have a population of objects labelled 1, 2, 3, ..., N, with N unknown.

From a random sample $x_1, x_2, \ldots, x_k$ of size k without replacement from this population we consider how to estimate N.

For instance, one may estimate the number of runners in a race, taxicabs in a city, or concession booths at a fair, based upon seeing just a sample of these labelled items.

Real applications (PAST)

- The legacy of A. Turing, J. von Neumann, J. Holland, A. Newell, J.C. Shaw, H. Simon, …
- The Cyc project (D. Lenat)

  (huge DB of common-sense knowledge → human-like reasoning)
- The Cog project (R. Brooks)

  (humanoid robot that develops similar to an infant)
- The JANUS architecture (H. Mühlenbein)

  (two-hemisphere brain coupled to hands+eyes: robot that learns)

  --see http://www.muehlenbein.org/

Real applications (PRESENT): tour guide robots

The goal is the development of mobile robots designed to educate and entertain people in public places.

In this example, the robot’s purpose is to guide people through a museum, explaining what they see along the way.

Artificial Intelligence Lab, University of Applied Sciences, Dresden, Germany

Real applications (FUTURE)
Robotic search for life (I):

Beneath Antarctica

Goal: develop a state-of-the-art cryobot (an ice-penetrating robotic vehicle) to search for life in lakes and oceans under miles-thick ice in Antarctica

The cryobot will melt through some of the thickest ice on Earth to access the pristine water beneath.

It carries a second hovering autonomous underwater vehicle (HAUV), to conduct reconnaissance, life search and sample collection, then return to the cryobot for subsequent data uplink and possible sample return to the surface.

http://www.lsu.edu/science/news_events/cos-news-events/SPINDLE.php

STONE Aerospace

Real applications (FUTURE) Robotic search for life (II):

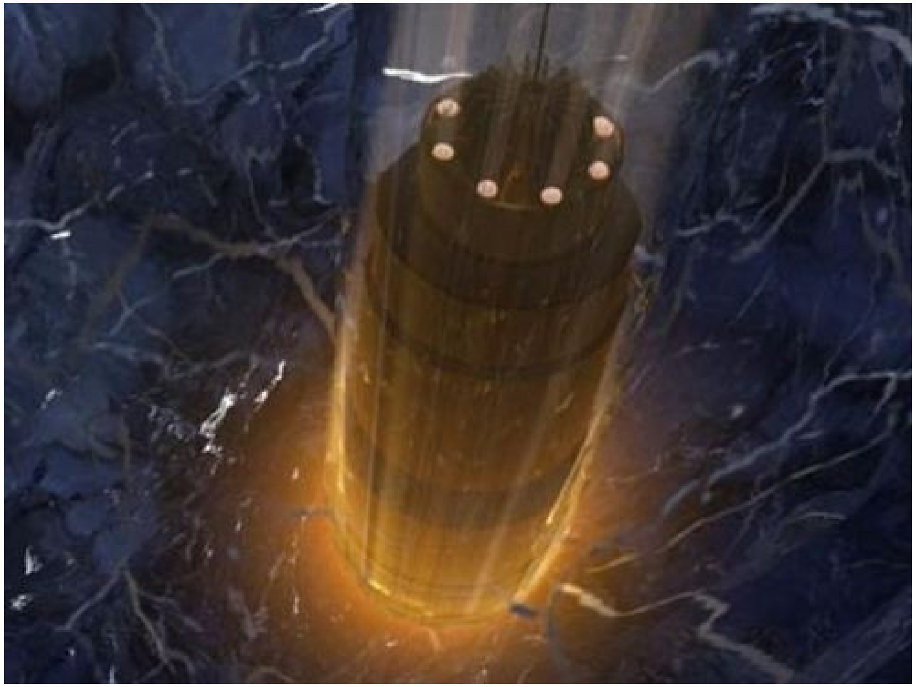
Europa

De profundis ad astra

A self-guided robotic submarine could be designed to look for alien life on Europa, an icy moon of Jupiter.

If Europa harbors life, it is most likely to be in a dark ocean sealed by an ice cap of unknown thickness

The idea is to release autonomous swimming robots that generate their own commands, crunching data in real-time from various instruments (cameras, microscope, accelerometers, velocity loggers and multiple sonar systems).



STONE Aerospace

First take-home message

Three kinds of computational problems:

- 1. There exists a <u>known *and* practical</u> solution by the use of direct methods:

→ use it!

Example: attach some sheets (≤20) in a reliable but reversible way

First take-home message

2. There exists a known and practical solution to a <u>similar</u> problem

→ use a CBR-like system!

- Create a DB of (problems/solutions)
- Fetch the most similar problem in DB
- Adapt its solution to ours
- Store the new (problem/solution) in DB

Example: gender identification in monkeys

Golden Snub Nose Monkey

Douc Monkey

First take-home message

3. There does not exist a known and practical solution (neither to a similar problem)

— use a CI technique!

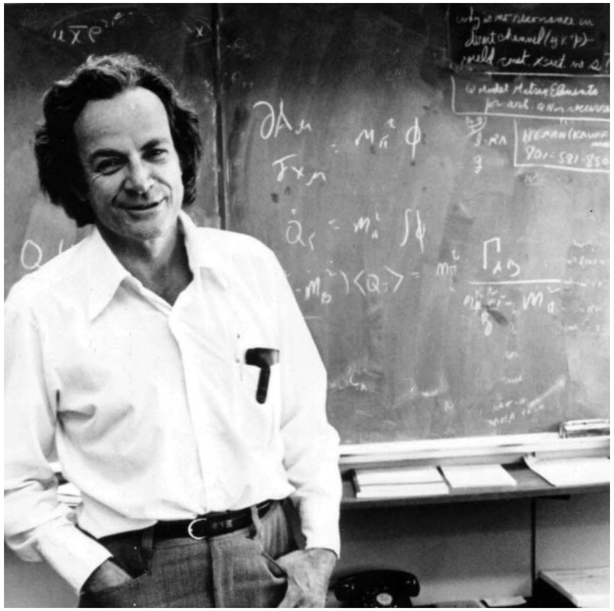
- Some key issues are:
  - how to choose the right technique(s)
  - how to combine them with more traditional methods
- Other issues: reliable technology, good programming, enough funding, right people, enough time, ...

Second take-home message

Even with advanced algorithmic techniques, there are problems that cannot be given an efficient solution, so we require very different (algorithmic) ideas:

- allowing randomness
- adding simple (or sophisticated) heuristic or happy ideas
- allowing/exploiting uncertainty, vagueness, noise, ...

"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."
Richard Feynman



Not-so take-home messages

"Part of the inhumanity of the computer is that, once it is competently programmed and working smoothly, it is completely honest."
Isaac Asimov

"Computers are useless. They can only give you answers." *Pablo Picasso*

- Bibliography:

  - Computational Intelligence - A Methodological Introduction. Kruse, R., Borgelt, C., Klawonn, F., Moewes, C., Steinbrecher, M., Held, P. 2013, Springer

    http://www.springer.com/computer/ai/book/978-1-4471-5012-1
  - Fundamentals of Computational Intelligence: Neural Networks, Fuzzy Systems, and Evolutionary Computation (IEEE Press Series on Computational Intelligence). James M. Keller, Derong Liu, David B. Fogel
  - Challenges for Computational Intelligence. Editors: Duch, Wlodzislaw and Mandziuk, Jacek

    https://www.springer.com/la/book/9783540719830
  - How to Solve It: A New Aspect of Mathematical Method. by G. Polya (Author), John H. Conway (Foreword)