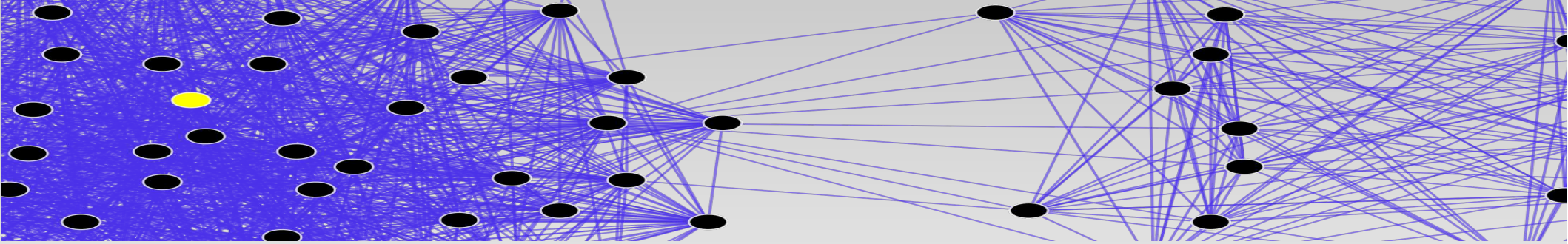

Computational Intelligence

Master in Artificial Intelligence

2023-24

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Introduction to Computational Intelligence

Soft Computing Research Group

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

What the course is about

- The CI “primordial soup”:
  - Core techniques:
    - 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 may be found in optional follow-up courses

Today's topics

- What **is** Computational Intelligence?
- Overview of core CI **techniques**
- **Challenges** for CI systems
- Important **notions** to bear in mind
- Application **examples** (past, present and future)
- Take-home **messages**
- Some **bibliography** (more will be given later)
- **Organizational** issues

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?)

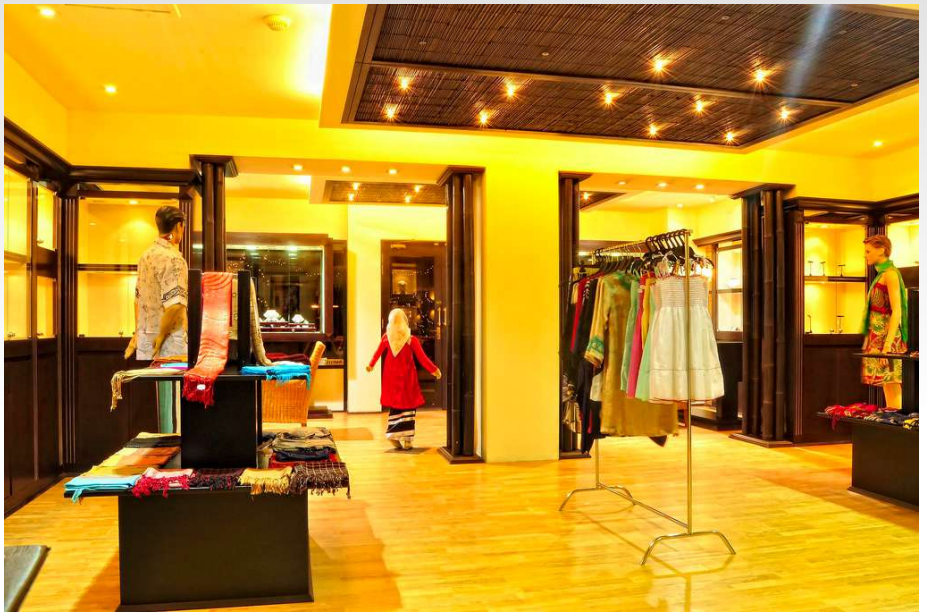
"Generally, a car can be parked rather easily because the final position of the car is not specified exactly. It it were specified to within, say, a fraction of a millimeter and a few seconds of arc, it would take hours of maneuvering and precise measurements of distance and angular position to solve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

* HUMAN COST: 2h + anxiety
* PRECISION: 100%

* Max. COST: 0€
* Max. WIN: 0€
  (theoretically)

OPTION 2: approx. counting (how?)

* HUMAN COST: 10s + smile
* PRECISION: 97.5%

* Max. COST: 75€
* Max. WIN: 75€

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)

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)

On living intelligent systems

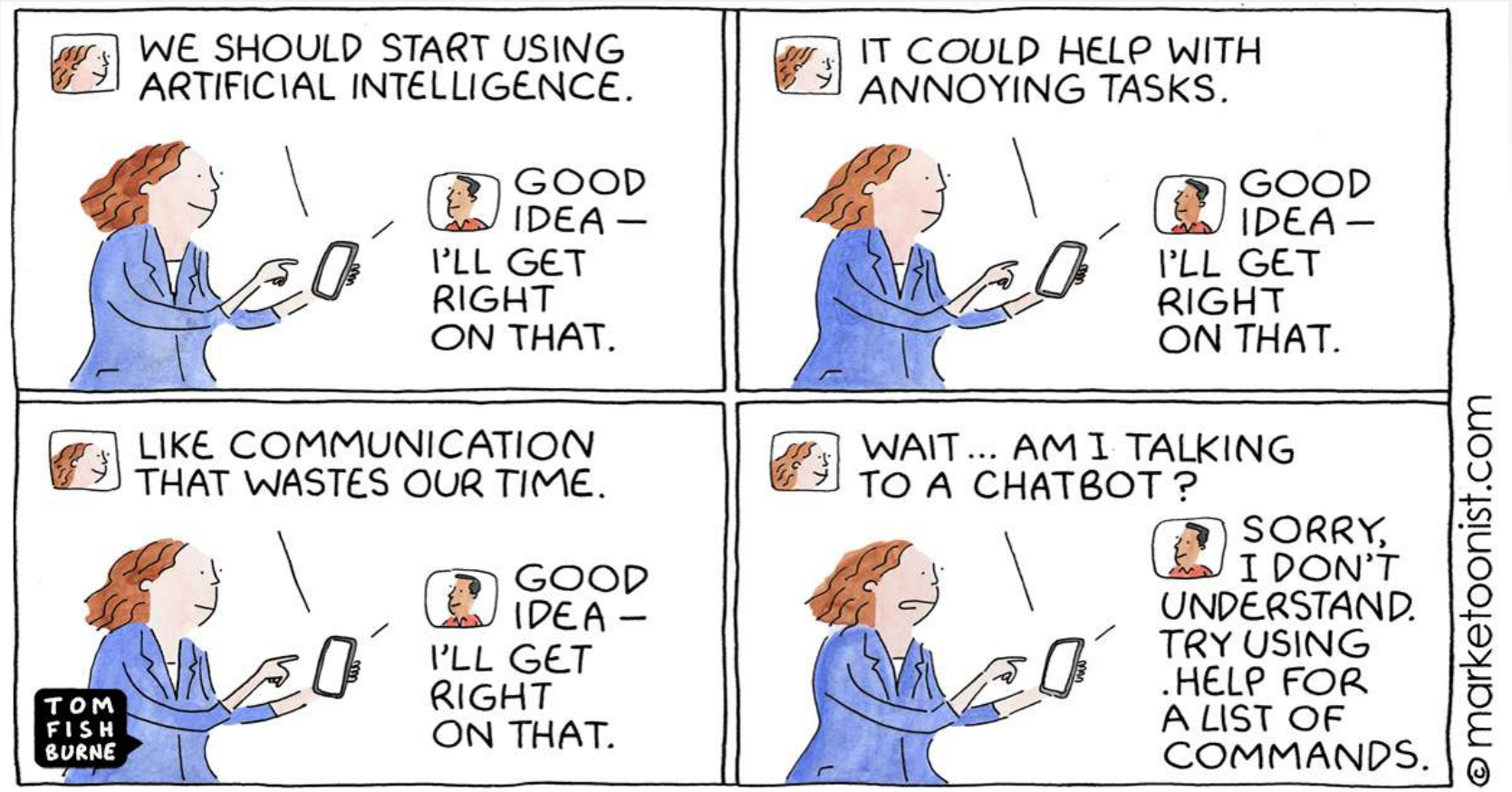
- What **is** intelligence? Don't know ...

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

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

What CI is “not exactly”: Artificial Intelligence

- Classical AI is the endeavor of making a machine appear intelligent (and most often in human 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

What CI is “a means for”: Artificial Intelligence

A famous (if newer) **AI success**: Alpha Go (developed by Google's DeepMind) vs. Lee Sedol (probably best human player at the time) in 2016.

5-game match: AlphaGo won all but one game (the fourth)

Alpha Go uses neural networks to estimate its probability of winning. It analysed a huge online library of Go (matches, players, analytics, …, as well as games played against itself and other players. It also uses tree search heuristics.

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 a heuristic?

A **heuristic** is designed to solve a (sub)problem in a faster and more efficient fashion than traditional methods by sacrificing optimality, accuracy, precision, or completeness for speed.

Generation
e.g. of good starting points)

Approximation:
e.g, replacement of a very precise computation with a (much faster) if less precise one (e.g. suppose we use 22/7 instead of π).

Use of surrogates:
e.g., very complex (and costly) computations can sometimes be replaced by a surrogate method. For example, a neural network can be trained to emulate a complex process from data.

What is knowledge?

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

“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)

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

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

“Les dones no tenim esquena.”
(my neighbour)

What is uncertain 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**

Core techniques

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

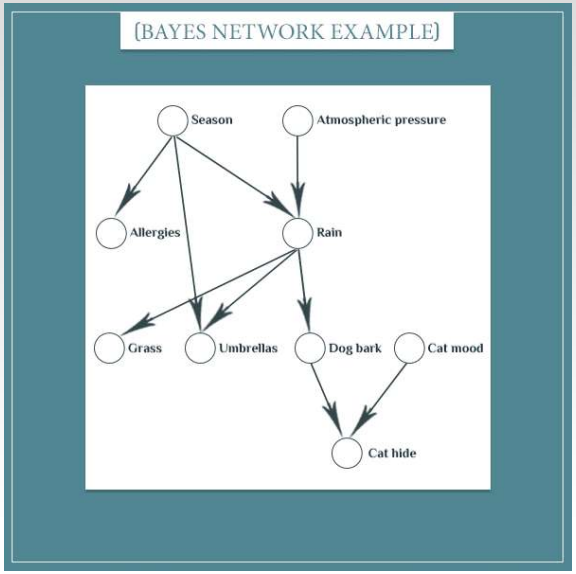
Fuzzy (possibilistic) computation

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

Other techniques

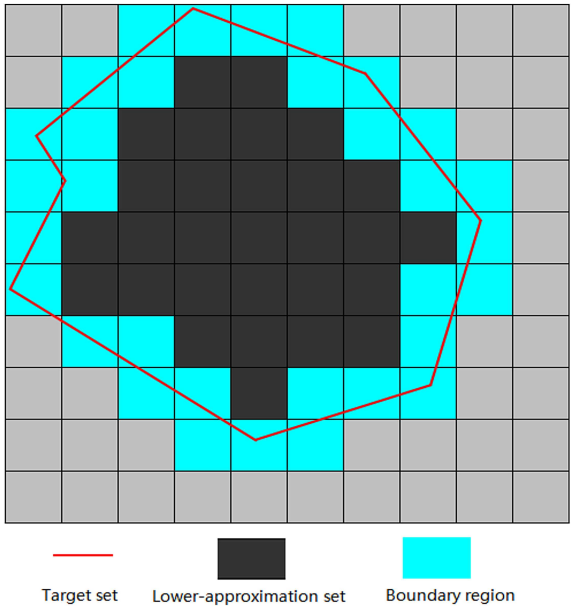
Probabilistic computation: belief networks

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:

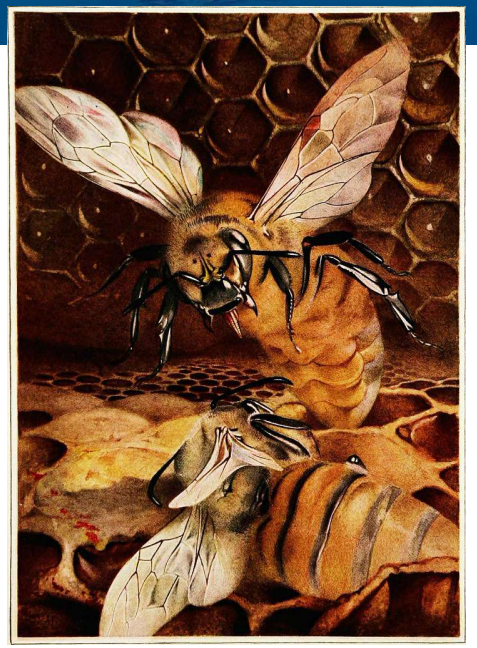


Other techniques

Swarm intelligence

Inspired by the observation of the collective behavior in societies in nature such as the movement of birds, fish, wolves, bees, ants, ...

Interactions between such agents lead to the emergence of "intelligent" global behavior, unknown to the individual agents



More 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 techniques: {DNA, Quantum, Optical, Chaos} computing

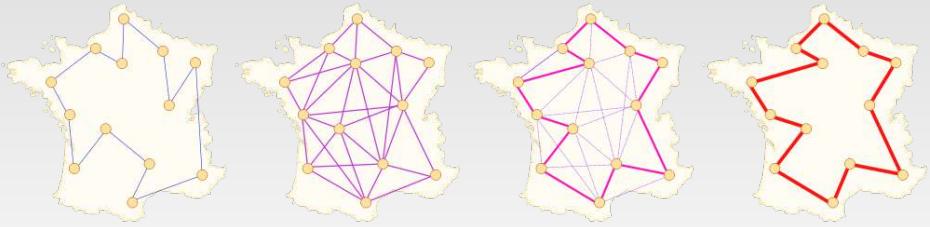
What are the challenges for CI?

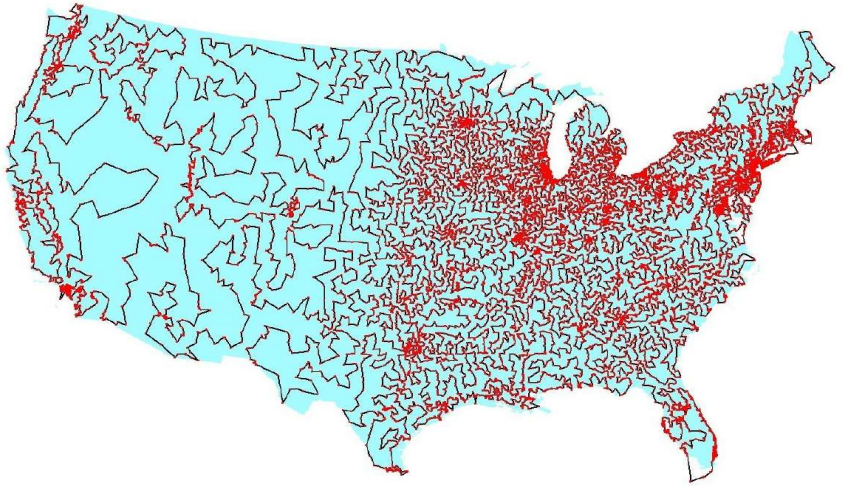
1. Problem solving (search/optimization)
2. Sensoring/moving (sensorimotor coordination)
3. Learning (induction)
4. (Natural) Language Processing
5. Inference/reasoning (logically sound)
6. Emotion handling (plus ethics, conflicts, ...)

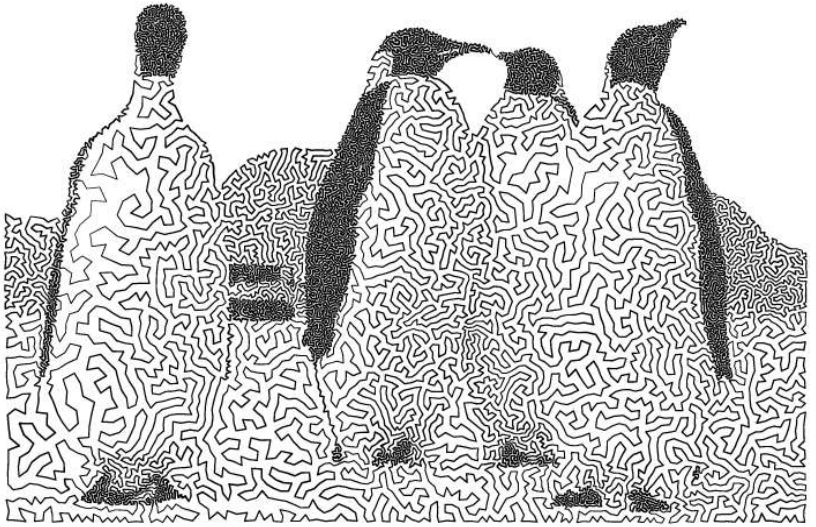
- How to put it all together ...
- Often in real time ...

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"

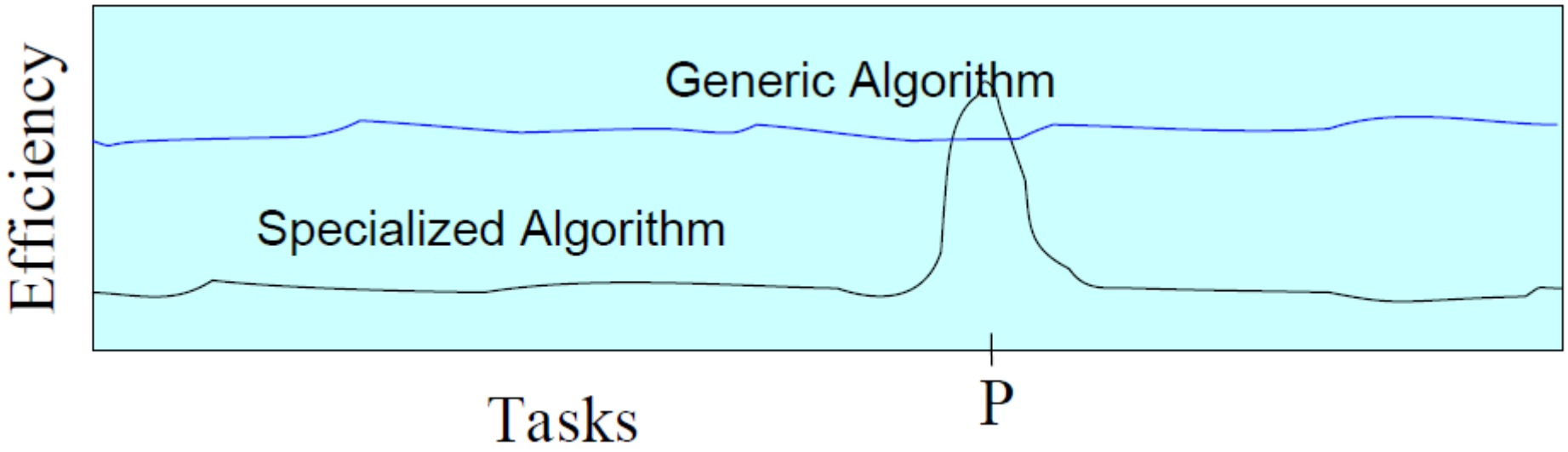




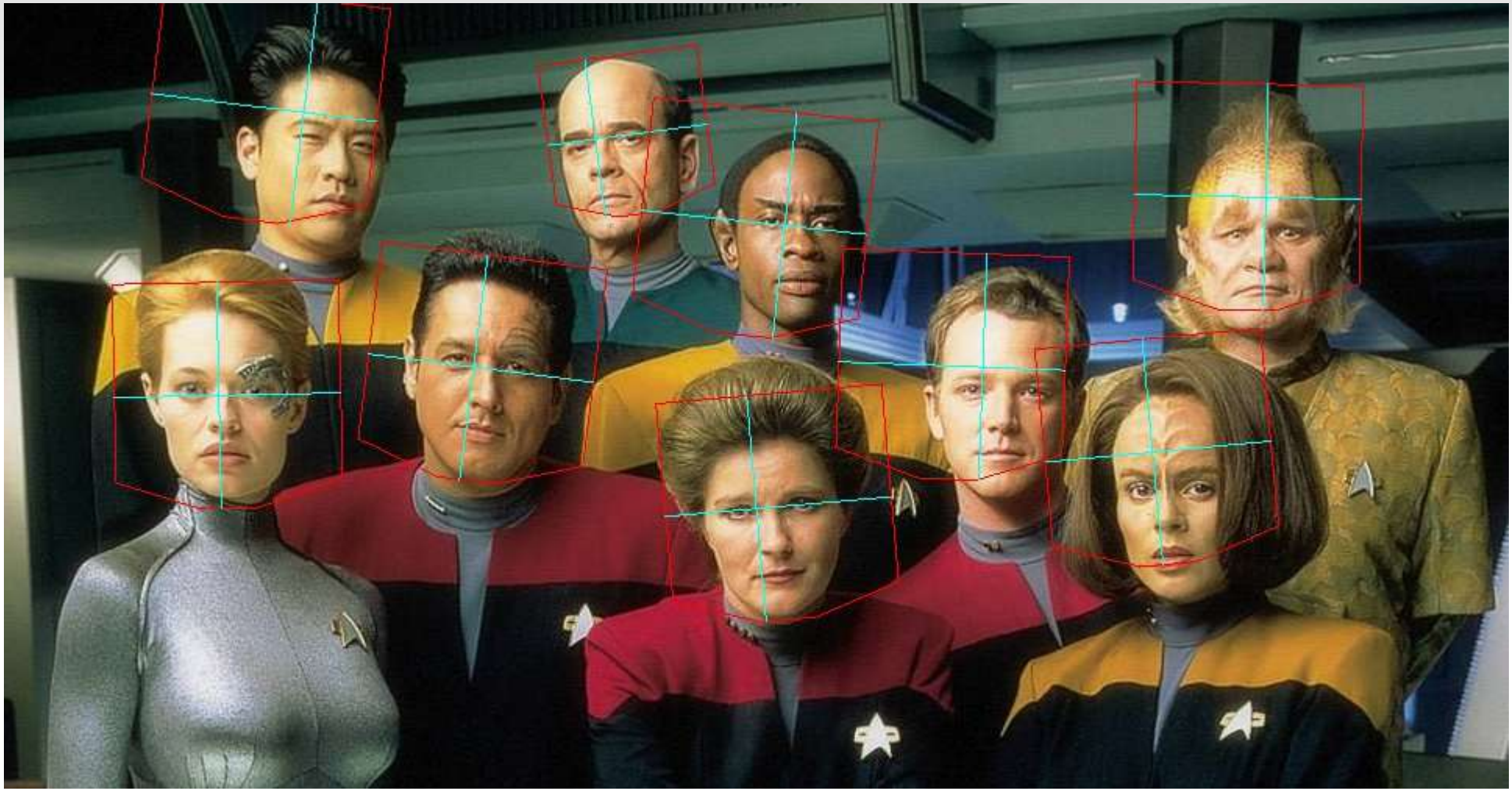


Kinds of algorithms (= solutions)

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 (Face Detection section)

An example of sensorimotor coordination: robots from the Atlas team at Boston Dynamics

Atlas 1 https://www.youtube.com/watch?v=tF4DML7FIWk

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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Now JA cannot fathom out the rule and asks the driver for an explanation
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 floating in an immobile sea, the whole room becomes a trap; angers and projects burst, uselessly.

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

Miquel Martí i Pol
(1929-2003)

An example of NLP
poetry translation (and back)

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.

De vegades una cortina gruixuda cau sobre tot, i tot es torna estèril.

No és silenci i és més que silenci.

Les paraules suren en un mar immòbil, tota l'habitació és un parany i les angoixes i els projectes esclaten, inútilment.

Res distreu d'aquests terribles moments com tancar els ulls i imaginar una noia amb un cos propici al joc, a la lluita.

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

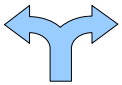
* motivating oneself

* 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/

Real applications: interacting robots

The Robot RHINO in the Deutsches Museum Bonn

The goal is the development of mobile robots designed to guide people through a museum, explaining what they see along the way.

Kaspar the friendly robot helps autistic kids

Eden Sawczenko used to recoil when other little girls held her hand and turned stiff when they hugged her.

Last year, the 4-year-old autistic girl began playing with a robot that teaches about emotions and physical contact - and now she hugs everyone.

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, return to the cryobot for data uplink and possible sample return to the surface. STONE Aerospace:

- https://www.youtube.com/watch?v=00UE9vpclTM

  (first 15 mins only)

- https://www.youtube.com/watch?v=0MY099C1PxQ

- https://stoneaerospace.com/news/

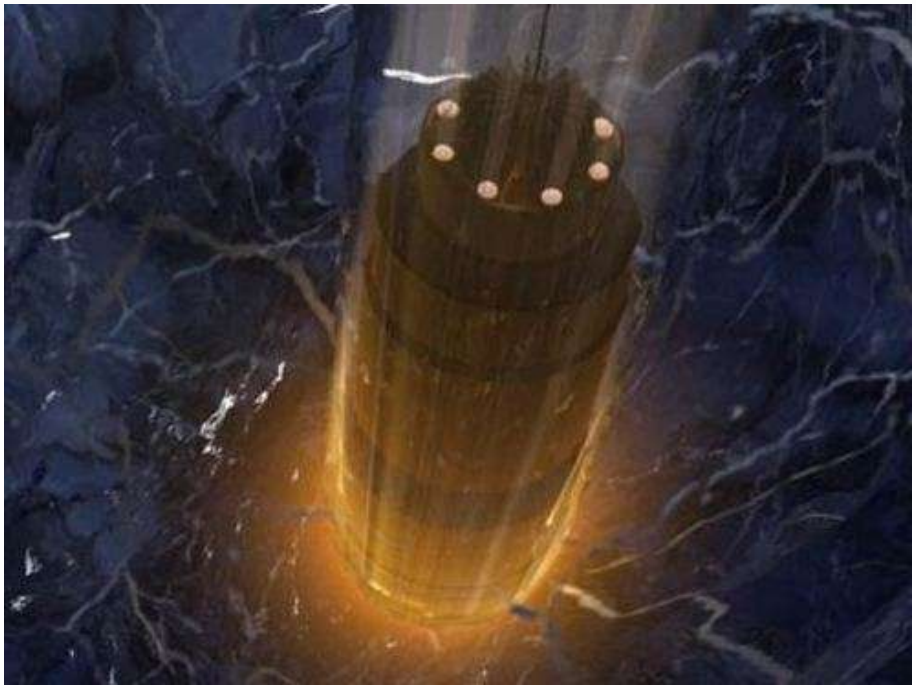
Real applications (FUTURE)
Robotic search for life (II):
Europa

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

Take-home messages

Three kinds of computational problems:

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

→ use it!

Example: attach some sheets (2 to 50) in a fast, reliable and reversible way

Take-home messages

Three kinds of computational problems:

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

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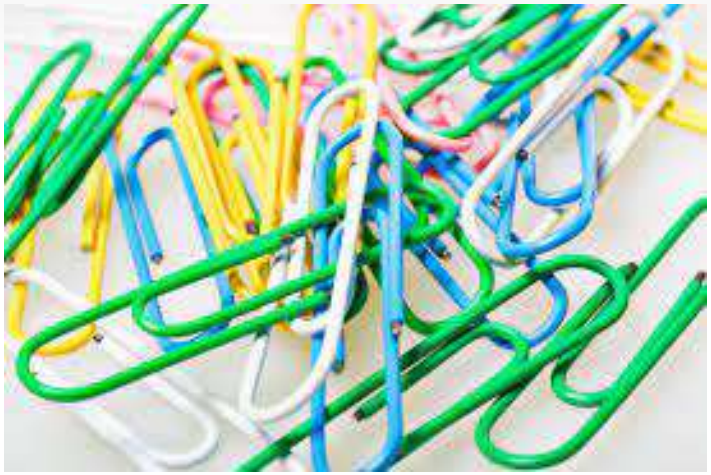

Example: attach some sheets (2 to 50) in a fast, reliable and reversible way

Take-home messages

2. There exists a known and practical solution to a similar 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

Take-home messages

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, ...

Even with advanced algorithmic techniques, there are problems that cannot be given an efficient solution, so we require very different (algorithmic) ideas:
- allowing for approximately correct solutions
- adding simple (or sophisticated) heuristic or happy ideas
- allowing/exploiting randomness, uncertainty, vagueness, noise, ...

What is a heuristic?

Surrogate

Very complex (and costly) computations can sometimes be replaced by a surrogate method. For example, a neural network can be trained to emulate a complex process from data.

Heuristics: Intelligent Search Strategies for Computer Problem Solving
Judea Pearl

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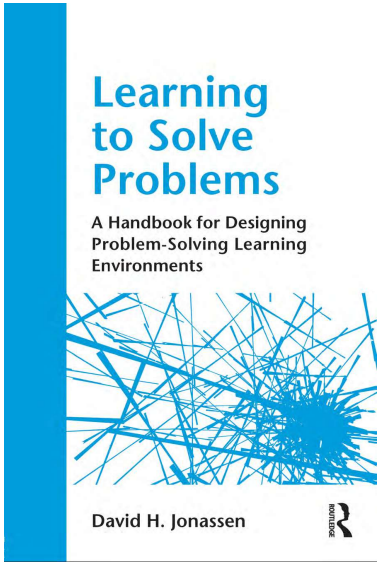

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Exam: 18/1/2024

Final Grade = 50% Projects Grade + 50% Exam Grade

Classroom: Theory: A6001; Lab: B5S201 & B5S202