LAU
Lebanese American University
Chartered in the State of New York
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UNITED NATIONS
ESCWA

SOE
School of Engineering
Department of Electrical & Computer Engineering
www.lau.edu.lb/ece

Introduction to ***Artificial Intelligence*** and its Impact on ***Sustainable Development***

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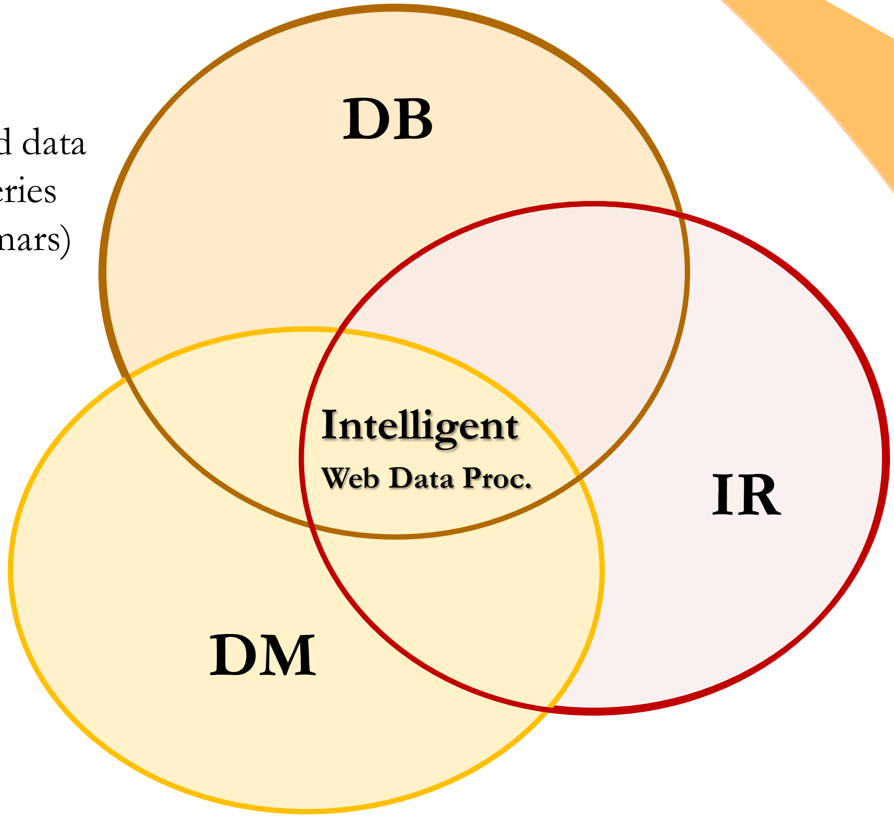
ARAB HIGH-LEVEL FORUM on WSIS and 2030 AGENDA for Sustainable Development

1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH

My Area of Expertise

- **Web**-based **semi-structured data processing & applications**
  - XML, RDF, & OWL are at the center stage of data engineering
    - ⇨ Main building block toward **Intelligent Web Data Processing**

DataBases
Handling structured data and complex queries (e.g., SQL, grammars)



Information Retrieval
Handling flat data & ranked queries (e.g., keyword search)

Data Mining
Discovering & inferring hidden data patterns (e.g., clustering, classification)

Let's try to look at the future…

Modern times (1936)

People are expected to spend less time on daily routines!

Content

Definition of AI

- **We are called *Homo Sapiens* = the Wise Man**
  - **Intelligence:** distinctive characteristic of the human race

- **What is Intelligence?**
  - Question with different perspectives: philosophical, scientific and moral
  - Intelligence characterizes the way we:
    - Think
    - Behave
    - Perceive things
    - Manipulate objects
    - Predict events
    - Interact with our environment
    - Communicate with other intelligent entities

- **Artificial Intelligence (AI):** field of study bridging **computer science** and **computer engineering**, aiming to create intelligent entities

Definition of AI

- There are different views of AI, aiming to simulate/create:

	Consistency with human performance	*Consistency with ideal performance*
Reasoning	**Human Reasoning**	**Rational Reasoning**
Behavior	**Human Behavior**	**Rational Behavior**

Definition of AI

- In this context, **we can redefine AI:**
  - Creation of **rational (intelligent) agents** capable of:
    - **Perceiving** their **environment**
    - **Making decisions**
    - To **maximize** their **chances** of achieving the **desired goal**
    - Given **time constraints** and restrictions in **processing resources**
    - While **resisting noise/uncertainty**, making decisions based on:
      - – Incomplete
      - – Inaccurate
      - – Partially incorrect data

STANLEY (VW)

Deep blue vs. Kasparov, 1997

PackBot (US Army)

ASIMO (Hoda)

DART (US Army)

Content

Content

- Introduction
- Definition of AI
- Fields of Study in AI
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- Impact on Sustainable Development
- Wrapping up

Fields of Study in AI

1. Search Agents

- **Main Premise**: Solving a problem intelligently by **searching** for the best solution in a space of many possible solutions

- **Problem definition:**

  1. Producing abstract mathematical representation of the **environment**
     - Called the **state space**: **S**, set of states an agent can find itself in

  2. Identifying the set of actions an agent can undertake to change states
     - Called the **transition model**

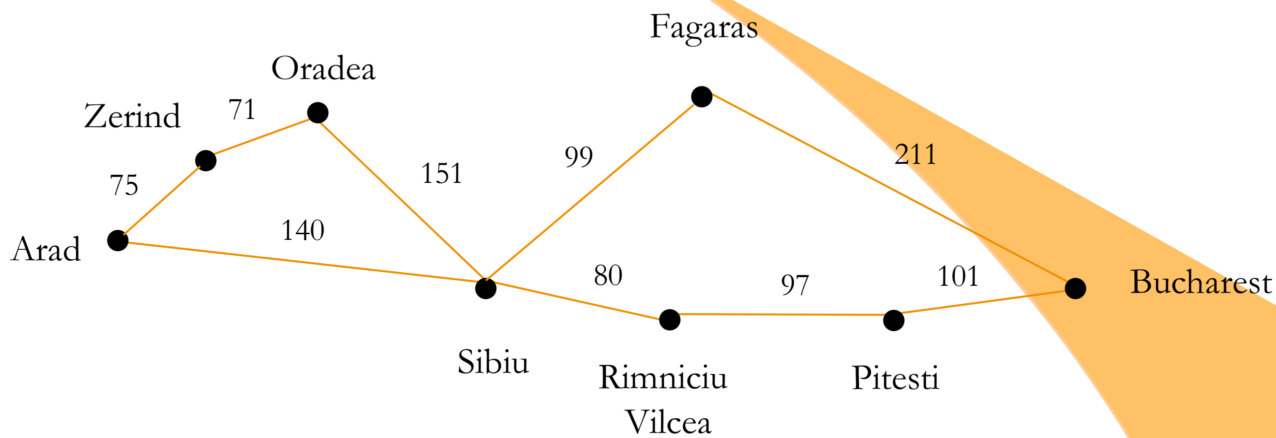
  3. Identifying the agent's **goal**, i.e., the state(s) the agent needs to reach
     - Representing the solution(s) to the problem being formulated

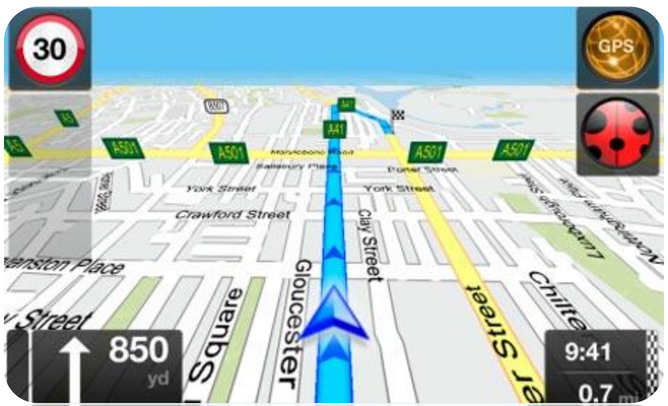
  4. Identifying the agent's **utility function**, i.e., a cost function evaluating the quality of a given solution

↳ The agent is supposed to reach the **optimal solution,** i.e., the most *cost effective solution*

Fields of Study in AI

1. Search Agents: Applications





GPS systems

STANLEY (VW)

A160T (US Army)

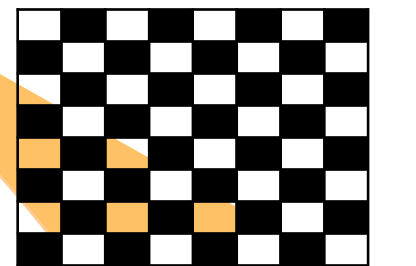
Intelligent navigation & transportation systems

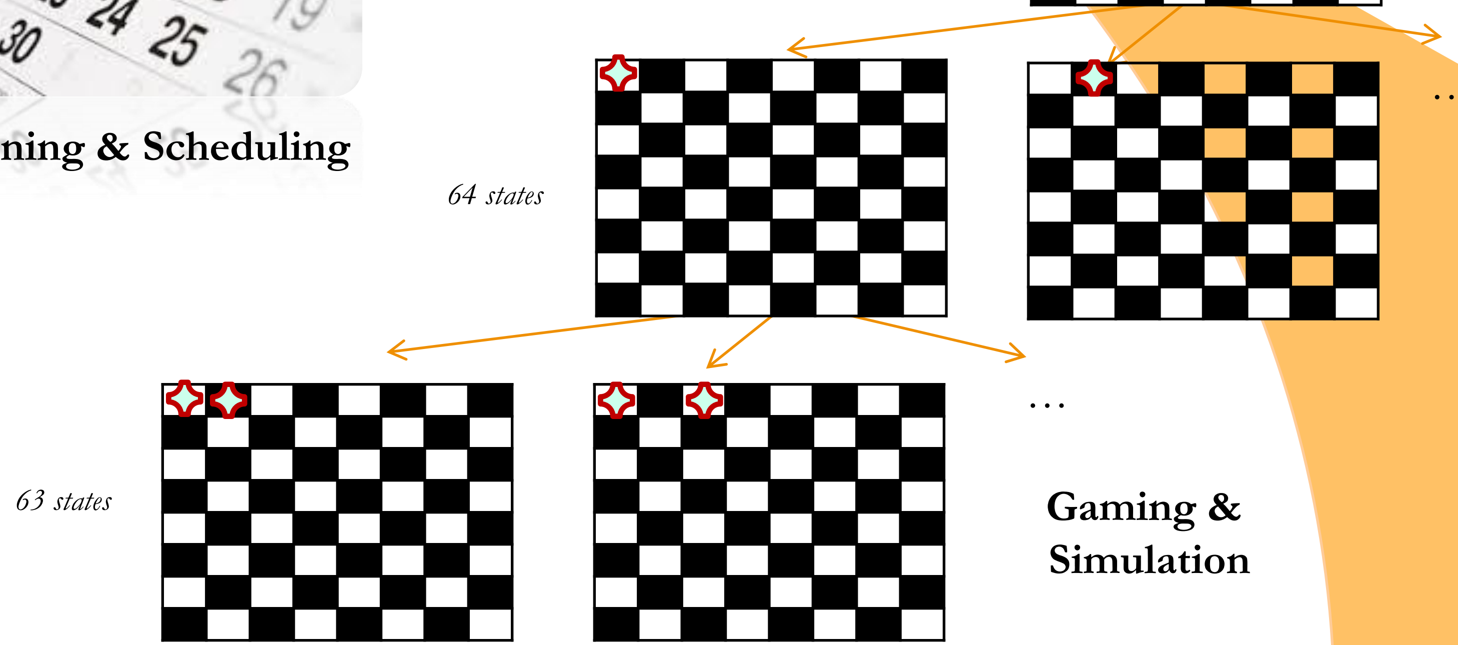
Fields of Study in AI

1. Search Agents: Applications

Planning & Scheduling

Problem solving





Gaming & Simulation

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- **Wrapping up**

Fields of Study in AI

2. Knowledge Representation

- Many of the problems machines are expected to solve will require extensive knowledge about the world

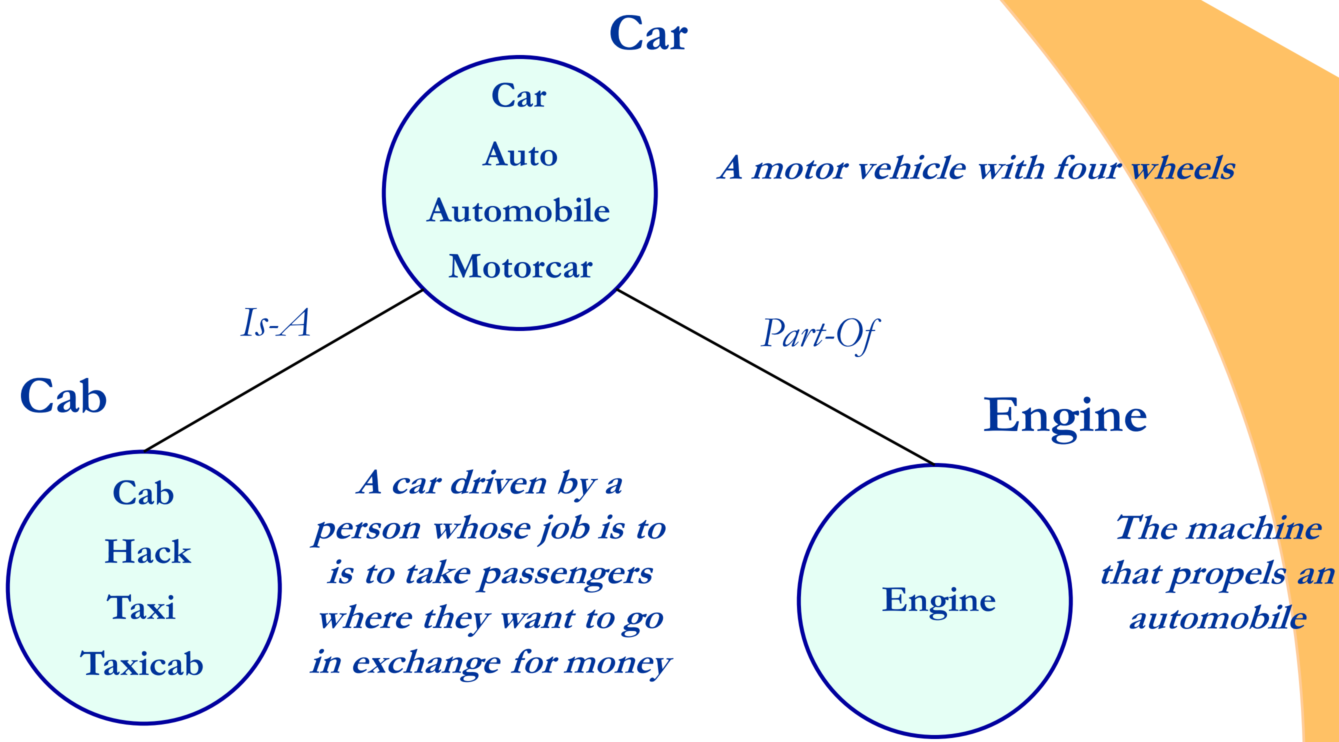
- **Main Premise**: Assigning information well defined **meaning**, to be automatically understood and processed by machines

- **Basic constructs:**
  - **Controlled vocabulary** (e.g., machine-readable dictionary)
    - A list of ordered words with explicit semantic meanings
  - **Thesaurus** (e.g., lexicon)
    - A dictionary enriched with semantic relations
      - Is-A, Related-To, Attribute-Of, See-Also, etc.
  - **Ontology** (e.g., knowledge base)
    - Thesaurus with an explicit formalization of relations
      - Using dedicated grammar rules

Fields of Study in AI

2. Knowledge Representation

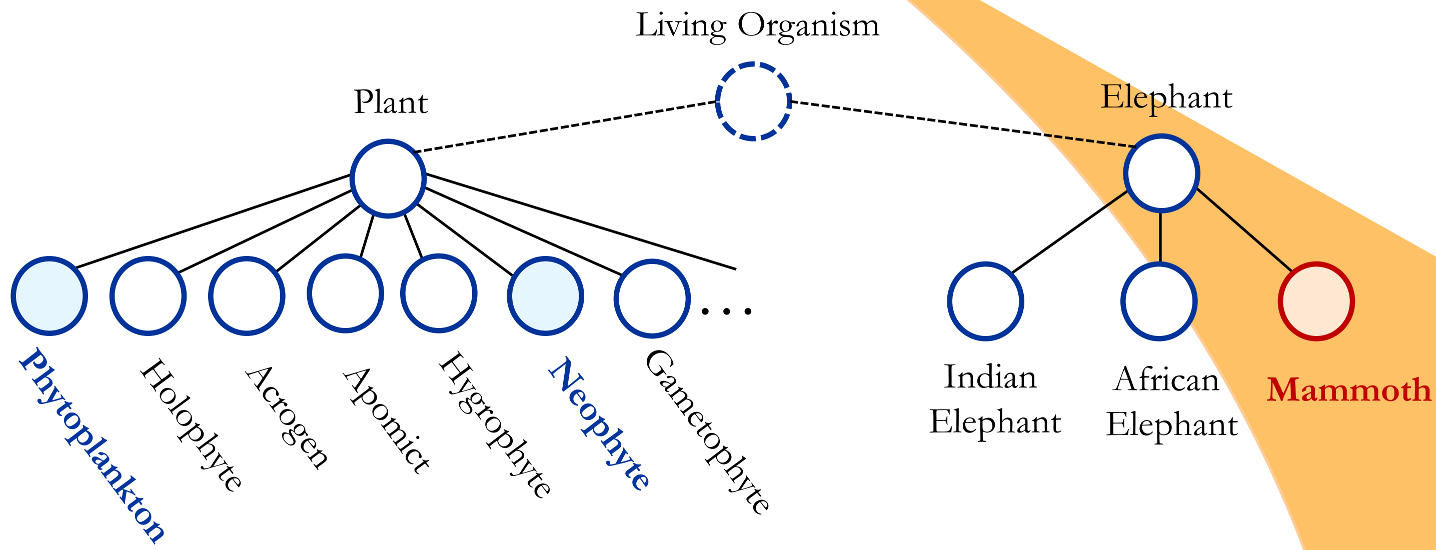
- **Knowledge base** (e.g., ontology)
  - Modeled as a **Semantic Network**
    - – Concepts connected via (hierarchical) relations



Fields of Study in AI

2. Knowledge Representation

- **Knowledge processing**: evaluating relatedness between concepts



$$\mathrm{Dist}(c_1, c_2, SN) = \sum_{c \in MinPath(c_1, c_2, SN)} Weight(c_1, c, SN)$$

$$Weight(c_1, c_2, SN) = \left(\beta + (1\text{-}\beta) \times \frac{\mathrm{Child}(SN)}{|\mathrm{Child}(c_2)|}\right) \times \left(\frac{\mathrm{Depth}(c_2)+1}{\mathrm{Depth}(c_2)}\right)^{\alpha} \times \mathrm{Type}(c_1, c_2)$$

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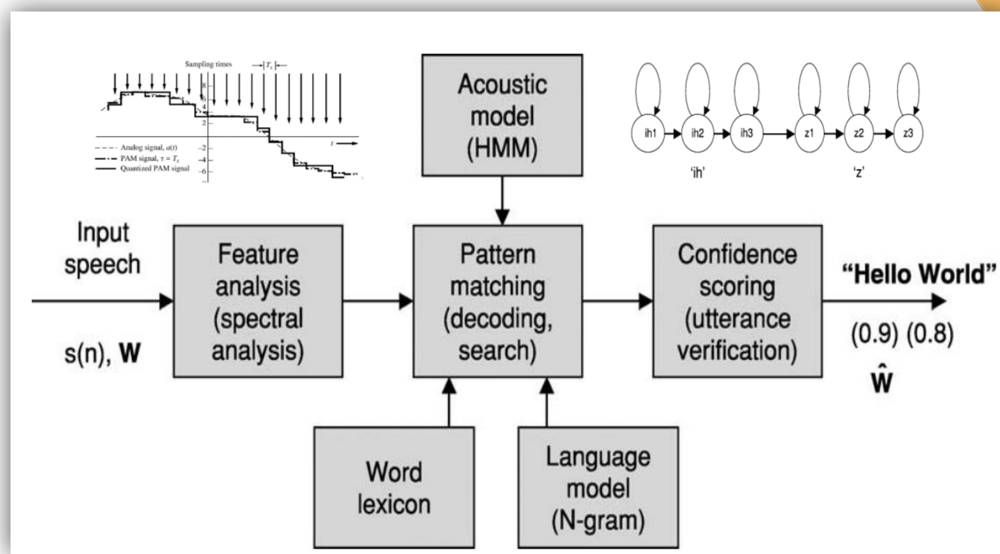
Fields of Study in AI

3. Natural Language Processing

- **Speech Recognition:**
  - A traveler calling United Airlines can communicate and book tickets, using:
    - A system of **automatic speech recognition** and a **dialogue management system**
  - **SIRI:** mobile application using voice commands to manipulate mobile phone



"Hello World"

Fields of Study in AI

3. Natural Language Processing

- **Machine Translation:**
  - Hot research area, requiring combination of various NLP techniques including: **semantic analysis**, **WSD**, and **DM**,
    - **PanDoRa:** machine translation system for hand-held equipment (Carnegie Mellon)

- **Information Retrieval**
  - Core NLP components in state-of-the-art search engines
- **Information Extraction & Content Analysis**
  - Central in DM applications: Part-of-Speech tagging & Text categorization
- **Lexicography**
  - Creating domain specific dictionaries

Fields of Study in AI

3. Natural Language Processing

- Useful in many application scenarios:
  - **Serving disabled people**
    - Special aids for the blind
  - **Telephony** and related domains
    - Automated call management systems
  - **Military**
    - High-performance fighter aircrafts
    - Helicopters
    - Battle management
  - **Medical field**
    - Digital doctors and digital clinics
  - **Home automation**

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Fields of Study in AI

4. Approximate Reasoning

- **<u>Main premise</u>**: The world is *imperfect*, *inaccurate*, and full of *uncertainty*
  - Need to add a **truth scale** between **true** and **false**
    - Pioneered in **Fuzzy Logic** (L. Zadeh)

- <u>Specifications</u>:

  1. Data: **Boolean Logic:** False (0) – True (1)

     Fuzzy Logic: 0 → 1

  2. Reasoning: **Boolean Logic:** *Hypothesis* ⇒ *Conclusion*

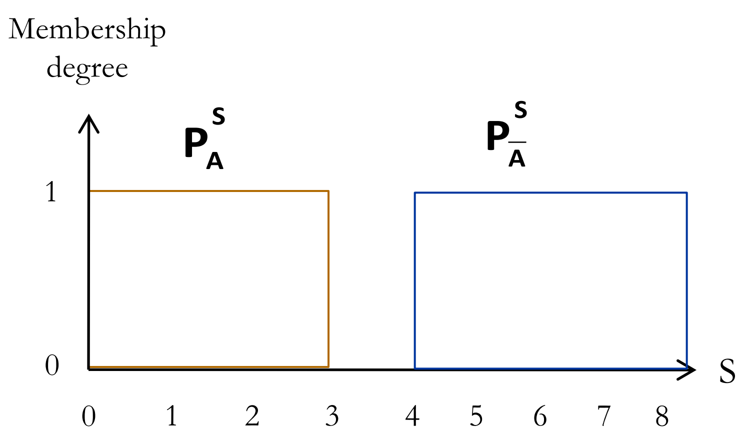
     Fuzzy Logic: *Hypothesis* ⇒ *Conclusion* with a *degree of truth*

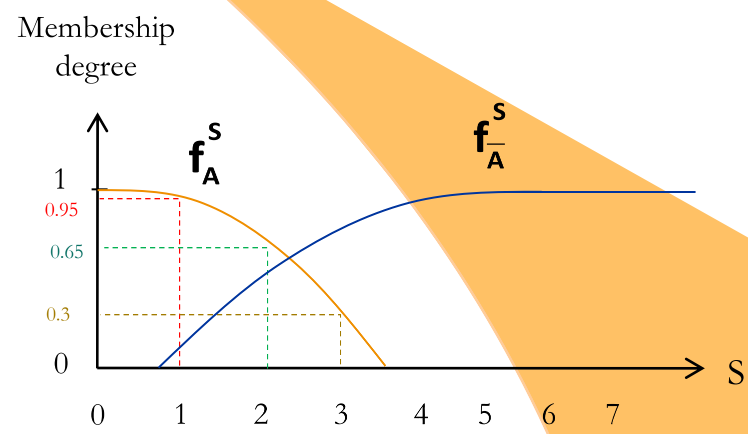
- <u>Origins</u>: Eastern Reasoning originated with **Buddha** around 600 B.C.
  - Each and every entity contains a little of its inverse, **A** and $\bar{\mathbf{A}}$
    - E.g., *A person is partly good and partly bad* (Yang Yin)

Fields of Study in AI

4. Approximate Reasoning

<u>Glimpse on Mathematical Constructs</u>:





Ordered referential set

$\mathbf{A} = \{0, 1, 2, 3\}$ and $\bar{\mathbf{A}} = \{4, \ldots, 8\}$

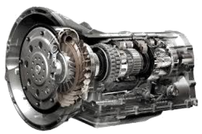
$f_A^S(0) = 1$ ⇨ Element 0 ∈ A with 100% precision, i.e., 0 ∈ 100% in A

$f_A^S(1) = 0.95$ ⇨ Element 1 ∈ A with 80% precision, i.e., 1 ∈ 95% in A

$f_A^S(2) = 0.65$ ⇨ Element 2 ∈ A with 65% precision, i.e., 2 ∈ 65% in A

Fields of Study in AI

4. Approximate Reasoning


<u>Useful in many scenarios</u>:

- Creating control systems based on the *"human common sense"*
  - Creating intelligent agents simulating **human reasoning/behavior**
- Used when it is difficult to utilize traditional mathematical methods
  - E.g., human reasoning is often **non-deterministic** or **stochastic**
- Creating **reflex-based systems** using condition-action rules

<u>Some practical applications</u>:

- **Autofocus** and **auto-tuning** in sensors (e.g., digital cameras)
- **Braking** and **handling** (gear change, acceleration) **systems in automobiles**
- **Speech recognition** in Natural Language Processing (NLP)
- **Robotic systems** simulating human (or animal) walk and/or behavior

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Fields of Study in AI

5. Machine Learning

- **Machine learning** is the science of getting computers to act without being explicitly programmed

- In the couple of years decade, machine learning has given us:
  - Self-driving cars, practical speech recognition, effective web search, among other applications, as well as a vastly improved understanding of the human genome…

    ↳ Key to make progress towards **human-level AI**

- Machine learning techniques fall within two main categories:
  - **Supervised** learning
  - **Unsupervised** learning

Fields of Study in AI

5. Machine Learning

5.1. <u>Supervised Learning</u>:

- **Main premise:** Identifying an output measure based on input data
  - By mapping inputs to desired output
    - Using sample input/output data provided by experts: **training data**

- Training data provided in the form of examples $(\mathbf{X}_1, \mathbf{y}_1), \ldots, (\mathbf{X}_m, \mathbf{y}_m)$
  - where $\mathbf{X}$ is a vector of $\mathbf{x}_1, \ldots, \mathbf{x}_k$ input values
  - And $\mathbf{y}$ is the output generate by unknown/**desired** activation function $\boldsymbol{f}$

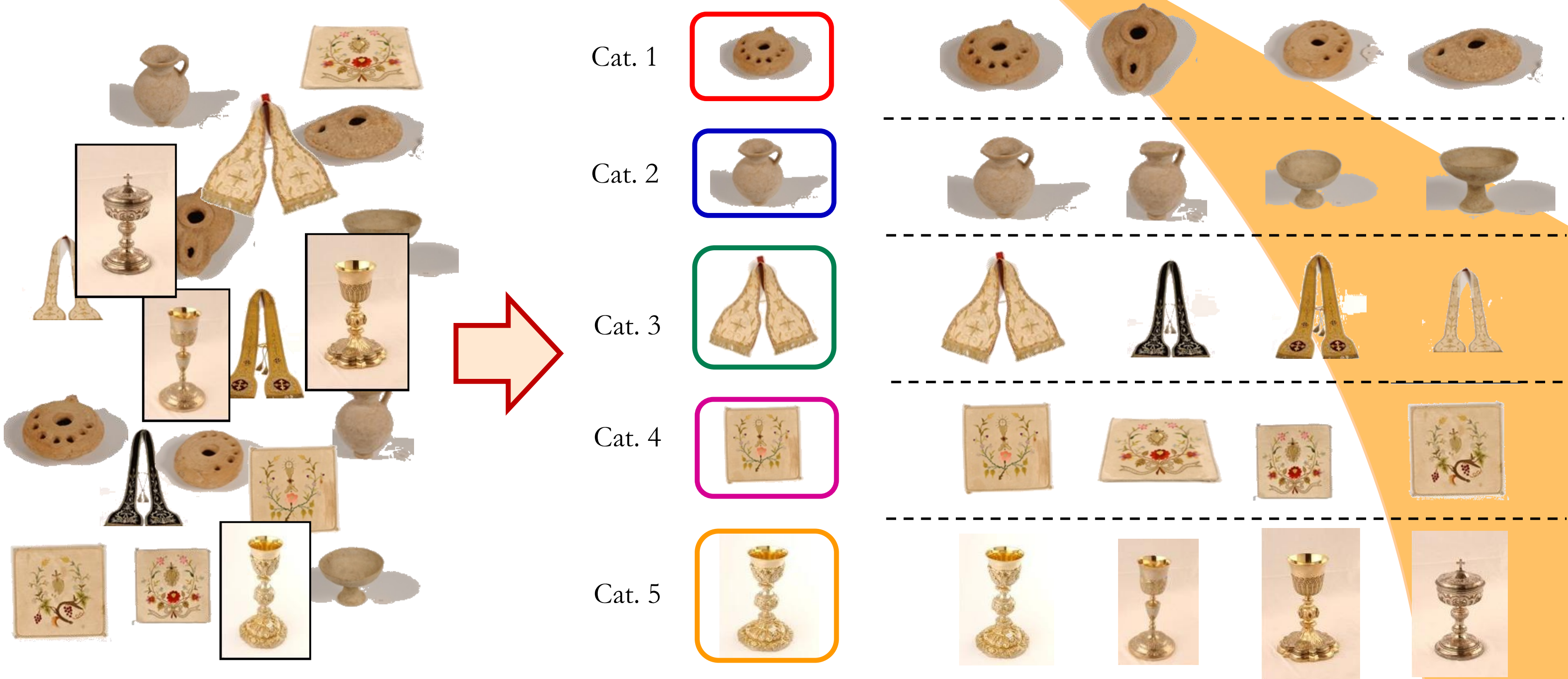
↳ Discover a function $\boldsymbol{h}$ that approximates the desired activation function $\boldsymbol{f}$

- Approach known as **classification**

Fields of Study in AI

5. Machine Learning

5.1. Supervised Learning:

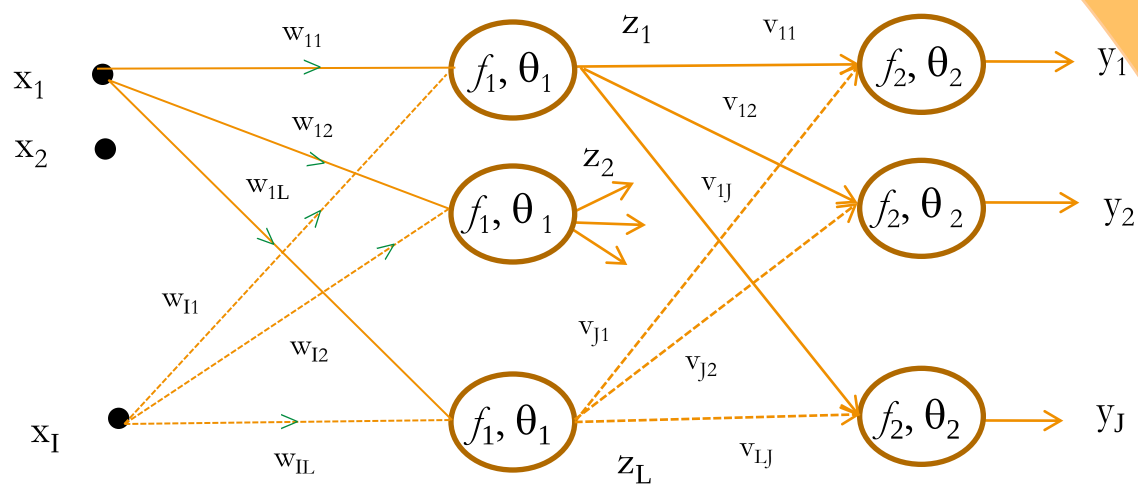


Fields of Study in AI

5. Machine Learning

5.1. Supervised Learning:

- Different classification algorithms exist in the literature
  - E.g., **Instance-based**, **Support Vector Machines**, and **Artificial Neural Networks**



Two-layer *feed-forward* neural network, known as **perceptron**

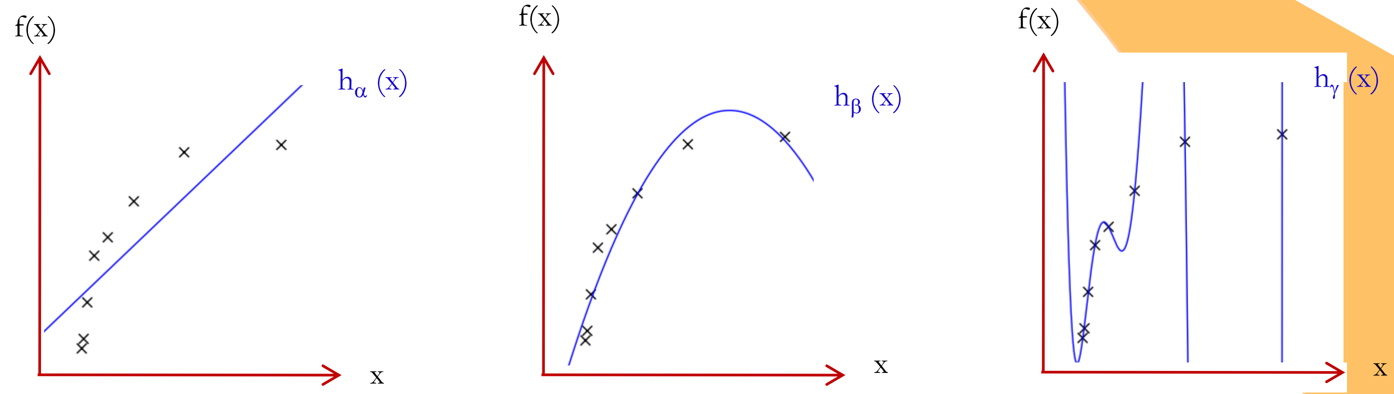
↳ Inspired by biological **brain**: ideal learning/recognition system

Fields of Study in AI

5. Machine Learning

5.1. Supervised Learning:

- When the output of classifier is a numerical value (e.g., temperature degree)
  - The learning problem is called **regression analysis**



- We can approximate ***f*** with different hypotheses, e.g., $\mathbf{h_\alpha}$, $\mathbf{h_\beta}$, and $\mathbf{h_\gamma}$

⇨ We usually choose the **simplest** (following ***Ockham's razor***)

Major category of techniques allowing **predictability**

Fields of Study in AI

5. Machine Learning

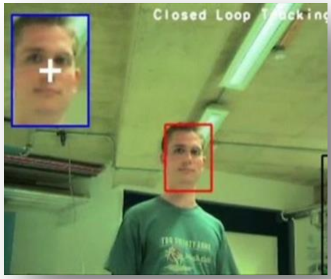
5.2. Unsupervised Learning:

- **Main premise:** Finding a **hidden pattern**/structure in unlabeled data
  - Absence of an expert/knowledge about expected outputs for inputs
    - ⇨ **Lack of training** data
      - ↳ Learning without external intervention

- Typical approach: **clustering**
  - Organizing/**grouping** related input data into **similar categories**
    - Based on the input data relatedness/**similarity** following certain features
      - ⇨ Without any expert knowledge or training data
        - Sample clustering approaches:
          - **Hierarchical agglomerative/divisive, partitional, spectral,** etc.

Fields of Study in AI

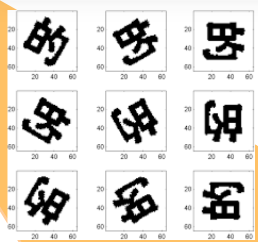
5. Machine Learning



- Essential in many applications requiring:
  - **Pattern learning**
  - **Pattern detection**
  - **Pattern recognition**
  - **Pattern discovery**

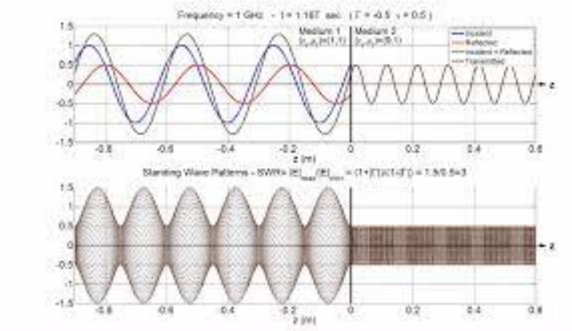
Supervised learning

Unsupervised learning

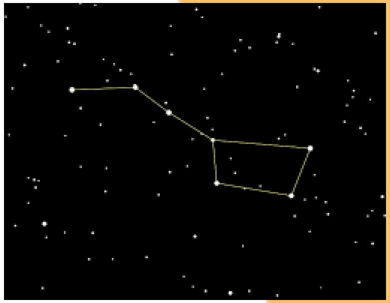


Hand writing patters

- A pattern can be:
  - An audio signal
  - A still image
  - A moving image
  - A radio-wave
  - A sound-wave
  - A part of speech
  - …



Ratio wave patterns

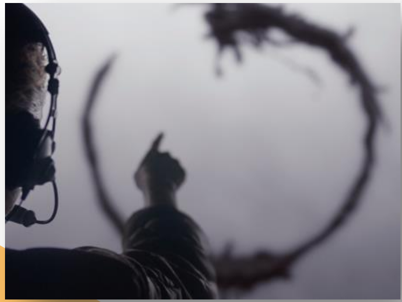


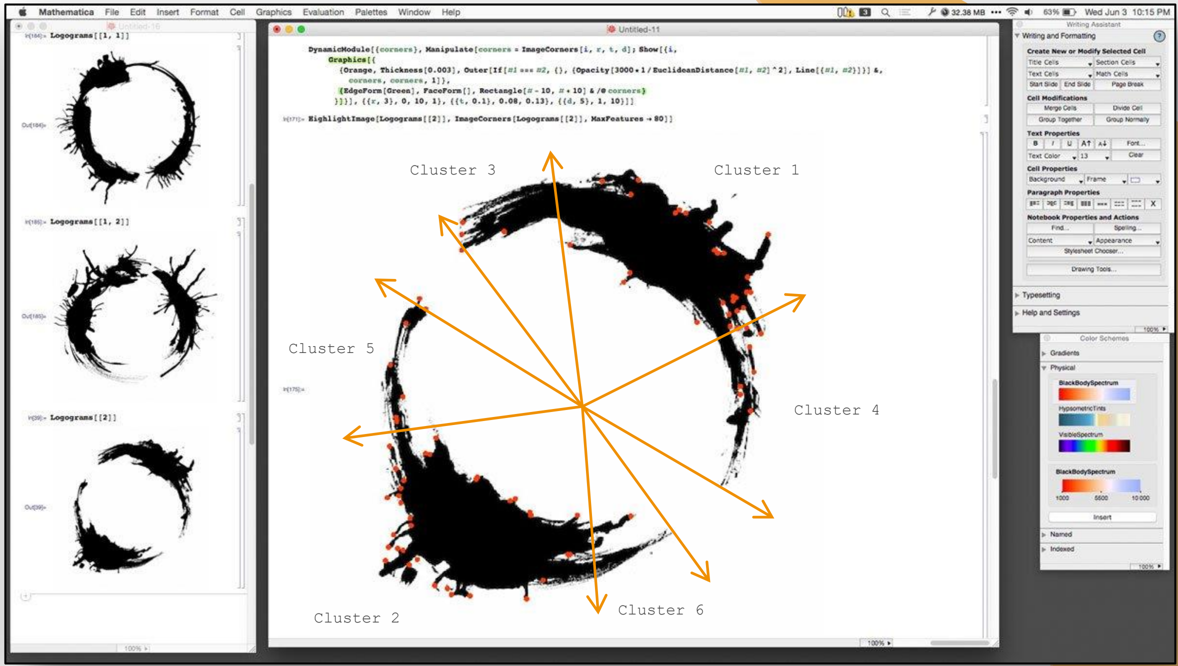
Star configuration patterns

Fields of Study in AI

Machine learning is useful as pre-processing

- **Preparing for other AI techniques**
  - Search, knowledge representation, NLP, Reasoning, etc.
  - E.g., deciphering **alien alphabet**





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- **Wrapping up**

Fields of Study in AI

6. Social Intelligence

- **Main premise**: Understanding **human emotions** and **intentions**, and **reacting** accordingly

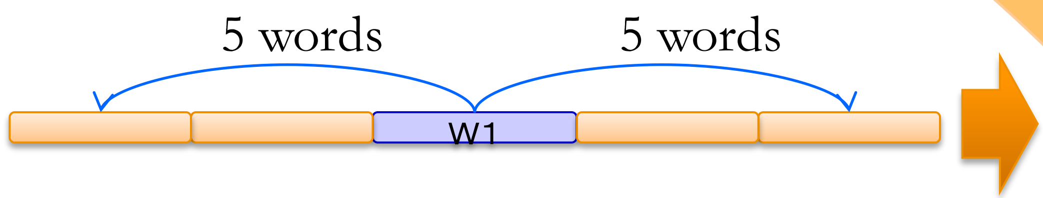
Sentiment Analysis

Corpus-based	Knowledge-based
Learning in Large Corpora	Ready-made Knowledge Bases

- **Reaction** depends on the goal of the intelligent agent being developed
  - Conducted based on input from **sentiment analysis**

Fields of Study in AI

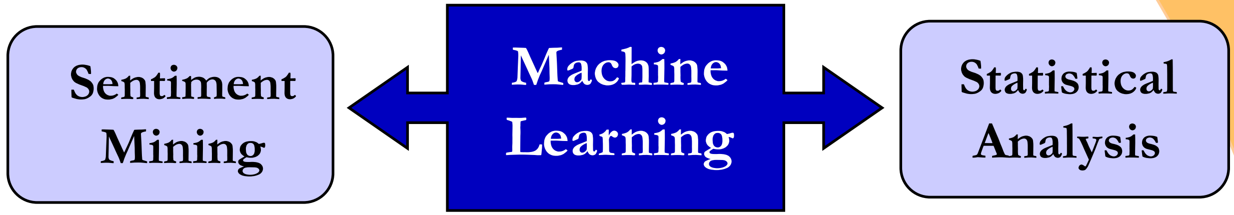
- **Terms highlighting similar emotions usually show**
  - Similar syntactic distributions in a corpus



Lexical Context

$W1 = \{2, 1, \ldots, 4\}$

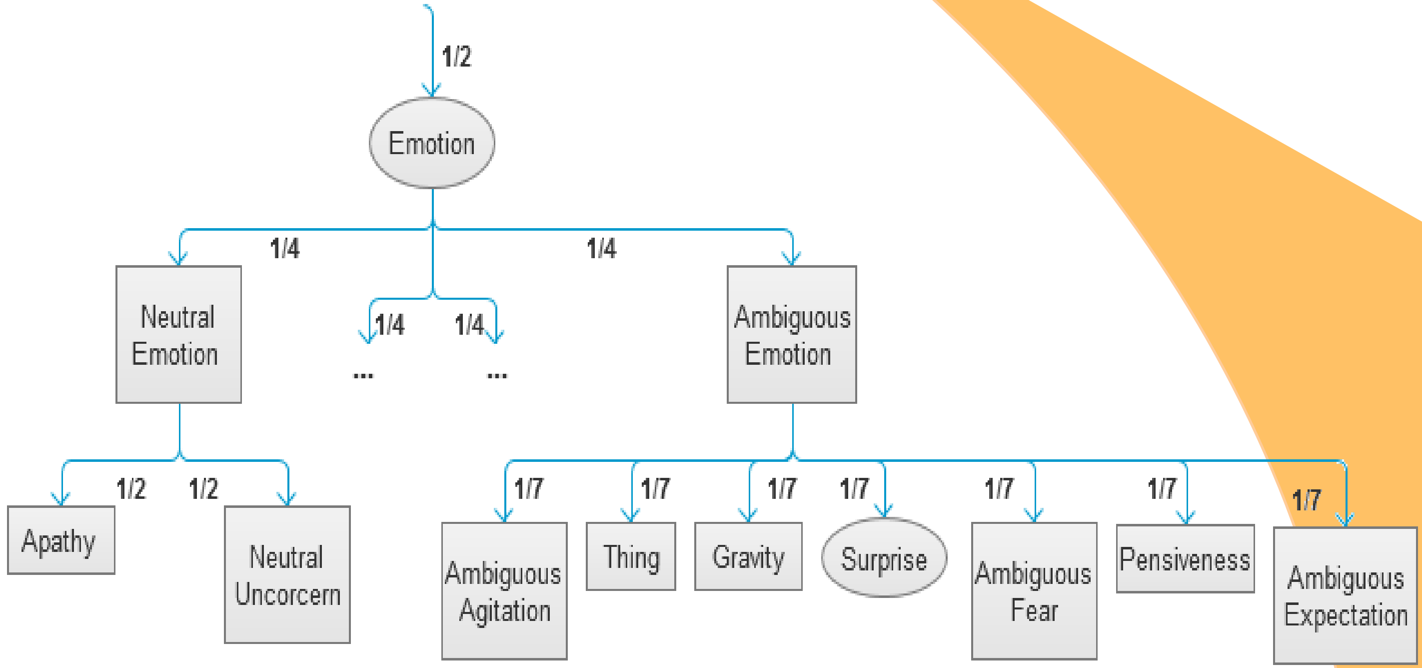
Context feature vector



- Co-occurrence	**- Decision trees**	**- Variance**
- Contextual	**- Bayesian networks**	**- Correlation**
- Sentiment patterns	**- Support vector machines**	**- Regression analysis**

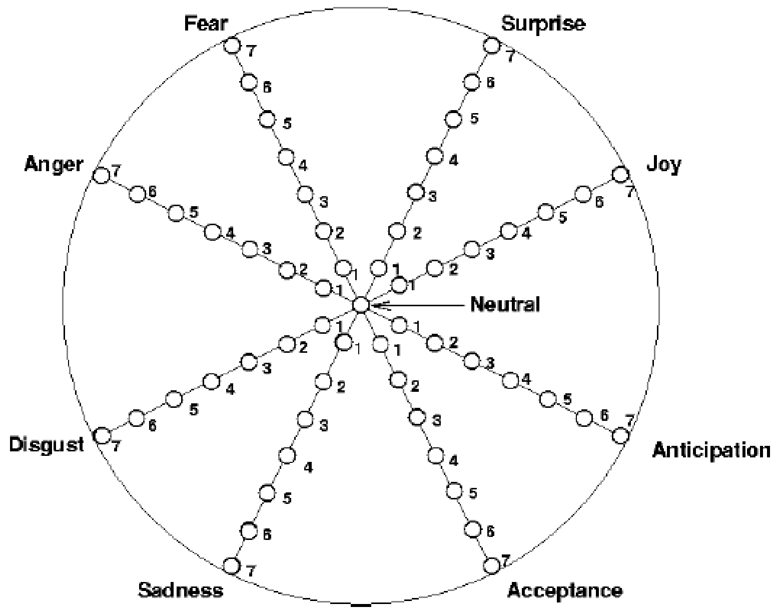
Fields of Study in AI

- Using **reference knowledge bases** describing affect sentiments
  - E.g., **WordNet Affect** and **SentiWordNet**

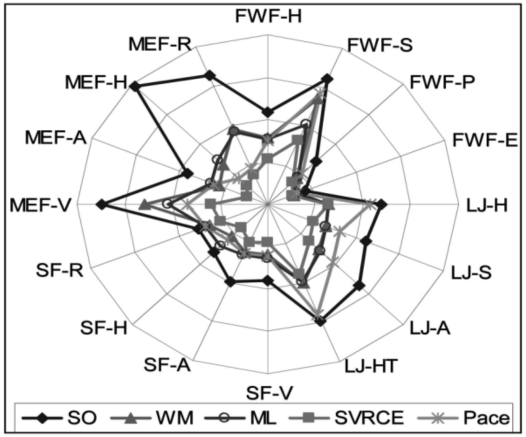


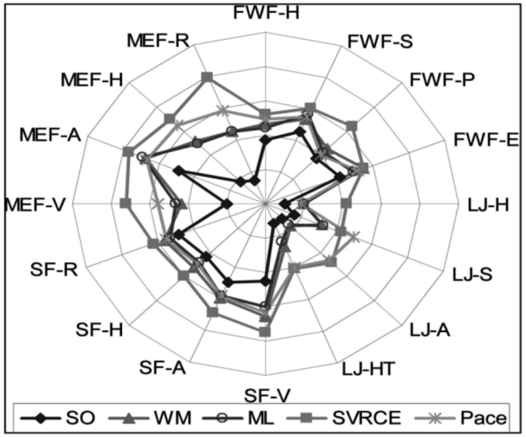
Fields of Study in AI

6. Social Intelligence



Activation-evaluation wheel.





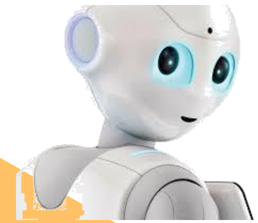
Assigning **sentiment scores** to data

- Text, images, audio, graph, etc.
  - Matched with input data to identify closest sentiment scores

Fields of Study in AI

6. Social Intelligence

- Central in many application scenarios:
  - Enhancing **social media** apps
    - With human like suggestions
  - **Customers reviews** on products
  - Information and **tutoring tools**
    - Digital instructors
  - **Elections** and **voting** stat analysis
    - Analyzing population mood
  - **Computational humor** systems
  - **Human-Computer interaction**
    - Human like robotics



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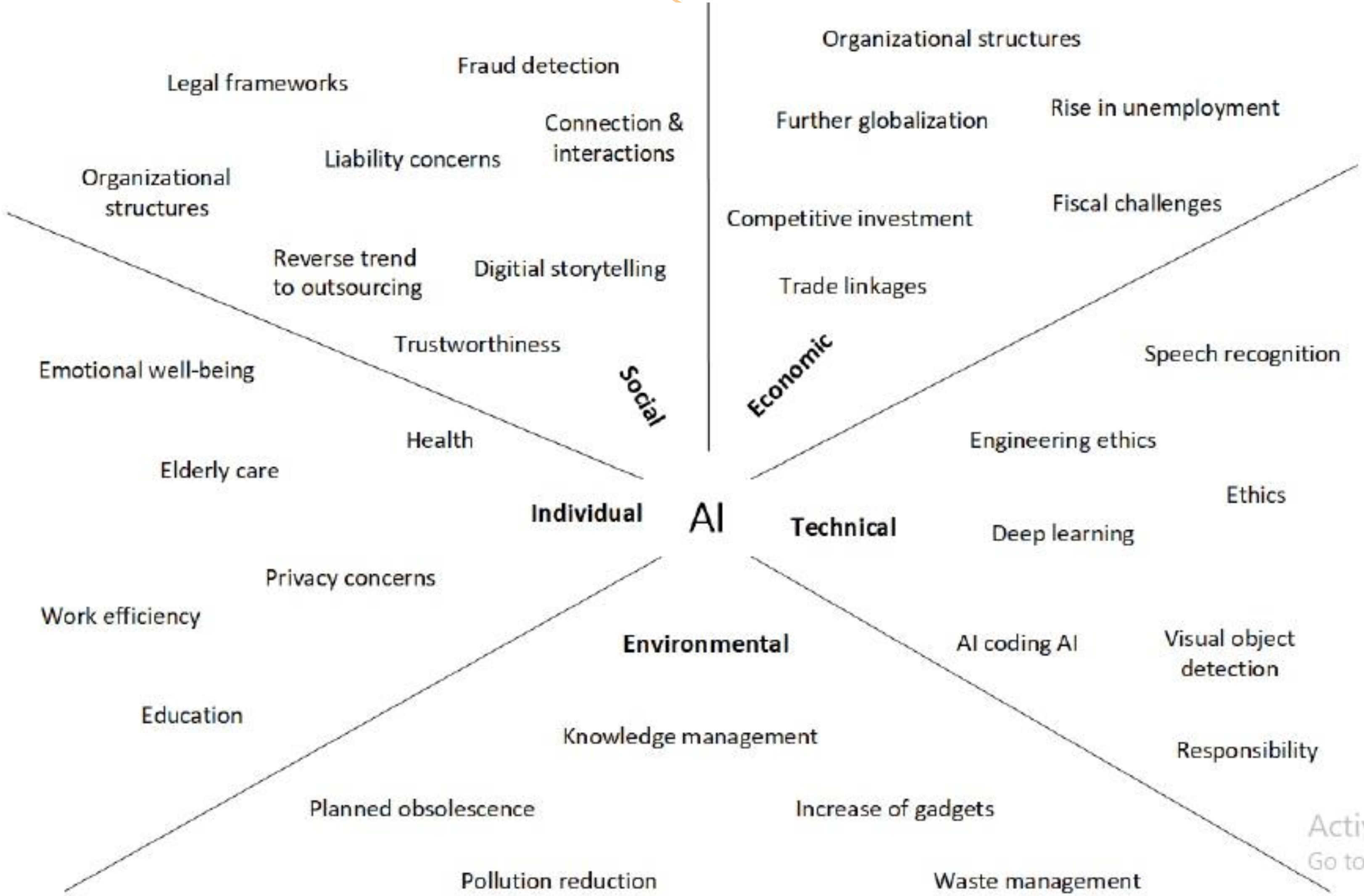
Impact on Sustainable Development

What is Sustainable Development?

" Development that meets the needs of the present, without compromising on the ability for future generations to meet their needs"

Impact on Sustainable Development

AI can impact the 5 dimensions of sustainability



Impact on Sustainable Development

1. Economic Dimension

- **Trend:** 40% of customer-facing employees will consult with AI for decision making and daily tasks
  - It will mainly happen in developed countries
    - CERN initiative to create European AI hub
    - French and German funding for AI
- **Upside:** Cheaper services in developed countries
  - Creation of high-end jobs back in-house
- **Downside:** Limited outsourcing to developing countries
  - Decreasing need for low-skilled workers

Impact on Sustainable Development

2. Technical Dimension

- **<u>Trend</u>:** Advances in ML and increase in computational power
  - Ushering in a whole bunch of practical applications
- **<u>Upside:</u>** Benevolent applications
  - Driverless cars, assistive agents (supporting elderly or disabled people), medical diagnosis through deep learning
- **<u>Downside:</u>** Warfare
  - Autonomous killer drones, swarm bots

Impact on Sustainable Development

3. Environmental Dimension

- **<u>Upside:</u>** Lots of potential
  - *Pattern recognition:* support waste and pollution management
    - Analyze state of animals and trees through imagery, ***enhancing local biosphere***
    - Autonomous vehicles: eco-driving and faster routes, leading to ***less pollution***
  - *Regression analysis*: predictive systems
    - Weather forecasting, environmental crises, likelihood of extreme events: ***early warning***


Impact on Sustainable Development

3. Environmental Dimension

- **<u>Downside:</u>** Many dangers
  - ***Planned obsolescence***: limited functional life of electronics, design for fashion
    - Competitive pressure
    - Lack of customer concern

  - ***Use of natural resources***: mining bots to extract rare earth materials like gold, silver, led, zinc, etc.

Impact on Sustainable Development

4. Individual Dimension

- **<u>Upside:</u>**
  - Can help reduce work hours
    - *Digital assistants, chat bots, analytical tools* can take over some of the simpler tasks
  - Medical and health informatics: from improved and *early diagnosis*, to *preventive care*, and *robotic surgery*

  - Elderly care: *smart homes and robot nannies*

Impact on Sustainable Development

4. Individual Dimension

- **<u>Downside:</u>** Work overload
  - ***Working more***: fast pace due to fast pace of technology and need to keep up
    - Less sleep and less exercise, leading to health and psychological problems
  - ***Decreased human-human interaction***: due to work, social media, and digital games
    - Change in human behavior: becoming more isolated
      - Can lead to functional decline
  - ***Reduced privacy***: social media and corporate hunger for data
    - Required to train more sophisticated AI systems

Impact on Sustainable Development

5. Social Dimension

- **<u>Upside:</u>**
  - ***Strengthen communities:*** improve information and communication technologies
    - Development and maintenance of networks

Mail courier (1980s)

Instantaneous
Reliable
Global

In 30 years

  - ***E-Learning, E-shopping, E-business*:** more efficient
    - Give you more time to socialize

Impact on Sustainable Development

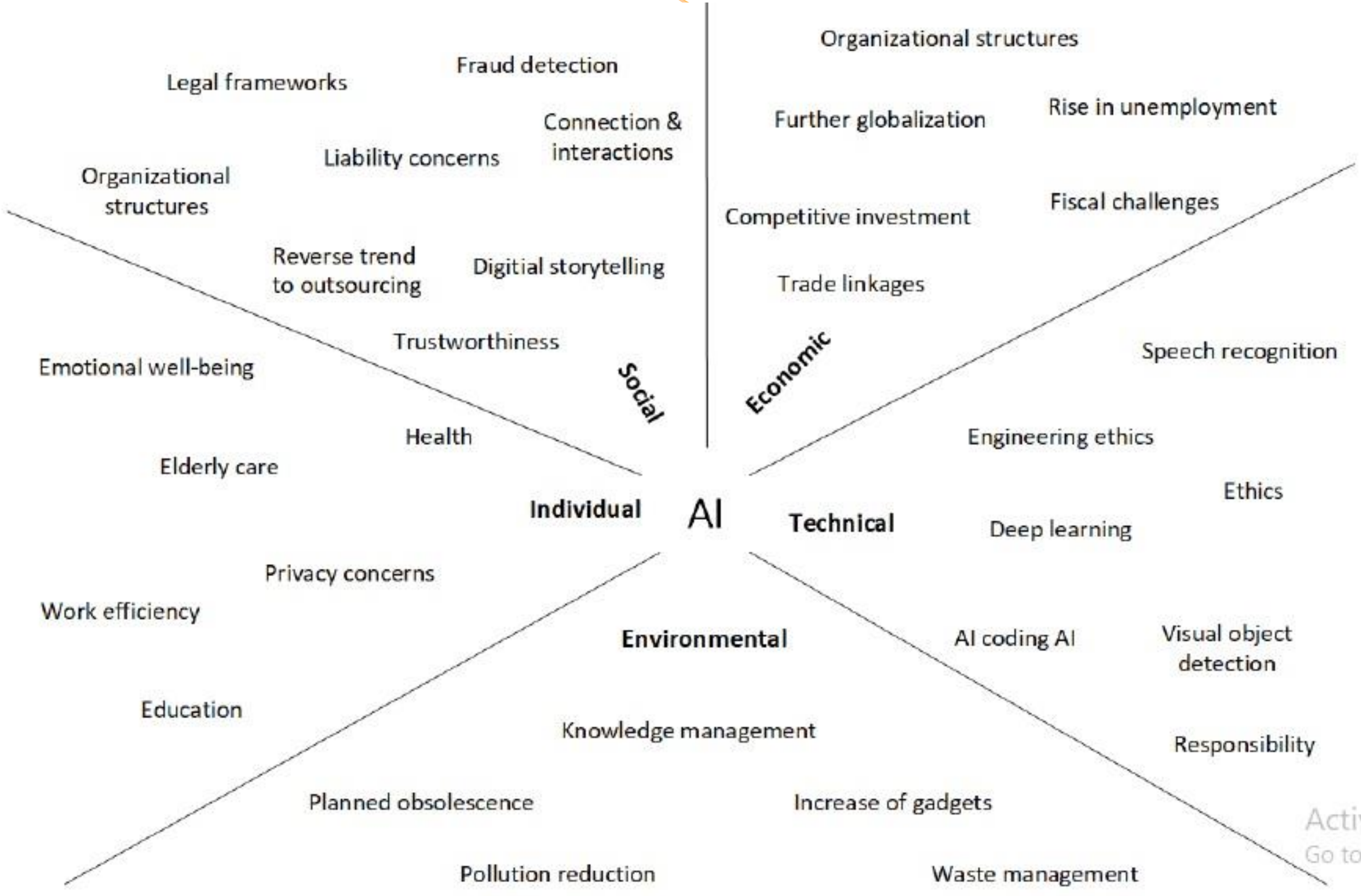
5. Social Dimension

- **<u>Upside:</u>**
  - ***AI promoting social wellbeing***: creating social campaigns (cleanliness on the road, stopping shisha smoking, building properly, anti-corruption campaigns)
    - Could be as simple as reminder of family birthdays: long time you haven't seen family, etc.

- **<u>Downside:</u>**
  - ***Data privacy***
  - *Data or service provide* ***trustworthiness***
  - ***Increased reliance on AI:*** if AI becomes increasingly used for social interactions: what if it forgets to remind us of a birthday?
  - What if AI results in injury or harm: whose to blame?
    - AI designer, data provider, or used interacting with the AI agent?

Wrapping up

AI can affect the 5 dimensions of sustainability



Wrapping up

Recommendations to move in the right direction

- **Economic dimension:**
  - Workers need to be properly and continuously trained to become highly-skilled
    - Early retirement and frequent change of jobs…
- **Technical dimension:**
  - Revising technical code of ethics (e.g., ACM)
    - What AI should and should not do, liability, responsibility, etc.
- **Environmental dimension**
  - Corporate strategies needs to change: encouraging upgradeables/add-ons to the existing systems and re-use/re-cycling of existing ones
  - Increase consumer awareness: to reuse and follow functionality rather than fashion

Wrapping up

Recommendations to move in the right direction

- **Individual dimension**
  - ***Adapting education***: need skills in mathematics, information technology, and scientific methodology: necessary to adapt to different jobs and tackling different problems
  - Education about dangers of technology and security risks, to avoid them

- **Social dimension:**
  - ***Aligning the values*** of all stakeholders, especially data producers and consumers
    - Citizens, civil society groups, news media, corporations, and governments
    - E.g., German government: ***declaration on cooperation on AI***
  - ***Refining legal framework*** to handle AI related cases

Wrapping up

17th century Amsterdam Town Hall

Wrapping up

"The unrestrained pursuit of profit poses serious threats to the soul of the nation"

Thank you!

The unrestrained pursuit of Data and AI poses serious threats to the soul of Humanity

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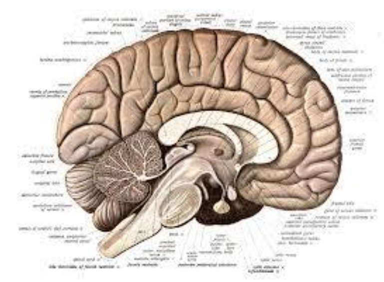
Definition of AI

1. Simulating **Human Reasoning**

- Creating a system that **thinks like a human** being
- This requires further study and understanding of the **inner-workings** of the human **mind**, which researchers are trying to achieve by:
  - **Introspection**: The subject examines her own method of analysis (we ask questions like: "How do I form ideas", "how do I create logical connections", etc.).
  - **Experimental Psychology**: Observing other subjects in action, their behavior, their reactions to different cognitive stimuli, etc.
  - **Study of the human brain**: through enhanced brain imaging and analysis techniques, allowing to identify and study neural activity, changes in synaptic performance, etc.

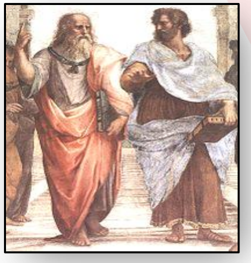


Definition of AI

2. Simulating **Rational Reasoning**

- Creating a system that **thinks correctly**: *ideal thought*
- Aristotle (384-322 BC. BC) was the first to codify **correct reasoning**
  - He introduced *syllogism*: a logical reasoning method, defining the formal structure of an argument
    - Based on two premises, and leading to a conclusion
    - Example: All men are mortal, Aristotle is a man, therefore Aristotle is mortal

Foundations of modern day **Logic**



- **Obstacles to rational thinking:**
  - Difficulty in dealing with uncertain information
  - Theoretical problem solving is not always practical (time limits & computing resources)

Definition of AI

3. Simulating **Human Behavior**

- Creating a system that **behaves like a human being**
  - The **Turing** test, proposed by Alan Turing in 1950, designed to test the ability of a machine to mimic human conversation
    - A machine passes the Turing test if, after a number of questions, the human tester (asking questions) cannot know if the answers come from a human or a machine
  - To pass the test, a machine must be able to perform:
    - **Natural language processing** in order to communicate with the human partner
    - **Knowledge representation**, knowledge to effectively store and handle information
    - **Automatic reasoning**, in order to use the stored information to answer questions
    - **Machine learning**, to evolve and adapt its behavior according to the constraints at hand (e.g., adapting to the tester's questions).

Definition of AI

4. Simulating **Rational Behavior**

- Creating a system that **behaves correctly**
  - ⇨ Creating **rational agents**:
    - A rational agent is a computer system assumed to function autonomously, with the capacity of:
      - Perceiving its environment
      - Adapting to changes
      - Creating and pursuing its own goals

    ↳ Persisting **without (human) assistance**, for a long time!

- Which brings us to **cybernetic systems:**
  - Acting on their environment, considering changes in the environment in order to control/adapt their behaviors accordingly

Overview

Content

- **Introduction**
- **Definition of AI**
- **Fields of Study in AI**
  - Search Agents
  - Knowledge Representation
  - Natural Language Processing
  - Approximate Reasoning
  - Machine Learning
  - Social Intelligence
  - Evolutionary Computation
- **Impact on Sustainable Development**
- **Wrapping up**

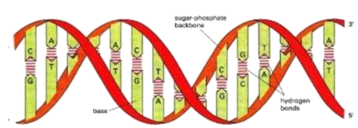
Fields of Study in AI

7. Evolutionary Computation

- **Main premise**: The AI system should be able to **create** and **pursue its own goals**
  - To **persist without** (human) **assistance**, for a long time
  - To **expand its knowledge** beyond predefined constraints

↳ To take the initiative: to **evolve**!

- **Evolutionary computation**
  - Inspired by the **Darwinian Theory of Evolution**
    - **Genetic algorithms**
      - Mimicking genetic processes nature uses



Fields of Study in AI

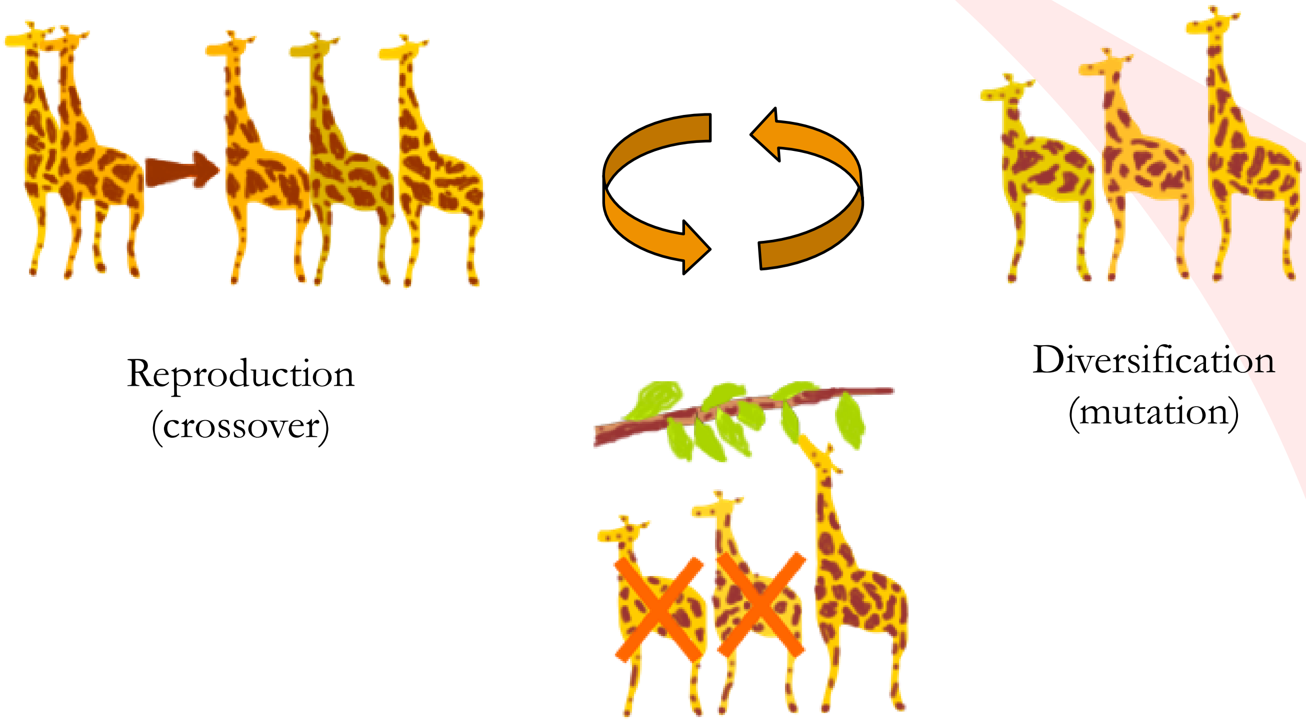
7. Evolutionary Computation

- **Background in genetics:**
  - Every **organism** has a set of rules
  - Rules are encoded in the **genes**
  - Genes are connected together to form **chromosomes**
  - Each gene specifies a certain **trait**
    - Hair Color, Eye Color, etc.
  - Each gene can have different **settings**
    - Blue, Brown, etc.
  - Organisms mate: **crossover of genes** to produce **offspring**
  - Genes can **mutate** over time, result in new unexpected genes
  - Only the genes producing the **fittest** organisms survive

Fields of Study in AI

7. Evolutionary Computation

- **Background in genetics:**



Reproduction
(crossover)

Diversification
(mutation)

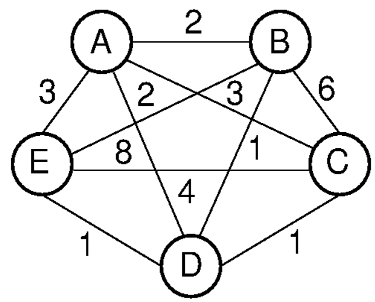
Natural selection
(survival of fittest)

Fields of Study in AI

7. Evolutionary Computation

- Example:

Travelling Salesman Problem



- Each node represents a **city**
- Each edge represents a **route**
- Objective: identify most **effective Hamiltonian path**

- Sample start chromosome: A B C D E F
- Single gene mutation: A B C **D** E F => A B C **C** B A ✗ Non-fit
- Gene swapping: A B **C D** E F => A B **D C** E F
- Crossover: A B C | D E F + F E D | C B A = A B C C B A ✗ Non-fit

  A B C | D E F + | F E D C B A = A B C F E D ✓ Fit

Overview

Introduction

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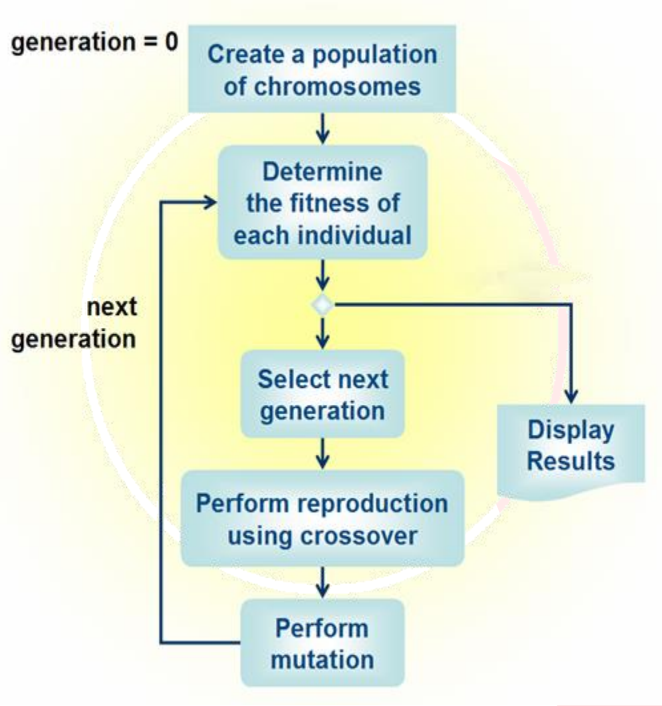
Fields of AI

Apps in Astro

Wrapping up

7. Evolutionary Computation

- **Same process mimicked in GA:**
  - An **organism** represents a solution to a problem
  - A **gene** represents a sequence of symbols
  - Simulating **crossover** and **mutation** functions
  - **Fitness** is evaluated using a performance function
    - To be maximized/minimized
  - Multiple **generations** are created
    - Until reaching the fittest



Reaching **unexpected/new** results

Fields of Study in AI

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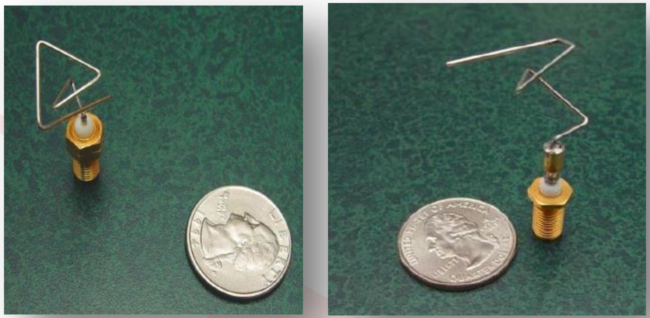

- Applications scenarios
  - **Antenna design**
  - **Drug design**
  - **Electronic circuits design (e.g., Koza)**
  - **Turbine engine design (e.g., GE)**
  - **Auto design (e.g., GM/Red Cedar)**
  - **Network design**
  - **Control systems design**
  - **Satellite design**
  - **Stock/commodity analysis/trading**
  - **Factory floor scheduling (e.g., Volvo, Deere)**
  - **Mission analysis and planning (e.g., NASA, US military)**