Intelligent Artificial Systems

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Intelligent Systems

**Intelligent Behavior**: perception, reasoning, learning, communication and action in complex environments.

Can Human level intelligence be captured by a computable model? *What about consciousness…?*
The Physical Symbol System Hypothesis (Newell e Simon)

A physical symbol system is a machine, as a digital computer, able to manipulate symbolic data - adding numbers, reordering symbol lists (as, for instance, putting in alphabetical order a list of names), substituting some symbols with others, and so on.

A physical symbol system has the necessary and sufficient means to exhibit intelligent behavior.

An important aspect is that it doesn’t matter what the physical symbol system is made of! An intelligent entity could be made of proteins, mechanical parts, transistors or whatever else, provided it is able to process symbols.
The Turing Machine

Church Thesis (1936):
Every computable function can be computed by a Turing Machine.
Universal Artificial Intelligence
(Turing Computability and Kolmogorov Complexity)

For a string:

\[ K(x) = \min_p \{ l(p) : U(p) = x \} \]

For a function:

\[ K(f) = K(y), \text{ where } y \text{ is a description of } f : \]
\[ f(x) = U(y, x) \]

\[ U \equiv \text{universal Turing machine} \]
The universal semimeasure
(Solomonoff’s probability)

Definition:

\[ \xi(x) \equiv \sum_{p : U(p) = x^*} 2^{-l(p)} \]

Universality property:

\[ \xi(x) \geq 2^{-K(\rho)} \cdot \rho(x) \]
Universal semimeasure and sequence prediction

\[ \sum_{k=1}^{\infty} \sum_{x_{1:k}} \mu(x_{1:k}) \left[ \xi(x_k | x_{<k}) - \mu(x_k | x_{<k}) \right]^2 \leq \frac{1}{2} \ln 2 \cdot K(\mu) \]
The universal agent model (Hutter)
The AI Model

- System: \( p : X^* \rightarrow Y^* \)
- Environment: \( q : Y^* \rightarrow X^* \)

\[
p^* = \arg \max_p C_{1T}(p,q)
\]

(Best system)
The Knowledge Representation Hypothesis  
(Brian Smith, 1982)

The realization of any intelligent process will be based on structural ingredients that:

a) For us, external observers, represent a propositional description of the knowledge the process exhibits, and

b) independently of any external attributed semantics, have a formal, but also causal and essential, role in producing the behavior that manifests such a knowledge.
Mathematical Logic

Facts represented as expressions containing Terms, Predicates, Logical Operators, Quantifiers.

Terms => Entities
Predicates => Relations among entities

For instance:

read(student, book)
family(father, mother, children)
on(pen, table)
Operators and Logical Quantifiers

\[(\text{rainy(\text{weather}) OR cold(\text{weather})) \rightarrow \neg \text{go(\text{me, outside})})\]

\[\text{FOR\_ALL(?X, man(?X) \rightarrow \text{mortal(?X)})}\]
Deduction

Premises:

man(Socrates)

FOR_ALL(?X, man(?X) --> mortal(?X))

Consequence:

mortal(Socrates)
Knowledge Bases

Axioms:

scientist(Antonio)
scientist(Riccardo)
scientist(Salvatore)
scientist(Vincenzo)
attends(Vincenzo, Consciousness-Workshop)

FOR_ALL(?X, scientist(?X) --> happy-worker(?X))
FOR_ALL(?X, attends(?X, Consciousness-Workshop)

--> in-Agrigento(?X, 2005)

in-Agrigento(Consciousness-Workshop, 2005)

………..

Query:

EXISTS(?T, in-Agrigento(Vincenzo, ?T))

Answer:

in-Agrigento(Vincenzo, 2005)
Class P: Problems that can be solved by a deterministic algorithm that requires polynomial time $O(l^k)$.

Class NP: Problems that can be solved by a non-deterministic algorithm that requires polynomial time.

$P \subseteq NP$

- NP-hard problems.
- NP-complete problems.
Intelligent Agents

**Rational Agents:** definition of the tasks, of the interaction with the external environment, and of the performance measures.

Use of **heuristics** to cope with complexity.
The Reference Problem

No formal system can univocally determine its model.
Interpretation

• An *interpretation function* cannot be defined exclusively in terms of other symbols, because it would give rise to an infinite regression.

• An *interpretation function* must be computed, at least for some symbols of the system (the “primitives”), by a subsymbolic device.
Need for subsymbolic cognitive levels

“Of primary importance they are the functional relationships with the external world in connection to perception, on one side, and action, on the other” (Hartman 1987)
But the problem remains.

Is human level intelligence computable?

Is consciousness computable?

If not, which other (natural, divine, exoteric, inesplicable, ecc.) tool do we have to build artificial intelligent systems and even artificial conscious systems?

In computation theory such a tool is called an oracle.
A cognitive architecture for artificial vision


Boundary Webs Extractor (BWE)

- An original implementation of the BCS architecture, proposed by Grossberg.

- A cooperative/competitive loop is used to determine a lattice of iso-luminance short contours in shaded images.

- BWE is aimed to improve contour extraction: the OC Filter and the Cooperation stage have been suitably re-implemented.

BWE in action
Superquadrics

\( f(x,y,z) = \left( \frac{x}{a_1} \right)^{2/\epsilon_1} + \left( \frac{y}{a_2} \right)^{2/\epsilon_2} + \left( \frac{z}{a_3} \right)^{2/\epsilon_3} = 1 \)

\( x(\eta,\omega) = \begin{bmatrix} C_\eta^\epsilon_{\epsilon_1} a_1 C_\omega^\epsilon_{\epsilon_2} \\ a_3 S_\eta^\epsilon_{\epsilon_1} a_2 S_\omega^\epsilon_{\epsilon_2} \end{bmatrix} = \begin{bmatrix} a_1 C_\eta^\epsilon_{\epsilon_1} C_\omega^\epsilon_{\epsilon_2} \\ a_2 C_\eta^\epsilon_{\epsilon_1} S_\omega^\epsilon_{\epsilon_2} \\ a_3 S_\eta^\epsilon_{\epsilon_1} \end{bmatrix}, \quad -\frac{\pi}{2} \leq \eta \leq \frac{\pi}{2}, \quad -\pi \leq \omega < \pi \)

\( n(\eta,\omega) = \begin{bmatrix} \frac{1}{a_1} C_\eta^{2-\epsilon_1} C_\omega^{2-\epsilon_2} \\ \frac{1}{a_2} C_\eta^{2-\epsilon_1} S_\omega^{2-\epsilon_2} \\ \frac{1}{a_3} S_\eta^{2-\epsilon_1} \end{bmatrix}, \quad -\frac{\pi}{2} \leq \eta \leq \frac{\pi}{2}, \quad -\pi \leq \omega < \pi \)
Recovering superquadrics form factors

Superquadrics recovery from range data

Each segment is fed to the net

Weights of the trained net provide all model parameters

Conceptual Spaces (Gardenfors, 2000)

- height
- softness
- color

knoixel
Conceptual Spaces

- Information organized according to a set of quality dimensions
- .....that are subdivided into *domains* (space, time, temperature, weight, color, shape, ...)
- Domains can have a topology or a metric.
- Similarity represented by a distance within the conceptual space.
A knoxel is a superquadric.

An object is a composition of superquadrics.

\[
f(\eta, \omega) = \begin{bmatrix}
    a_x \cos^{\varepsilon_1}(\eta) \cos^{\varepsilon_2}(\omega) \\
    a_y \cos^{\varepsilon_1}(\eta) \sin^{\varepsilon_2}(\omega) \\
    a_z \sin^{\varepsilon_1}(\eta)
\end{bmatrix}
\]

\[
k = [a_x, a_y, a_z, \varepsilon_1, \varepsilon_2, p_x, p_y, p_z, \varphi, \theta, \psi]^T
\]
Linguistic Component
Symbolic KB

Cylinder

Box

CS

Symbolic KB

Hammer

has-handle

Cylinder

has-head

Box

CS
Dynamic Conceptual Space

\[ m(t) = [a_x(t), a_y(t), a_z(t), \varepsilon_1(t), \varepsilon_2(t), p_x(t), p_y(t), p_z(t), \varphi(t), \vartheta(t), \psi(t)]^T \]

- Smooth motions approximated by DFT
- A *simple motion* - delimited by two discontinuities - can be approximated by the superimposition of *frequency harmonics*
Dynamic Conceptual Space
Interpretation
Situations and Actions

- Situations: objects maintain their motions states
  - knoxels maintain their positions
- Actions: an event occurs, and some objects may change their motion state
  - Scattering of knoxels
Situations and Actions
Focus of Attention and Expectation
The Self of the robot

✦ Self-consciousness is perception of the robot inner world
✦ Higher-order CS
The Self of the robot

- Flow of consciousness of the robot
Knowledge Management and Natural Language Interaction

- A framework for human-behaviour inspired information supplier;

- Intuition combined with traditional, more rigid, rule-based knowledge.
Data Driven Conceptual Space

- **Concepts**
  - meanings of words, sentences or documents

- Data driven Conceptual Space $S$
  - Statistically inferred by occurrences of words in sentences and documents
Knowledge Management and Natural Language Interaction

Conceptual interpretation of a data-driven semantic space

- Application:
  - “Intuitive” Chat-bots for Efficient Information Retrieval
  - Language Models
Latent Semantic Analysis

- Given: N documents and a set of M words appearing in them,
- Generate a word-document co-occurrence matrix $A$

Using Singular Value Decomposition, $A$ can be univocally decomposed into three matrices: $U$, $\Sigma$, and $V$

Frequency of the i-th word in the j-th document
Singular Value Decomposition

0 = 0 words documents w^T w

A

U

Σ

V^T

Rows of U (associated to words)

Weights (in decreasing order) of the components of the words and documents vectors

Columns of V (associated to documents)

Frequency of the i-th word in the j-th document
Truncated Singular Value Decomposition

The most informative part of the rows of $U$ (associated to words)

The most relevant components of the words and documents vectors

$0 = 0$ words documents $w^M d^N$

The most informative part of the columns of $V$ (associated to words)

Frequency of the $i$-th word in the $j$-th document

$A$, $U$, $\Sigma$, $V^T$
The “Conceptual” interpretation

The most informative part of the rows of $\mathbf{U}$ (associated to words)

The most relevant components of the words and documents vectors

This represents a conceptual axis

This axis can be labelled with words having the higher components
Artificial Linguistic Intelligent Computer Entity (www.alicebots.org)

Knowledge Base described in AIML (Artificial Intelligence Markup Language)

AIML Category
- The basic element of the chat-bot knowledge base
- Composed of a question / answer pair
- Interaction is based on pattern-matching

```xml
<category>
  <pattern> WHAT IS A CIRCLE </pattern>
  <template> A circle is the set of points equidistant from a common point called center </template>
</category>
```
Intuitive Chatbots

- Intuitive/associative capability can be obtained by using the conceptual space S:
  - User queries are mapped in the space S
  - The closest template to the mapped query in S is selected as the answer
  - The original pattern matching is a special case.

- IntuitiveBots show better robustness than Alice with respect to grammatical errors in the question.
Intuitive Chat Example

- **UserQuery**: World?
- **Alice**: Can you tell me any gossip?
- **IntuitiveBot**: The world has been created by God

- **UserQuery**: Do you know C plus plus language?
- **Alice**: Can you speak any other languages?
- **IntuitiveBot**: C plus plus is the object oriented extension of the C programming language.

- **UserQuery**: What is tha Earth?
- **Alice**: Interesting question.
- **IntuitiveBot**: Earth is a planet going around a star. Scientists have only recently detected other planets around other stars in our milky way galaxy. Do you like astronomy?
Word Modelling: a sub symbolic approach

 Which word we expect in a given context?

 Context representation:
   Mapping of words in a conceptual space
A proper function of the number of times the j-th word follows the i-th word, for each text segment.
Which word we expect in a given context?

To guess the word \( w \), we calculate the conceptual similarities between:

- the right context of \( w_i \) and the left context of \( w \)
- the right context of \( w \) and the left context of \( w_j \)

The best choice is that one that maximizes a function of both the similarities
Selected Publications


