Hexagon of Intelligence

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Abstract. In this paper we discuss the nature of artificial intelligence (AI) and present a hexagon of opposition (generalization of the square of opposition) to characterize what intelligence is, its relation with computability, creativity, understanding and undecidability.
In a first part, we make some general comments about the history, development and objectives of AI. In a second part, we present two diametrically opposed ways of reasoning, one computational, one creational. In a third part, we talk about the relation between AI and logic, emphasizing that reasoning can be described or/and performed by different logical systems, mentioning the fact that non-monotonic logical systems have been promoted by AI researchers. In a fourth part, we present the theory of oppositions, with the three notions of opposition that are used to build squares and hexagons of opposition, and we then we present a hexagon of intelligence.

Keywords: Intelligence · Reasoning · Logic · Square of Opposition · Computability · Chess · Creativity · John McCarthy · Aristotle.

1 "Artificial Intelligence" and the challenge of the correlated field

The expression "Artificial Intelligence" is attributed to John McCarthy (1927-2011) in the mid-1950s (cf. [13]) and it has become since then a major field of research. An expression does not necessarily lead to a field of research and a field of research may have no fixed and definite name, for example *Physics* was previously named "natural philosophy" (philosophia naturalis). But in the case of AI there is a narrow connection between the two.

McCarthy and Hayes (1969) [14] say that we can consider that the starting point of AI are two papers published shortly before the expression was coined: one by Turing [19] and one by Shannon [18], both in 1950. The expression "Artificial Intelligence" can be compared to "Cybernetics" and "Cognitive Science"; the three correlated fields being interrelated. The choice of "Artificial Intelligence" was made by McCarthy in some way to replace or improve "Cybernetics".

The expression "Artificial Intelligence" is compound of two words. The word "artificial" means created by humans and is opposed to "natural": a plane, a building, a piano, a contraceptive, a computer are artificial; a tree, a cat, the sun are natural. The adjective “artificial” may have a negative connotation, when considering a failed or fake replication.

The challenge of artificial intelligence is to develop something which is similar to human intelligence or even better. Human beings have fully succeeded to create many artificial devices. A plane, inspired by natural birds, is going at a speed higher that any bird. And it makes sense to say that human beings can now fly.

Flying is something pretty clear, intelligence is more difficult to define. Some years ago a man able to quickly perform mentally a multiplication of two big numbers could have appear as very intelligent, but nowadays any calculator can do this better than a human being and a calculator is not generally considered as a symbol of intelligence.

The objective of AI is to perform more complicated tasks, typical examples since the beginning of AI (cf. [18]) are:
• Playing chess.
• Translating a language into another one.
• Orchestrating a melody.
• Proving a theorem.

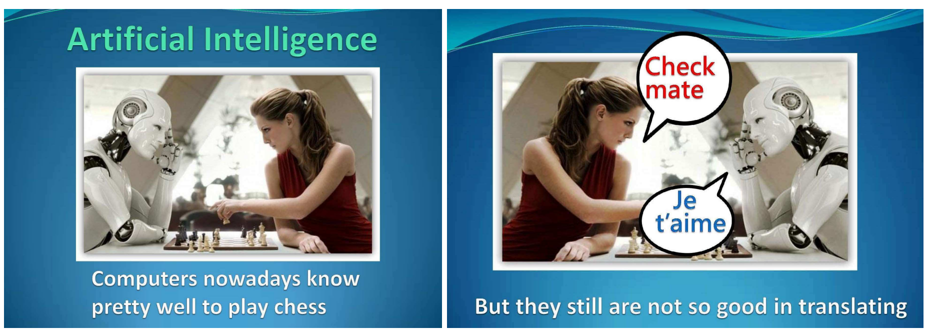

Fig 1. Translation: a hard AI task

Turing, Shannon, McCarthy and many other AI researchers have worked on developing programs that play chess and after some years a program was able to beat the best human chess player, Garry Kasparov. Although there are already lots of programs able to approximately translate a language into another one, it is not clear at all, up to now, if it will be possible one day that a program can perform translation is a satisfactory way (Fig 1). This is an open problem related to the question whether a program can think or/and reason.

2 Two different kinds of reasoning

Reasoning has many different aspects. Let us present here two diametrically opposed ways of reasoning, one computational, one creational.

Let us consider the following example: we have a board with 64 boxes; excluding the two boxes indicated in the diagram below, is it possible to place 31 dominos in the remaining boxes ? (Fig 2)

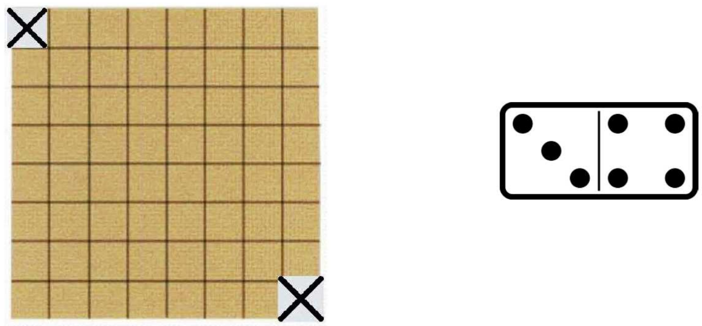

Fig 2. 62 boxes and 21 dominos

It is not arithmetically impossible, since a domino occupies two boxes, and therefore 31 dominos occupy 62 boxes.

To check this possibility one may build a program (using for example LISP created by McCarthy) that will enumerate all the possibilities. This is in some sense what can be called a "step by step procedure". On the other hand there is a more ethereal reasoning, something that a program cannot necessarily perform.

Considering the black and white coloring of the board below (Fig 3), we see that the two excluded boxes are white, so that at the end we have 30 white boxes and 32 black boxes. Since a domino necessarily occupies a white and a black boxes, we immediately see that it is not possible to place 31 dominos in the remaining boxes.

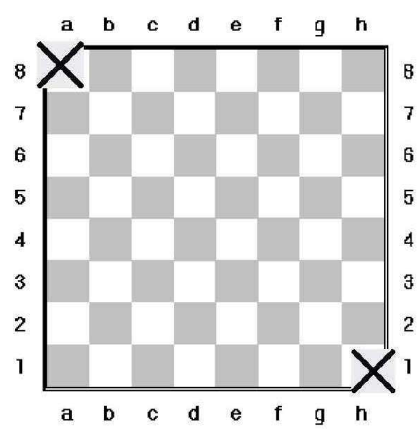

Fig 3. Black and white coloring of the board

This proof depends on the idea of black and white coloring. How can a computer have such an idea? A computer may be able to better play chess than a human being, but it is not clear that he may have the intelligence of coloring a 64 box board into a chess board.

3 Logic(s) and Artificial Intelligence

Artificial Intelligence is deeply related to logic. Logic is one of the oldest fields of investigation but its name and its scope have been varying. Moreover there is a fundamental ambiguity surrounding logic: it can be considered as reasoning and/or as the theory of reasoning (cf. [2]). In ancient Greece, human beings were considered as "logical animals" ("rational animals" is the Latin transposition of this expression, see [6]). Human beings are reasoning. Logic, as a theory of reasoning, is a way to understand this capacity but also to correct or improve it. Logic since the beginning has a strong normative aspect.

Logic changed dramatically with the work of Boole in the mid XIXth century, in particular with his book entitled *The laws of thought* (1854) [10]. Boole's objective was not to reject the famous system of Aristotle, *Syllogistic*, but to improve it using mathematical tools. However it led to a new era of the science of reasoning called "mathematical logic" or "modern logic".

In modern logic there are many different systems. The most famous one is called "classical logic". But classical logic is not only one system of logic, it is a family of systems: classical propositional logic, first-order classical logic, second-order classical logic, etc. Simultaneously were developed lots of different systems commonly called "non-classical logics": many-valued logic, intuitionistic logic, paraconsistent logic, relevant logic, fuzzy logic, linear logic, etc. AI researchers have developed various systems of logic, most notably the so-called "non-monotonic logics" (see e.g. [15]) .

When we have a system of logic SL, we can ask:

- Does SL properly describe reasoning?
- Is SL a good tool for developing/performing reasoning?

Fig 4. Non-monotonic logic, symbolized by the penguins

Due to the problematic double descriptive/normative aspect of logic, it is not clear how a system of logic should be assessed. Some people have rejected classical logic considering that it does not properly describe the way that we naturally reason. But this natural way of reasoning can be seen as limited, in the same was as a natural way of counting according to which there is *one*, *two*, *three*, *many* and that's all, can be seen as rather limited.

The objective of AI researchers is not to simulate these limitations, but to catch some features of human reasoning which are not necessarily those of mathematical reasoning. For example mathematical reasoning is monotonic in the sense that when something has been deduced from a set of hypotheses, it would remain valid if we add further hypotheses. The idea of non-monotonic logic is to reject this monotonicity considering for example that at a certain stage we can infer that all birds fly, but the day we meet penguins, we revise this conclusion. This is related to what has been called "belief revisions" (see [1] and subsequent works). The idea is to construct a system of logic that can explain how we can systematically do that and such a system of logic can lead to the development of programs that can also do that.

A system of logic can give a better understanding of what human intelligence is and moreover help to develop human intelligence. Such a system can be considered as artificial as any scientific theory, since it is a product of humans but it can also be considered as developing an artificial intelligence in the sense that it helps to develop an intelligence which is not naturally there right at the start, like in fact other mathematical theories.

A program that can also perform such kind of artificial intelligence is another step which is not necessarily straightforward. In particular we have to keep in mind that many systems of logic are not decidable even if they are recursive, the typical case being classical first-order logic.

4 The theory of oppositions

To have a better understanding of intelligence, it is useful to develop a theory of intelligence and this can be done using a simple logical tool like the theory of oppositions. According to this perspective, logic is used at a meta-level, not to directly perform intelligence but to model it. The theory of oppositions goes back to Aristotle. From his ideas was developed the square of opposition (Fig 5) which is a structure based on implication (below in black) and three notions of opposition defined as follows.

Two propositions are said to be:

- **Contradictories, when they cannot both be true and cannot both be false.**
- **Contraries, when they can both be false but cannot both be true.**
- **Subcontraries, when they can both be true but cannot both be false.**

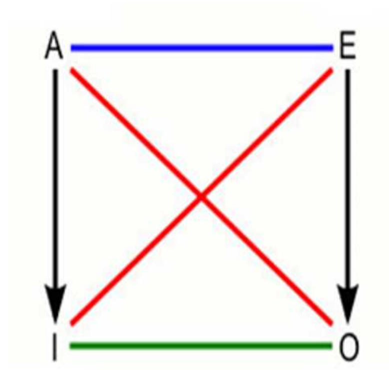

Fig 5. The Square of Opposition

These oppositions were originally defined for propositions but they can naturally be applied to concepts. Below (Fig 6) on the left the original square presented by Apuleius and on the right a square describing the relations between various classes of numbers ([4]):

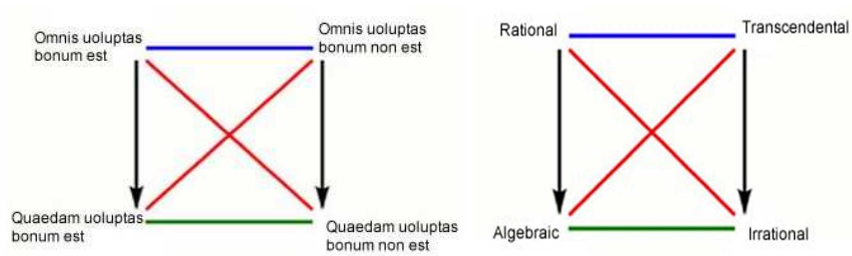

Fig 6. Two examples of Square of Opposition

The square was generalized into a hexagon of oppositions by Robert Blanché [9], adding two additional "corners", defined as follows (Fig 7):

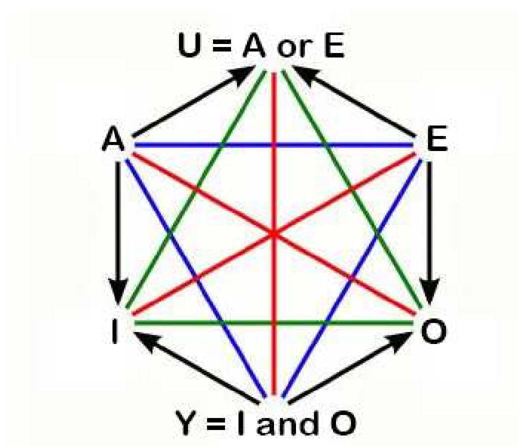

Fig 7. The Hexagon of Oppositions

This hexagon can be used to understand many different concepts, ranging from quantification, to music, economy, painting, theory of colours, etc. (see [3], [12], [7], [8], [11]). In (Fig 8) one of the most famous one, the deontic hexagon.

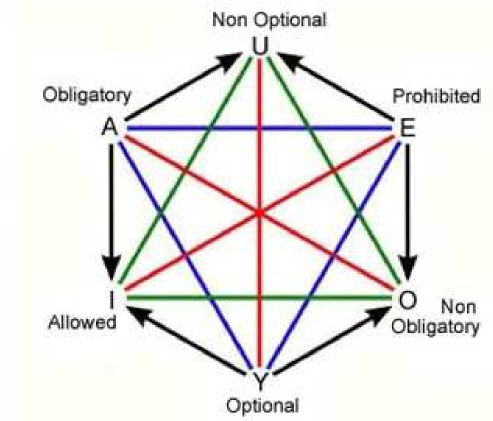

Fig 8. The Deontic Hexagon of Oppositions

It can even be applied to the theory of oppositions itself, as illustrated by the hexagon of oppositions below (Fig 9).

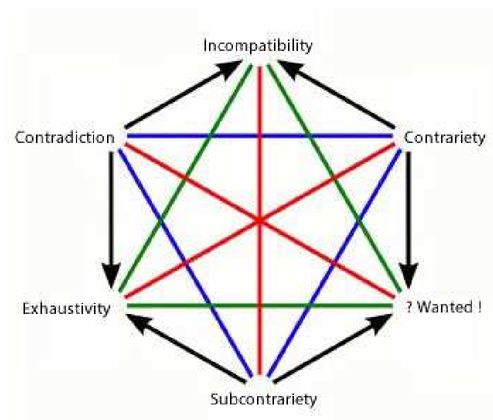

Fig 9. The Hexagon of Oppositions of Oppositions

As illustrated by this example (see [5]), it not necessarily obvious to find a positive determination for each of the corners of a hexagon. The O-corner in the above hexagon can be defined purely negatively as “non-contradiction”. But what would be a good name for it that would help to develop a positive understanding of the related notion? That’s not clear.

In any case, before presenting a hexagon of intelligence, let us emphasize that a hexagon of oppositions is based on a logical structure and that it shall not be confused with some artificial constructs, like the hexagon below (Fig 10) designed by G.A Miller [16] to describe cognitive science. The arrows and edges of this hexagon do not correspond to logical relations.

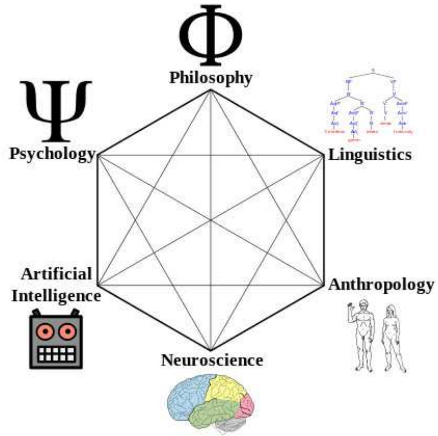

Fig 10. The Hexagon of Cognitive Science

One possible characterization of intelligence can be given through the following hexagon of oppositions (Fig 11):

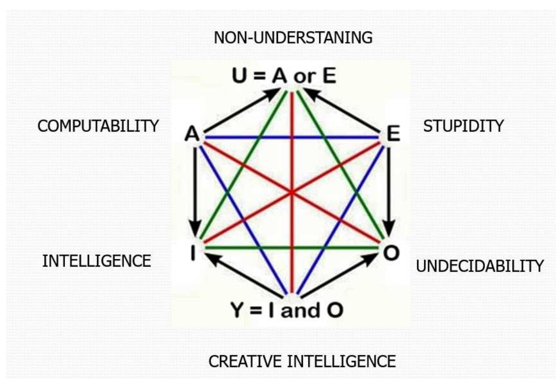

Fig 11. The Hexagon of Oppositions of Intelligence

We have two pairs of contradictory opposites, each having positive intuitive readings, for both sides: intelligence vs. stupidity and computability vs. undecidability. Undecidability may be seen rather negatively but recursion theory gives to it a precise definition.

The contradictory of creative intelligence, which according to the structure of the hexagon is the exclusive disjunction of computability and stupidity, may also appear as rather negative under the label of "Non-understanding". But we have tried to define it not literally as "Non-creative-intelligence". It is based in part on the claim by John Searle: " we can see that the computer and its program do not provide sufficient conditions of understanding since the computer and the program are functioning, and there is no understanding" [17].

We hope this hexagon will provide inspiration for future developments of artificial intelligence aiming at catching creative intelligence.

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