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Preface

The progress in computer science is now mainly achieved by scientific circles and constitutes a kind of indicator of the position of centres dealing with this area. This is because nowadays one cannot talk of highly developed scientific units, economic growth or world-class achievements in various disciplines of knowledge if one does not conduct research in computer science (whether technical or mathematical). The development of computer science is now so rapid that we, the readers, increasingly receive technology news about new solutions and applications which very often straddle the border between the real and the virtual worlds. Computer science is also the area in which cognitive science is witnessing a renaissance, because its combination with technical sciences has given birth to a broad scientific discipline called cognitive informatics. And it is this discipline which has become the main theme of this monograph, which is also to serve as a kind of guide to cognitive informatics problems.

This book is the result of work on systems for the cognitive analysis and interpretation of various data. The purpose of such an analytical approach is to show that for an in-depth analysis of data, the layers of semantics contained in these sets must be taken into account.

This approach to this subject was made possible by work to combine the subjects of intelligent information systems and the cognitive aspects of the human analysis process. The interdisciplinary nature of the solutions proposed means that the subject of cognitive systems forming part of cognitive informatics becomes a new challenge for the research and application work carried out.

The authors of this monograph hope that it will guide Readers on an interesting and accurate journey through the intricacies of information and cognitive science. Thus it may make us, when we look at the world around us, wonder (sometimes jocularly) whether we have really got to know it, whether we understand it, and whether we will ever be able to accurately and unanimously (avoiding contradictions) explain what happens around us.

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Chapter 1
Beginnings of Cognitive Science

The first mention of cognitive science can be found in the works of Aristotle, who proposed two dominant categorisation methods describing all varieties of cognitive science in different ways. Aristotle's considerations, also of the concept of a category, led to distinguishing accidental and substantive categories based on the differences Aristotle saw between the subject of a sentence treated as the substance and the predicate treated as an accidental category. The substantive category includes concepts that describe something and present something concrete, so they were a 'concrete substance', the subject of a sentence, something material. Within the accidental categories, Aristotle distinguished nine basic notions, which included quantity, quality, relation, place, time, location, property, action and sensation.

Aristotle's considerations gave birth to a method currently referred to as 'top-down', which defines a concept based on the type (genus) and the appearance of a single or several differences (differentiae) allowing new genera of forms from to be distinguished other forms of the same genus. This type of propositions Aristotle formulated in his works on logic, but in those on biology he criticised the limitations of the top-down approach and at the same time proposed an approach currently called 'bottom-up', which starts with detailed descriptions and definitions of an individual, classifying collections of individuals into species and genera and grouping different genera in groups. Aristotle considered the top-down method to be right for presenting and describing the results of his analyses, reasoning and proofs on this method, but he clearly favoured setting apart the bottom-up method as better for discovering subsequent research procedures on a new object.

In the third century after Christ, Aristotle's considerations of a concept, definition and category became the foundation of the work by Porphyry[1], who undertook the effort of writing a commentary to Aristotle's categorisation. This commentary contained the first notes on a tree diagram shown in Figure 1.1.

This tree shows categories and references to syllogisms with Aristotelian laws and rules concerning reasons associated with genera and types of defined subgenera.

The diagram shows an ideal genus, genera, lower levels, subgenera, the closest level, a species and an individual.

[1] Porphyry, a recognised ancient Napoli philosopher and astrologist. Known as commenter of Plato's and Aristotle's works, edited the works of the ancient philosopher Plotinus. Porphyry became famous for his collection of commentaries written to Aristotle's *Categories*, known as *Isagoga*, which constituted the most important text on logic in the Middle Ages and formed the starting point of research on logic and the dispute about universals. Porphyry's commentaries showing the dependencies of species and genera presented using a tree became the cornerstone of contemporary taxonomy.

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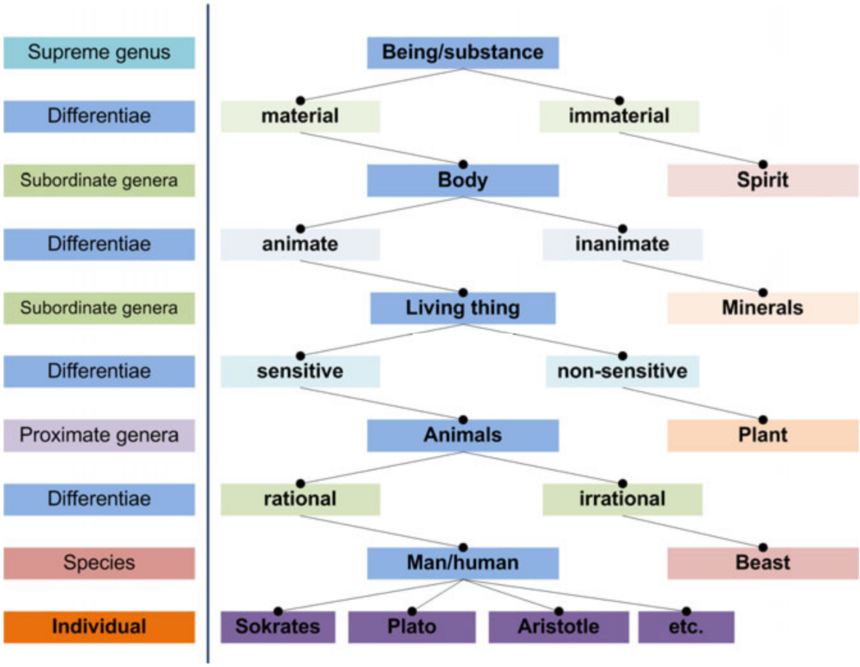

Fig. 1.1. Porphyry's tree presenting the diagram of Peter of Spain (1239/1947). Source: developed on the basis of [24]

In this diagram, one can observe how an ideal genus called the 'being' moves to a lower level, as a sub-type and one of genera of this being turns into a being called the 'body', and at the same time a non-material genus of a 'being' at a lower level turns into the sphere of the 'spirit'. The entire technique of heritage presented in the process shown in the Porphyry's diagram also combines other categories, which include living organisms, defined as animate 'beings' made of matter and a 'man' defined as a 'being' that is rational, sentient, living and made of matter. Porphyry uniquely points to representatives of the human species, in particular the known fathers of philosophy: Socrates, Aristotle and Plato.

Cognitive science developed further in the times of Blessed Ramon Llull, the first to propose a concept of the machine application of sentences for simple categorisation jobs. It is worth noting that he did this as early as in the 13th century.

Ramon Llull invented a mechanical device, a logical machine, in which the subjects and predicates of theological statements were arranged in circles, squares, triangles and other geometrical figures and when a lever was thrown, a crank handle or a wheel turned, these statements formed true or false sentences, proving themselves. Llull called this device *Ars Magna* [66] and devoted his most important works to its description. His work, *Ars Magna,* was physically a set of inscribed discs with primary concepts which could be combined in various ways by the appropriate rotation of these discs (Fig. 1.2).

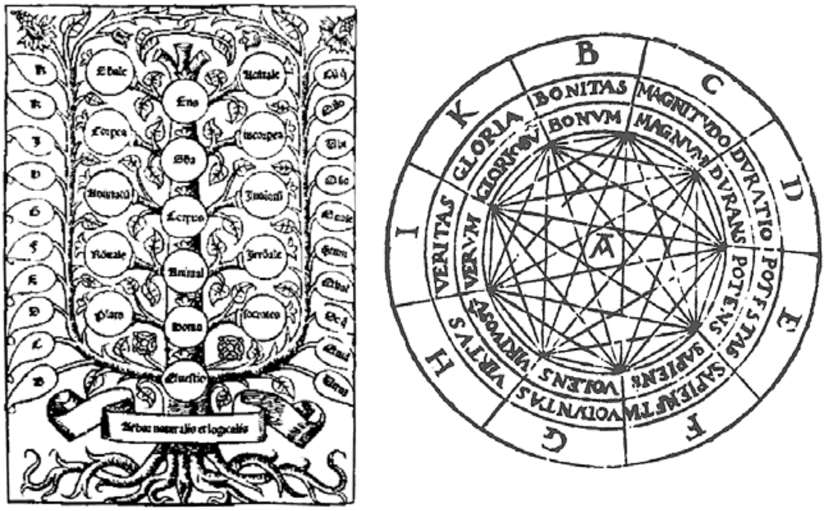

Fig. 1.2. *Ars Magna* by Ramon Llull. Source: [192]

His plan was founded in theoretical philosophy, or rather theosophy, as the primary motive for Ramon's method was that theology was identical with philosophy. He claimed that there was no difference between philosophy and theology, reason and faith, so that the highest secrets could be proven using logic and his machine – the *Ars Magna*. The best known edition of the work in which Ramon Llull described his logical machine was the Strasbourg edition of 1651.

Ars Magna has also been the subject of contemporary work, and one of the most often cited versions is an attempt at the automatic implementation of Llull's solutions made by Steven Abbott and Yanis Dambergs of 2003 (Fig. 1.3).

Llull's system originally inspired Gottfried Wilhelm Leibniz to propose his idea of *Characteristica Universalis* [64], presenting very simple sentences using numbers and at the same time building sentences resulting from its operation.

Expressions like "All *A*s are *B*" were checked by holding the number assigned to the concept *A* and checking whether that number was divisible by the number assigned to the concept represented by the letter *B*. If the noun 'flower' was represented by number 12, and the adjective 'creeping' by the number 23, their smallest common multiple was treated as a common conceptual category. In the example problem, the result – the number 276 – represented a 'creeping flower'. If 'grapevine' was represented by the number 11,316, then the sentence 'All grapevines are creeping' was true, as the number 11,316 is divisible by 276. Today, looking back, Leibniz can be said to have proposed a universal dictionary capable of converting words, sentences or syllogisms into numbers which could be the subject of reasoning based on the rules of arithmetic. To simplify the calculations necessary for his method, Leibniz also proposed the first computing machine capable of multiplying and dividing.

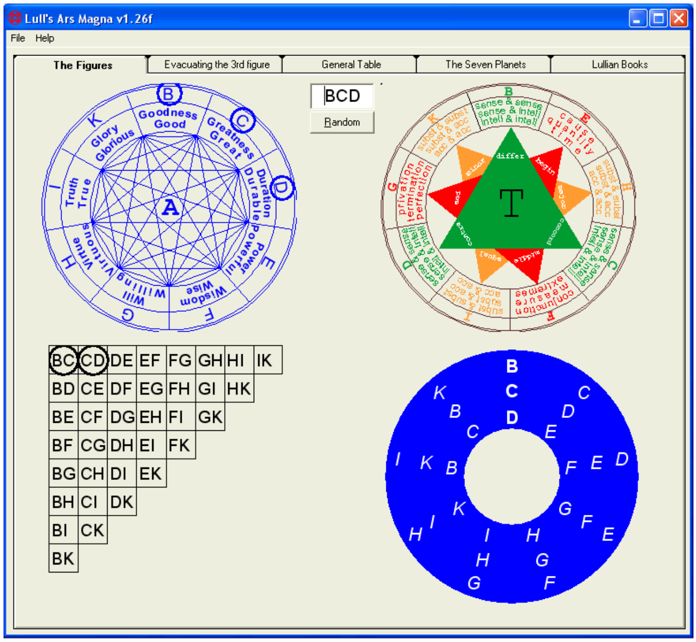

Fig. 1.3. The implementation of Ramon Llull's *Ars Magna* by S. Abbott and Y. Dambergs. Source: [185]

Thus computational linguistics begun with the introduction and implementation of Leibniz's universal dictionary. It is noteworthy that this method is still of interest today. One example comes from 1961, when for the purposes of a machine translation system, Margaret Masterman, a former student of Ludwig Wittgensteins, defined a network of 15,000 words based on compounding 1,000 simple, basic concepts [70]. In 1975, Roger Schank reduced the number of primary actions that had to be executed when using computational linguistics to just 11 [125]. According to his concepts, the transformation of high-level concepts into simple, basic ones, had to use two different phrases synonymous to one another.

When considering methods of computational linguistics, it is worth remembering that the system generally used in it must allow the transformation of high-level (complex) concepts into concepts (words) of a lower level. Such a system must also have a constructive component enabling the construction of complex concepts from correctly combined simple concepts, but this enhancement of the system, treated as a certain change of the basic rules, must be optional, not obligatory.

All the methods mentioned above were based on logical foundations. They used a logical apparatus for their operation, starting with Porphyry's tree down to formal ontologies, exemplified by Aristotelian top-down approaches. However, let us remember that Aristotle himself preferred the use of a bottom-up method for empirical data analysis. In 1858, William Whewell extended the definition of the top-down method, making it more precise and dedicating it to natural science [149]. In 1865, John Stuart Mill proposed conjectures and defined the final conditions for creating a ‘closed form’, while still believing it possible to define a 'closed form' [74]. He was an advocate of proposing criteria based on necessary characteristics and suggested the optional selection of those of them which, after a given theory was proven, could serve effectively. Various phases can be distinguished in J. S. Mill’s works, in which he professed various beliefs and preferred various methodologies. During the period in which he supported utilitarianism, he detailed and adjusted the concept of the empirical theory of cognition, several thoughts and theories from which have become the foundations of today's mathematical logic. The most important of them undoubtedly include the first attempt to narrow down the concepts of traditional Aristotelian logic. Mill presented the rules, which in Aristotle’s works had the form of unclear narrations, as diagrams, schematics and symbolic representations. In addition, he proposed to stop elevating logic and mathematics to a superior level and instead view both of these sciences as languages which can be freely, but in a non-contradictory way, adjusted to the needs of their users. Important achievements of Mill’s also include the attempt to structure inductive reasoning rules into so-called Mill's principles: methods, whose use led to producing categorical judgements by way of induction.

Mill’s methods are as follows: the method of agreement, the method of difference, the method of residue, the method of concomitant variations and the joint method of agreement and difference. These subjects are too broad and too detailed to discuss them in this book, but should be suggested to the Reader as the direction of further study. The progress in Mill's thinking and views meant that this philosopher later moved closer to naturalistic views of the theory of cognition, while in ethics he went in the direction of neo-Kantian theories. However, this subject goes far beyond the limits of this book.

For centuries, philosophy and science struggled, with greater or smaller success, with attempts that were to produce a prototype learning system and at the same time to create a general cognitive system that could be used to describe the human process of acquiring knowledge, but without losing the ability to describe similar processes taking place in an artificial, computer system. Every great scientist tried to relate to the theories and theses of his equally great predecessors as well as extend and improve those theories, whose aim was to get better knowledge of not just the human being, but also the entire world around it.

Over the last centuries, methods aimed at the formalised writing of definitions, logical methods, fuzzy methods and prototype building have developed greatly. All the above methods are aimed at defining words, concepts, meanings etc. Even though they had already been proposed in the 19th century, they were then effectively implemented also in modern computer systems.

The progress of civilisation, particularly the western one, has for many years been accompanied by the belief that only correctly conducted scientific research could ensure progress in knowledge. This conviction also applied to the processes of cognition (and understanding) treated as the subject of research at the time when the toolbox already developed for science was applied to studies of these phenomena. The pioneers of this approach were Hermann von Helmholtz [44],