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Elementary Principles for Representing Knowledge

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The vast majority of publications in language theory and philosophy start with the language as the given and ask about their structures, about the meaning of their words and about the correct interpretation of texts. This paper approaches the language problem from just the opposite side: the given is here a certain content; what is sought for, is an appropriate artificial language to represent this content. To this end, seven elementary representation principles are proposed. To illustrate the way they work, syntactic pattern recognition is introduced as a simple, but non-trivial example for representing knowledge in formal language. Another central thema of the paper is LEIBNIZ's characteristica universalis and the so-called LEIBNIZ project. LEIBNIZ's investigations in this field are reviewed against the background of the tasks required in syntactic pattern recognition. It is demonstrated that LEIBNIZ had, in fact, already worked with six of the seven representation principles proposed, further, that his characteristica universalis is an early form of a formal language, and lastly, that - contrary to the prevailing view - the LEIBNIZ project is not a matter of logic but rather one of knowledge representation, a field largely unexploited in today's logic-oriented epistemology and philosophy of science. It is precisely this one-sided orientation of these disciplines, which is responsible for the distorted picture of LEIBNIZ's work found in the literature; some typical misunderstandings are finally discussed. (Author)

1. Introduction

From childhood, we are accustomed to communicate in natural language. We take it for granted that the words we speak and write will be understood by all those sharing with us the same mother tongue. We assume that we can convey in our language all our thoughts without any restrictions although we may have to contend occasionally with difficulties in wording. Words are used by us in such a way that they would in fact carry a meaning; we learn their meaning in using the language, but we do not concern ourselves about where the meaning comes from, nor about the way language functions: we use language unconsciously. Perhaps for that reason linguists and philosophers tend to be quite vague about the origin of meaning and about representation principles. Interested in topics like comparative analysis, linguistic structures, linguistic relationships, etc., they are in the apparently enviable position of starting always with a fully qualified research subject.

For theoretical scientists the situation is less favourable. Their task is to represent given knowledge in a systematical way; their main problem may best be characterized by the question: how to represent something? It falls into two subtasks: first, theory formation, i.e., the systematic preparation of the content to be represented, and second, construction, or, if possible, selection of a tool adequate for representing that content. The first subtask has already been dealt with elsewhere being characterized as domain-internal knowledge organization (13); the second subtask appears in artificial intelligence in the context of knowledge representation. However, in artificial intelligence with its emphasis on implementation techniques, the matter is treated quite pragmatically, and the fundamental representation problems concerning the interdependence between form and content are generally neglected. LEIBNIZ was apparently the first (and perhaps the only thinker to date), who recognized and seriously treated both problems. In numerous attempts, he tried to express knowledge in a system of symbols in such a way that reasoning could be performed by symbol manipulation. His plan, now called *the LEIBNIZ project*, has a futuristic touch, enticing one to compare it with what we know today about this field. In confronting his ideas with approaches now practiced with computers, this paper intends to contribute to an up-to-date understanding of LEIBNIZ's efforts. Thus it pursues two lines of thought interlaced with each other: Knowledge representation as such and the LEIBNIZ project in particular.

To begin with, seven elementary principles will be proposed for representing knowledge in an artificial language. They are illustrated using formal language and the syntactic approach to pattern recognition as an example of how a formal language can be applied for representing knowledge. It is concluded from the parallels found in the tasks of the syntactic approach and those described in the relating works of LEIBNIZ, that his ars characteristica aims at knowledge representation, and that his characteristica universalis is an early form of a formal language in which his ars iudicandi and ars inveniendi can be viewed as bottom-up, respectively top-down parsing. The confusing variety of LEIBNIZ's efforts is shown to be orderable in a natural way as attempts to apply his project to concrete cases. Because knowledge representation is currently neglected in logic-dominated epistemology and philosophy of science, the LEIBNIZ project is generally misconceived here as a logical undertaking, an interpretation which yields a quite distorted picture of LEIBNIZ's intentions. To correct this one-sided view, some typical misunderstandings concerning thinking and symbol processing, and concerning the relation between artificial and natural languages are discussed. The paper concludes with a plea for a more intensive consideration of knowledge representation in philosophy.

2. Principles

About 40 years ago, the literary movement called concrete poetry took rise world-wide, claiming to meet modern humans's desire for quick and concise communication. Aiming at a most economical use of linguistic resources, the concrete poets addressed themselves to the most elementary language constituents, the letter and word. The concrete poets removed them from their usual position in sentence structure and treated them as self-contained units of expression (8, p.155). In contrast to the conventional way of writing poems based on sound, rhythm and meaning, the visual form of the language constituents was taken up by the concrete poets as a styling element; thus the „poetry of surface" was created (25, p.167). The new poem is a matter of both reading and seeing and as such they are even displayed in art galleries.

The language constituents may be arranged on a surface either in a pictorial-figurative or in a schematic manner. Both styling tools are often used simultaneously. An important feature of the pictorial-figurative arrangement is the use of the blank space serving as separator and as surrounding a space; in this way, the blank space creates possibilities of thought association, since it not only seperates the elements but also connects them (9, p.163), like in the poem[1]:

Hommage à Che

AB D FG I
JKLMNOPQR
STUUVWXYZ

Here the schematic element of the poem is the alphabet. Concrete poets emphasize formal operations with the elementary language constituents; thus inversion, combination and permutation are the styling instruments of their choice (8, p.157f). Like theorists in the sciences they normally start with a message and look for a suitable representation for it; their premise is that the form must fit the content. Consequently, there are, for them, no art rules to restric the sphere of poetic activity; the poet - as the expert of the language game - is completely free in his selection of the linguistic elements and their ordering in schemata; indeed even violations of fundamental conventions are allowed. For instance, in the lines

(1) freedom is no freedom
duty is duty,
etc.

contradiction and tautology alternate with one another. The underlying schema

(2) A_n is no A_n
B_n is B_n
$n = 1, 2, \ldots$; A_n, B_n any abstract concepts,

easily recognized by the reader, can be considered as an instruction to form further text. Thus the reader can participate to the creative process by taking up this instruction and continuing the text, or indeed by feeling him stimulated to invent his own forms, thus generating new content. In inventing new forms, character manipulation in general is understood as a universal tool of representation. Thus the concept of concrete poetry includes the principles of representation in nuce.

In order to produce such a creative effect, a concrete poem must transmit some content to the reader. How does this work? The text (1) - apparently absurd from a logical point of view - was constructed according to the schema (2) found by „feeling". For this schema, there is neither a formal justification nor a justification by content; nevertheless there are interpretations which can give it a meaning. Contradictions, even violations of language convention, do not impede the mediation of content, no more than observing grammar rules guarantees a meaningfulness. The schema alone cannot produce the content. Where then does the content originate? The answer is: It originates in the mind of the interpreter; the signs percieved trigger associations either directly, or, more abstractly, in applying rules. In any case, the associated thoughts are perceived as content inherent in the system of the signs used in the poem.

The perception of signs calls for interpretation; in giving himself to the interpretative process, the interpreter may gain attractive new insights (i.e., new connections between ideas stored in his memory). Using free associations, one is therefore capable of reading apparently meaningful content into structures originating purely by chance like tea leaves in a cup or playing cards in a pack. Perhaps this phenomenon of creative association might explain why unclear concepts in publications hardly ever cause offence to their readers, and why unclear authors may often have more followers than authors who, like LEIBNIZ, aim at accuracy. Self-generated insights are taken up more willingly than bare existing truthes presented in dry words. Obviously it is more attractive to give free reign to ones own cognitive processes than to struggle to comprehend someone else's thoughts. A further manifestation of this phenomenon can be found combined with the belief in a divine being or a legendary person giving rise to caballistic and similar mystic practices. Because of their triggering effect, signs have an informative character regardless of how they are came into being or by whom they were created. To represent knowledge, however, it does indeed matter, whether or not the signs chosen evoke precisely that content which they are intended to represent. To meet this goal, one must take care that the signs chosen evoke the intended and only the intended associations. This can be achieved by following

Representation principle 1:
Dissect the content to be represented into clear basic components, determine their relations and then assign uniquely to each component and to each relation an elementary language character[2].

LEIBNIZ, taking mathematics as his model, assumed that this could be done:

„If it would be possible to find characters or signs suitable to express all our thoughts as straightly and stringently as the arithmetic represents the numbers, or as the geometry represents figures, then all things, as far as they are subjected to reasoning, could be dealt with in the same manner as is done in arithmetic and geometry" (20, p.155; 22, p.90).

Thoughts, of course, can be very extensive; principle 1 deals only with the basic components. How to handle the complexer contents is defined in

Representation principle 2:
A complex content is represented in two steps: first, it is dissected into its basic components and relations and, by means of the characters assigned to them, the term for the complex content is formed, second, in such a way that the relations between the basis components correspond to the relations between the characters.

This famous principle, now called the *isomorphy principle*, can be found word for word by LEIBNIZ[3]. He seems to have been the first to recognize that representation consists in a structural equivalence between terms and objects. Isomorphy is often viewed as the representation principle par excellence; in fact, however, more principles are needed to succeed in knowledge representation[4].

The next complex of questions deals with the transmission problem.

When signs do not themselves carry meaning but only trigger content already existing in the mind of the receiver, then the question: How does meaning get into a system of signs? becomes itself meaningless. Moreover, it also remains unclear, how any information at all can be transmitted by means of a system of signs. If only signs are sent, and if these signs do not transport anything, then nothing would appear to arrive at the receiver end. But this contradicts everyday experience: To return to the example of the poem *Hommage à Che*, with the exception of the title, the poem consists only of meaningless characters, nevertheless it evokes a meaning in the mind of the reader. Hence it must be possible somehow to transport content with „containers" having no content.

A transmitter communicates content to a receiver by selecting an appropriate set of signs, e.g. words, and by choosing the order in which the signs are transmitted. The assumption is that the receiver has available in his/her mind a set of content elements capable of functioning as a carrier set. In perceiving a certain sequence of signs, a certain sequence of content elements from the carrier set is activated and held in the memory, i.e., the „transmitted" content constitutes a subset standing out from the carrier set like a trace of ink on a blank sheet of paper. It can only be triggered insofar as it already exists. But the induced trace itself can now become a new content which is added to the carrier set as a new element, which again and in turn itself can be activated by new signs. In reading a novel, e.g., not the words, but the plot is remembered. This shows, that the sequence of signs may indeed be very long, and that, consequently, the induced content may be very extensive. In spite of the transmission principle's apparent simplicity, far-reaching conclusions can be drawn from it. Thus, for example, the so-called *hermeneutic circle* is based on this principle[5]. From the transmission principle follows

Representation principle 3:
Content is recorded in a system by distinguishing a subset from a carrier set.

In an artificial language, principle 3 is applied by selecting a certain subset of words from the set of all words over an alphabet. Principle 3 would appear to be a general principle holding for all kinds of representation; in particular, it is not restricted to content representation in formal systems.

In order to communicate with each other, all members of a speech community must use the words of their language more or less in the same sense, i.e., a given sequence of words must evoke in all these persons nearly the same sequence of associations. Because of this universality, it is justified in a figurative sense to speak of a meaning of words. Usually it is here objected, that the meaning of a word could be reconstructed only in the context; however, this is a misleading point of view: Which of the associations a word sequence triggers, depends on the mental state of the reader/listener; and this state again is determined more or less by all his preceding experiences. However, it is an acknowledged fact, that with respect to a new communication, the immediately antecedant thought exercises a special dominance; we may call this phenomenon *pre-text dependency*. It is rooted in (human) memory processes, which can neither be deliberately influenced, nor evaded. The pre-text dependency can therefore be used to point the reciever's attention in a certain direction, thus influencing his/her mental state, e.g., by informing him/her that the message to follow is something worth knowing, or by manipulating the opinion, or by causing confusion. In knowledge representation, pre-text dependency is used to produce a chain of coherent thoughts:

Representation principle 4:
To be understandable and to effect transmission of extensive contents, the pre-text must always give information about how the immediately following text should be interpreted.

This principle is the presupposition for applying rules.

LEIBNIZ complained about the fruitless disputes in philosophy and theology in his time, but unlike the analytic philosophers of our time, he did not hold that the natural language is responsible for these shortscomings[6]. Instead he located the source of confusion in the disorderly state of the sciences. He compares them to a large general store offering for sale a wide range of goods, which, however, are displayed chaotically (20, p.214; 21, p.177). Searching for a remedy, LEIBNIZ looked for a tool to represent proven knowledge so that talented persons are no longer induced to search their laurel by overthrowing what was handed down from predecessors (20, p.215, 21, p.118). Behind these ideas - the use of an (artificial) language as an aid to thinking and preserving knowledge - there is a hidden assumption that only genuine knowledge, not nonsense can be represented formally. Under this assumption, representability emerges as the touchstone for objectivity:

Representation principle 5:
The regularities of a content are the keys to its representation.

Regularities are expressed as subsets according to principle 3. But before a genuine content can be represented, it must be put into a systematic form. LEIBNIZ realized very clearly, how close is the connection between representability and the quality of the content. Thus he devoted considerable effort to systematisizing the knowledge of his time in the form of a general encyclopedia.

The preceding discussion has referred mainly to the natural language used above all as a tool for communication. But here one must ask whether natural language is adequate to fulfill the requirements for the representation of scientific contents? In principle, LEIBNIZ gives an affirmative answer to this question, but he concedes that, to achieve this goal, it would require far-reaching modifications of natural language and such interventions have no chance of a realization however advantageous they might be (22, p.12; 22, p.21). In our day, by contrast, it is customary to deny rashly the suitability of natural language for this purpose. This is done, for the most part, without making any effort to precise what *suitable for scientific purposes* might mean. Against the scientific use of natural language, the objection is often made, that texts in natural language would be too ambiguous, that they would always leave open too much scope for interpretation, something good for poetry, but bad for the science. This, however, is not true. Only words alone can be ambigous; if a text is ambiguous, then only because the author has made faulty use of words and rules of the language. In that case, it is not the language which is to blame. Thus, in terms of the two requirements, unambiguity and storage capacity, there is no plausible argument against the use of a natural language in sciences as can be seen, e.g., from the role of natural language in mathematics.

However, in mathematics there is also extensive use of formulae. Evidently, there are contents for which it is more economic to use other means to represent them. Although any natural language can incorporate a nearly unlimited spectrum of content, it does not cover exaustively all the possibilities of language. Thus LEIBNIZ searched for an formalism which could serve thinking as a kind of Ariadne's thread, providing certainty and clear navigation through the labyrinth of thoughts when used correctly (20, p.351 et passim; 5, p.14, p.22 et passim), i.e., such an artificial language must guarantee that each correctly constructed statement proves itself to be true, and that, in principle by systematic and correct application of its grammar rules all true statements can be found. With natural languages, this goal cannot be achieved: A syntactically correct sentence is not necessarily also a meaningful sentence. Thus, in contrast to his predecessors LEIBNIZ realized that knowledge representation requires in addition

Representation principle 6:
An artificial language must be a rule-based system in which syntax and semantic are identical.

This principle is the presupposition for his ars iudicandi and inveniendi. Grammar rules combine in such a system clarity of order with certainty (22, p.21) and thus provide orientation, but they do this only for a restricted domain of knowledge. In natural langages, syntax and semantics are only very loosely connected[7]: This is the price which must be paid for their being open for (nearly) any content.

Principle 6 describes what is called *formalization* in modern usage:

Definition: Formalization
Formalization is the process of representing knowledge in a formal language in such a way that syntax and semantics are identical.

In the literature, one finds considerable opposition to this definition. Formalizing is often confused, for instance, with formal operating, whereas in fact formalization only provides the prerequisites for such operating. In addition, *formal* is often used mistakenly in a pejorative sense suggesting *abstract, mechanistic, being without meaning*. Properly understood, however, because of the identity between syntax and semantics, formalization produces a language without redundancy; in this sense, it is „knowledge pure". A further misunderstanding confuses formal terms with logical terms and views formalization as a task of logic.

In principle 1, the use of atomic units was called for, on the assumption that complex subjects can be constructed from such atomic units. However, the merely sequential addition of basic units to represent complex ones fails to provide structuring and recursivity. For both tasks abstract objects are required as auxiliary units:

Representation principle 7:
The formalism must be capable of distinguishing between entities in different levels of abstraction.

This important principle provides the basis for a recursive use of rules, making it possible to comprehend an infinite number of objects by means of a finite number of grammar rules as will be shown in more detail later in this paper in the context of formal language. Abstract entities are generalizations and as such are not real objects and events; they must first be invented before they can be used for representation, therefore they are not included in principle 1 and 2. Principle 7 has remained pretty much unknown. Recursive operating according to rules was a technique presumably discovered by LEIBNIZ (22, p.21; 22, p.24f; 22, p.27; 5, p.206; 22, p.114); nevertheless he made use of it only in recursive formulae. Although he repeatedly emphasized its importance, it seems that he did not know how to handle it with respect to characters and grammar rules.

3. Formal languages

The representation principles compiled above seem to be quite simple when considered in isolation. However, when taken together in connection within one and the same formalism, some interesting conclusions can be drawn from them. For their illustration, now the formal language approach is introduced as a tool for a special, but non-trivial knowledge representation. In philosophy, the concept **formal language** is often applied quite unspecificly. In this paper, by contrast, it is used as a terminus technicus in the sense of mathematical linguistics; the origins of which may be traced to the middle 1950s when CHOMSKY began developing mathematical models of grammar. For our purposes here, the basic ideas alone may suffice[8].

An alphabet Σ is a finite nonempty set of characters. A word *P* over an alphabet Σ is a finite sequence $x_1x_2...x_n$ of characters in Σ; $n \geq 0$ is the length of *P*. The word of length zero, called *empty word*, is denoted by ε. The set of all words over an alphabet Σ, including the empty word ε, is denoted by Σ^*. A formal language *L* is a well-defined set of words over an alphabet Σ, i.e.,

$$L \subset \Sigma^*.$$

Normally, no distinction is made between words and sentences.

Σ^* has a function very similar, e.g., to that of the Cartesian plane. Both Σ^* and the Cartesian plane form carrier sets: the former is a general contentless spectrum of potential words, the latter is a general contentless two-dimensional space containing a potentially unbounded number of figures; both are in a certain sense blank sheets providing the condition for the possibility of representing content. According to principle 3, a content is recorded in such a system by selecting a particular subset from the respective carrier set, i.e., by selecting a certain subset of words from Σ^*, respectively by selecting a certain subset of figurative elements from the plane, e.g. a particular curve. Subsets of words are described in formal languages by characters combined according to rules of grammar. Thus the problem of defining a formal language is shifted to the problem of defining a grammar.

Definition:
A *phrase-structure grammar* G is a four-tuple

$$G = (V_N, V_T, P, S)$$

in which:

1. V_N is the alphabet of nonterminals

2. V_T is the alphabet of terminals

3. P is a finite set of rewrite rules (or productions) denoted by $\alpha \rightarrow \beta$ where α and β are strings over $V_N \cup V_T$ and with α involving at least one symbol of V_N.

4. $S \in V_N$ is the starting symbol of a sentence.

Production starts with any appropriate starting rule; it stops when no further rule can be applied. By convention it is a „leftmost" approach, since the general order of processing the symbols in the sentences is from left to right whenever possible. Characters mentioned in principle 1 correspond to the terminals; the terms for describing complex objects according to principle 2 are the words (sentences) of the language. Nonterminals are needed to grasp abstract entities according to representation principle 7.

One of the most attractive aspects of the syntactic approach is the recursive nature of grammar. A grammar rule can be applied any number of times (point 3 in the above grammar definition), so it is possible to express in a very compact way some basic structural characteristics of an infinite set of sentences by using small sets of simple elements and grammar rules. The basic idea here is often illustrated by LEIBNIZ's pointing out the way numbers are constructed, especially binary numbers (20, p.284f, p.429ff). And, indeed, the set of all binary numerals

$$\{ 0, 1, 10, 11, 100, ... \}$$

can be considered as a formal language:

Example: Grammar for constructing binary numerals

G = (V_N, V_T, P, S) where

V_N = { S, A }
V_T = { 0, 1 }

and P:
(1) S → 1A
(2) S → 0
(3) S → 1
(4) A → 0A
(5) A → 1A
(6) A → 0
(7) A → 1

With G, e.g., the numeral '1011' can be derived as follows:

$S \rightarrow^{1} 1A \rightarrow^{5} 10A \rightarrow^{4} 101A \rightarrow^{7} 1011$;

the numbers indicate the rule used. Note that G excludes numerals with a leading 0 except for a single 0 (rule 2).

It can be seen from the above example, that the remaining representation principles are likewise fufilled by formal language: Each interim result functions as pretext focussing attention on the next rule to be applied (principle 4). The law governing binary numerals, and, at the same time, the knowledge to be represented, is that '0' and '1' can occur in any order, as long as no leading zero appears in a multi-figure numeral (principle 5). In this example, syntax and semantics are identical (principle 6), because each object generated by this grammar is a numeral, and there are no numerals which can not be generated by this grammar. Finally, the ability to distinguish between different levels of abstraction (principle 7) is realized by the nonterminal, *A*, meaning *numerals following a leading numeral*. This abstract concept is needed to exclude leading zeros by omitting the starting rule S → 0A, the counterpart to rule (1). Nonterminal, *A*, causes recursivity, as can be seen very clearly from the grammar. The grammar rules can be viewed as axioms, and the words derived from them as theorems. Seen in this light, formalization is a kind of axiomatization.

4. Representing and using knowledge in a formal language

The main application area of formal languages outside linguistics seems to be syntactic pattern recognition. Recognizing patterns means assigning them to their respective classes. Typical applications of pattern recognition include character recognition, target detection and identification, analysis of biomedical signals and images, speech recognition, identification of human faces and fingerprints, automatic inspection etc. The many different techniques used to solve recognition problems may be grouped into two general approaches: the decision-theoretic approach and the syntactic approach. The former is based on numerical description; the latter rests upon the analogy between the structure of patterns and the syntax of a formal language. In the syntactic approach, a pattern is an image-like idealized description of an individual real object or event like the „filigrees" in fig. 1. Such patterns are composed of subpatterns in various ways, just as phrases and sentences are built up by concatenating words, and words are built up by concatenating characters. Each pattern is thus described by a string of characters[9] which is assumed to be a word or sentence in a formal (pattern description) language. Syntactic pattern recognition proceeds in two stages: **formalization** and **recognition.** Formalization is a matter of knowledge representation whereas pattern recognition is the application of the represented knowledge. The following introduction is restricted only to the basic ideas[10].

4.1. Formalization

With respect to syntactic pattern recognition, formalization deals with **primitive selection** and **grammatical inference.**

The first step in formulating a syntactic model is to determine a set of pattern primitives and their relations in terms of both elements the patterns can be described (principle 1). At present, there is no general solution available for the primitive selection problem. It will be largely influenced by the nature of the data, by the specific application in question, and by the technology available for implementing the system. The primitives must be so constituted as to provide a compact but adequate description of the complex patterns, and they should be so simple in their structure that they can be easily recognized. After primitives and relations have been identified, to each primitive is assigned a character from the terminal alphabet (principle 1). The basic relation is that of concatenation; other relations are likewise assigned a character from the alphabet of terminals.

A formal language is then most appropriate for representation, when the patterns to be recognized can be built up from a small set of primitives by recursively applying a small set of production rules. A pattern class is a set of patterns sharing some common structural properties (principle 5) from which appropriate grammar rules have to be inferred. A straightforward approach would be to construct for each of the *m* classes of patterns m grammars G_1, G_2, ..., G_m such that the strings generated by the grammar G_i would exactly represent all patterns in class w_i (principle 6).

4.2. Recognition

Formalization provides the linguistic means for describing the objects under study; it must be designed specifically for each recognition problem. Recognition itself is the application of the formalization result; it must be carried out for each pattern to be recognized. Recognition consists of two steps, **pattern description** and **syntax analysis.**

Before recognition can begin, the real event or object (given, e.g., as a digitize picture) must be transformed into an image-like pattern according to the tools established in the phase of primitive selection. This procedure normally requires an extensive non-syntactic preprocessing to extract significant features or structures from a background of irrelevant details. After that, the image-like pattern is segmented into its primitives, and the relation of the primitives are identified as shown in fig. 1. Then the corresponding terminal characters are assigned to each primitive and to each relation in such a way that at the end, the pattern is desribed by a string of concatenated symbols.

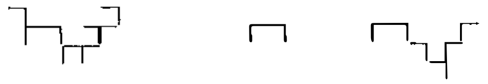
Classification is the work of the syntax analyzer or parser. It decides whether or not a sentence x describing an unknown pattern is syntactically correct, i.e., the problem of recognition x is reduced to the answer of the question:

Is $x \in L(G_i)$ for $i = 1, ..., m$?

$L(G_i)$ is the language generated by the grammar G_i. A pattern is uniquely assigned to the ith class if it is a sentence only in $L(G_i)$ and in no other language. If a pattern is not a sentence in any of the languages under consideration, it is assigned to a rejection class consisting of all invalid patterns. The output from the analyzer usually includes more than the class number; the parser is also able to produce the derivation tree of the string, which, provided that the sentence is syntactically correct, gives the complete description of the pattern and its subpatterns.

4.3. Recognition of filigrees

Suppose that there are stroke patterns as shown in fig. 1. Some of them are of special interest called 'filigrees'; the recognition task consists in subdividing stroke patterns into filigrees and non-filigrees. The patterns are quite simple, being composed of only two primitives, ⌈ and ⌉, respectively. The filigrees are two-dimensional patterns; to describe a position, the two relations *one line above* and *one line below* are needed.



(1) (2) (3)

Figure 1: Filigree-like patterns.

The sequence of units from left to right is described by concatenating the characters in that direction; thus for this relation no further character is required. To the two primitives and their two relations terminals are assigned:

⌈ $\leftrightarrow$ a, ⌉ $\leftrightarrow$ b, one line above $\leftrightarrow$ x, one line below $\leftrightarrow$ y.

Using these terminals, the filigrees can be transcribed as follows:

(1) byabyaaxbaxb
(2) ab
(3) abybybxaxa.

Since there is only one pattern class, only one grammar is required. In order to establish it, the characteristic features of the filigrees must be known; it is the knowledge to be represented. Assume that filigrees are patterns having always an equal number of ⌈ and ⌉ primitives and that a switch from the above to the below position or vice versa is only possible when different primitives adjoin each other. A primitive may occur twice only if its predecessor changed the position. The grammar, $G_{filigree}$, of the respective pattern language can then be defined as follows:

Filigree grammar

$G_{filigree} = (V_N, V_T, P, S)$ where

$V_N = \{ S, A, B \}$
$V_T = \{ a, b, x, y \}$

and P:
(1) S → aB
(2) S → bA
(3) S → axB
(4) S → bxA
(5) S → ayB
(6) S → byA
(7) A → aS
(8) A → a
(9) B → bS
(10) B → b.

Applying the filigree grammar, it can be shown that pattern (1) and (2) belong to the class of filigrees, whereas pattern (3) does it not (numbers added to the arrows indicate the production rule used):

(1): S $\to^{6}$ byA $\to^{7}$ byaS $\to^{6}$ byabyA $\to^{7}$ byabyaS $\to^{3}$ byabyaaxB $\to^{9}$ byabyaaxbS $\to^{3}$ byabyaaxbaxB $\to^{10}$ byabyaaxbaxb

(2): S $\to^{1}$ aB $\to^{10}$ ab

(3): cannot be derived, because the subpatterns *axa* and *byb* are invalid; the rules 3 - 6 only permit terms where at the left and the right side of x and y different characters are standing.

Again the nonterminals cause recursivity and serve at the same time as structuring elements: A and B can be interpreted as *a-balancing* and *b-balancing*, respectively. It goes without saying, that in inferring the grammar, the search for suitable nonterminals is the crucial problem.

5. The LEIBNIZ project reviewed

In numerous fragments, LEIBNIZ speaks astutely about the features of an artificial language system called by him among other expressions *characterista universalis*. For this thought complex, the name *LEIBNIZ project* has been coined.

Definition: The LEIBNIZ project
The *LEIBNIZ project* is the search for an artificial language as a representation formalism

- **to store knowledge,**
- **to clarify controversial statements,**
- **to produce new statements,**
- **to provide certainty,**
- **to provide unambiguity.**

One of LEIBNIZ's main ambitions was to bring together in compact form the knowledge of his time scattered in diverse sources. Clarifying controversial statements and bringing forth new knowledge should be done by the ars iudicandi and by the ars inveniendi, respectively. With the ars iudicandi, each statement can be tested to see whether it can be generated with the rules of the artificial language; if so, the statement is judged to be a true statement belonging to the store of knowledge represented in this language; if not, it is judged to be false (16, p.138). In LEIBNIZ's conception, instead of fruitlessly disputing about the truth of a statement, one can, with the help of the ars iudicandi, compute the decision, and because of this, the result will be certain and convincing for all (20, p.156). The aim of the ars inveniendi is to discover new truths by applying the rules of language systematically (16, p.138). Although LEIBNIZ sometimes speaks about the ars iudicandi and the ars inveniendi as distinct arts, they in fact make use of one and the same formalism. Finally, artificial language should exclude ambiguity, i.e., because a statement is not only true or false, but has also a reference, it must be represented in such a way that in reading it, in every mind will experience, in principle, the same sequence of associations. Substituting *pattern* for *thought* when reading LEIBNIZ texts, one sees the close connection between knowledge representation and LEIBNIZ's ideas. This connection becomes clearer, when comparing the problems of syntactic pattern recognition with their counterparts he inevitably encountered in attempting to realize his ideas. In his work, LEIBNIZ addresses questions of knowledge organization, primitive selection, grammatical inference and recognition.

Many of fragments reveal that LEIBNIZ knew what is called in syntactic pattern recognition primtive selection. This expression, of course, does not appear in his work, but the matter itself is often dealt with in the context of analysis. According to LEIBNIZ, the seemingly infinite variety of thoughts is only apparent; it originates from the infinite number of possibilities in which the basic thoughts can be combined with each other. He asserts repeatedly that all human thoughts can be reduced to only a few „original“ ones (22, p.112) which, when identified, can serve as an alphabet of human thoughts (5, p.185). Similarly, he claims that most concepts can be split into subconcepts and these again into still more elementary concepts etc., until the „ultimate“ concepts are reached which are no longer capable of decomposition (5, 292ff). All such analyses involve the notion of resolving a complex object into its elementary components and identifying the basic relations governing their association. Thus, LEIBNIZ clearly distinguishes between primitives and relations of the type illustrated by the example of feligree recognition. Examples of LEIBNIZ's usage are fundamental thoughts or concepts, fundamental geometrical figures, equivalence, ordering relations, similarity, congruence[11].

Likewise he assigned characters to basic units and to their relations on a one-to-one correspondence (18.1, p.200). For formal operations, the form of the characters assigned is without importance; however, for a better understanding, it is preferable to choose signs which illustrate their function (5, p.192; 18.1, p.200). Thus, in the filigree example above, the initial letters of the alphabet are reserved for primitives, whereas the final letters are used to characterize the relations.

The most difficult task in syntactic pattern recognition is to find the appropriate grammar, and so, as expected, LEIBNIZ had to struggle with the corresponding difficulties, too. The greater part of his calculus fragments deals precisely with the problem of establishing a suitable set of rules to represent such different domains as logic, geometry, optics, differential calculus etc. Beginning with LULLUS, there is a continuing tradition of attempts to represent knowledge by an artificial language and to discover new knowledge by manipulating the elements of such a language. But LULLUS and the other predecessors of LEIBNIZ, as indeed the early LEIBNIZ himself, had a fixation about very simple grammars of the type *all combinations of*, or *all permutations of*. Taking such operations for granted, they confined their efforts to research for basic concepts; to put it in our terminology: they restricted themselves to primitive selection and to some elementary symbol manipulations. In his letters, LEIBNIZ prides himself for the insight that to represent something, adequate rules must be sought. It would appear, however, that he failed to recognize the need for nonterminals. He confined himself, for the most part, to principles 1 and 2, in keeping with his early idea of using words as „adding pieces“: his „grammars“ are based on terminals. At first he experimented with combinations and permutations; later he took up concatenation, rewriting, and changing symbols (5, p.31) as is done today in using formal language, i.e., he switched from *all combi-*

nations to *some combinations* the latter being separated by certain rules from the set of all combinations. Nevertheless, his „grammars" allow only non-hierarchical flat structures, i.e., complex objects can be described with it, but for generating them, a genuine grammar is required having nonterminals. For example, filigree grammar permits only patterns in which the a's and b's are equal in number; this feature is reflected in its nonterminals. When these grammar rules are considered as laws of growth, it becomes clear that they describe all ten possibilities of creating filigrees. It would appear that LEIBNIZ was aware that his syntactic methods insufficiently expressive, thus he also tried arithmetical approaches. For instance, he operated with the multiplication of prime numbers to combine propositions, anticipating in this way GÖDELization. He also invented the plus-minus-calculus, etc. However, in using a ready-made mathematical formalism, one is bound to its „grammar", and, consequently, by its restrictions: Although, e.g., inclusion can be represented arithmetically by the relation of divisibility, it is not possible to represent incompatibility by multiplication, because there are no unvalid products (16, p.106). LEIBNIZ had the right idea, but he failed to apply it successfully. But there is still another problem which he failed to observe:

For a given set of patterns, a different selection of pattern primitives will necessarily result in a different grammar. As a rule, the complexer the primitives, the simpler the grammar. This crucial point can become quite important in the implementation of the recognition system. Often, a compromise is necessary in order to develop a suitable grammar. It is generally recognized that increased descriptive power of a language must be paid for in terms of increased complexity of the analysis system. It follows from this, that there are no true basic units as LEIBNIZ and many others had erroneously assumed. Consequently, primitive selection and grammar construction should be treated simultaneously rather than successively. Because of this interrelation between the primitives selected and the grammar, one should be very careful in speaking about structures found in the object which can be represented one-to-one in any language. One frequently encounters such assumptions in discussions of the isomorphy principle (principle 2) where it is overlooked that, according to principle 7, structuring also requires „virtual" abstract entities, which are born in the mind and therefore to some degree arbitrary: For one and the same recognition task and for one and the same set of objects, there is an infinite number of possible grammars and, as a consequence, also an infinite number of structures.

As the above discussion shows, primitive selection and grammar inference presuppose a profound knowledge about the domain to be formalized. For example, if size or shape or location are relevant for recognition, then the primitives must contain information relating to size, shape or location, in such a way that patterns from the different classes are distinguishable by whatever recognition method is to be applied. For one and the same set of data, different problem specifications will result in different selections of primitives and rules. However, the knowledge of the subject alone is not enough: this knowledge also must be made available in a systematically ordered way (22, p.60; similarly: 20, p.296). Inconsistencies in the knowledge of his time was one of the main obstacles to LEIBNIZ's efforts, and it is still crucial for the today's knowledge engineers. Where, as in case of the differential calculus, the field of knowledge was easily comprehensible, LEIBNIZ was successful. With respect to other subjects, however, he saw very clearly that the domain in question would first have to be systematized **before** a characteristica universalis could be applied. Many of his fragments therefore deal with theoretical clarifications, but also, at the same time, with establishing rules. He knew, however, that such isolated clarifications must be inserted into a general context to assure validity. This task was to be achieved by his encyclopedia, which he viewed as a compedium of scientific theories (20, p.31-41; 21, p.177).

Until now, we have been discussing LEIBNIZ's theoretical approach to knowledge representation. As regards the use of the represented knowledge, LEIBNIZ extols the advantage of his method as being ars iudicandi and ars inveniendi at the same time. By means of the ars iudicandi it should be possible to decide for a given statement whether or not it has a special feature, e.g., whether it is true or false. By means of the ars inveniendi it should be possible to generate systematically the complete knowledge of the domain. Until now, most authors have not known what to do with these arts. HERMES (11, p.93), for instance, is irritated by the fact that both arts are referred to LEIBNIZ apparently without distinction. However, the comparison with syntactic pattern recognition can help illuminate this matter. Here use is made of two complementary parsing approaches, top-down and bottom-up parsing. In the first case, syntax analysis proceeds top-down from starting symbol S through intermediate sentential forms until the sentence in question is achieved as done in the examples above. In the second case, one begins with the sentence and, by applying rules in a reverse fashion, attempts to reduce the sentence to the starting symbol S. Although both approaches require somewhat different techniques, there are no differences in principle. The bottom-up parsing is comparable to the ars iudicandi, since for each pattern described by terminals the class membership can be determined. Conversely, with top-down parsing, in principle all patterns of a class can be generated systematically, i.e., new structures can be discovered this way, being comparable to the ars inveniendi. Note that both approaches are based on one and the same grammar; they differ only in the way they use this grammar.

To summarize the above discussion, we can conclude that the LEIBNIZ project, i.e. his ars characteristica conceived as *the art of generating characters and ordering them in such a way that they represent thoughts* (1, p.80) can best be understood by treating it in the context of what is called *knowledge representation*, and what today is a key issue in artificial intelligence. In using a formalism in practical applications, this understanding is in best accord with LEIBNIZ's maxim *theoria cum praxi*; it excludes a mere logical interpretation of his project. The artificial language needed for this task should be the characteristica universalis; it is an early form of a formal language in today's understanding. LEIBNIZ clearly understood what his project required, in particular, he realized that, before formalization can be done, the knowledge must be prepared in a systematical way; this is the task of knowledge organization. He realized too that the whole undertaking must be put on a general methodological foundation. Admittedly, LEIBNIZ's strange and sometimes confusing terminology impedes correct understanding, thus, with all due caution we suggest translating his terminology in the following modern terms:

characteristica universalis	formal language
ars characteristica	knowledge representation
ars inveniendi	top-down parsing
ars iudicandi	bottom-up parsing
analysis	primitive selection
synthesis	grammatical inference
encyclopedia	scientific knowledge represented in theories
scientia generalis	philosophy of science

This table, though oriented to syntactic pattern recognition, reflects the different tasks necessary for realizing the LEIBNIZ project. LEIBNIZ himself took them into account, but not systematically. Thus someone not familiar with the demands of knowledge representation can easily gain the impression that he would pursue contradictory goals. However, the confusing variety of topics found in his fragments can be explained, for the most part, by referring them to different tasks involved in knowledge representation.

6. Discussion

Because of a lopsided logical/meta-mathematical point of view, problems of knowledge representation have hitherto been treated in philosophy with little real understanding. To a certain extent, this holds true as well for the relating subdisciplines of artificial intelligence. In this section we shall consider some fundamental misunderstandings appearing in contemporary discussions about what the formal approach can accomplish and what it cannot. There are two topics: confusion between thinking and symbol processing, and misunderstandings about the relationship between natural and artificial languages.

6.1 Confusion between thinking and symbol processing

LEIBNIZ points out that a mathematical proof is not performed with the things themselves, instead, it is performed only on a sheet of paper by manipulating characters which stand in for things[12]. This and other utterances lead interpreters to conclude that LEIBNIZ thought it possible to reduce operations with thoughts to operations with characters; in short: they claimed that for LEIBNIZ, thinking is nothing more than symbol processing[13]. This is the interpretation usually given to his statement:

> "Omnis ratiocinatio nostra nihil aliud est quam characterum connexio et substitutio, sive illi characteres sint verba, sive notae, sive denique imagines"[14].

It is normally translated as *all our thinking* ... as in (22, p.110), however, *ratiocinatio*, or in French, *raisonnement* does not mean *thinking*, but among others *proof, reasoning*[15]; thus the statement must be translated:

> "Each of our proofs/all of our reasoning is nothing more than connection and substitution of symbols, whether those symbols be just words, or characters, or even pictograms."

That for LEIBNIZ, thinking does not consist in symbol processing is evident from the fact that thinking at least is needed to establish the first calculus. Some authors appear not to realize the consequences of their assertion: If the goal of symbol operations be to determine the truthness of a statement, and if thinking be nothing more than such symbol manipulations, then it would follow that thinking be identical with the investigation of the truth value of propositions. There is no basis in LEIBNIZ's work for such a naive position.

LEIBNIZ's goal was much more ambitious: Our intellect, he says, is unreliable; as soon as we depart from experience, the intellect is confused immediately by darkness and by the diversity of the things. It is governed by deceptive conjectures and by vain opinions. Thus an organon of thinking, an organon mentis, is needed to guide us in making judgments and to lead us to new discoveries (21, p.187f). Clearly, LEIBNIZ did not plan to replace thinking by formal operations; rather, his intention was to use such operations as a **tool** for helping our thinking to achieve clarity (19, §5). In using characters, we can order our thoughts (18.2, p.481); characters are especially necessary to shorten and to summarize long trains of thoughts and to make them accessible to our limited mind (18.2, 481).

A major problem is that of controling such long trains of scientific thoughts. This is a problem of human memory which, at one moment, can only hold a restricted amount of information in view. Written language serves as an aid to the memory: a sequence of characters evokes a succession of associations. In reading a text, for example, only a limited amount of content is activated at a single moment; each association includes only so much information as the mind can hold actively at one moment of time. Texts, thus, can control long trains of thought. If, however, an artificial language should be an instrument of the human mind to invent new experience, its linguistic structure cannot consist of closed complex texts; instead it must consist of small texts capable of generating (new) small texts according to rules. LEIBNIZ recognized that a rule formalism can serve several purposes: For transmitting knowledge, correct sequence of associations must be induced by a sequence of symbol groups; such groups can be generated step by step in applying suitable rules. With such an instrument, the mind is directed in a two-fold way: first, the percieved symbols trigger associations for the content to be transmitted and, secondly, they provide at the same time information about which rule has to be used in the next step to get new symbols triggering again new associations etc. In following the rules strictly, the mind has a kind of Ariadne's thread to help it find its way through the labyrinth of thoughts. On the other hand, it is possible for the mind to follow the rules strictly because each idea can be transformed from the domain of mind into visible signs. Trains of thoughts are thus made comprehensible for the eyes of the reader, thus giving them certainty (21, p.187, p.196). According to LEIBNIZ, the success of mathematics is based precisely on its use of visual guide lines which can be taken in with the eyes and which, so to speak, can be grasped by hands (21, p.185; 20, p.335, p.351, p.420; 5 p.11, p.14, p.22, p.57, etc.). That is what LEIBNIZ had in his mind when speaking of ratiocinatio. Thinking, however, is knowledge-driven and therefore based on associations not necessarily triggered by language signs.

6.2. Misunderstandings about the relationship between natural and artificial language

It is a grave misunderstanding deeply rooted in modern epistemology, to think that form and content could be separated, i.e., that it should be possible to define forms (in the sense of logical calculi) independently on any content. This view assumes the existence of two different and independent steps. In the first step, the characters and formulas allowed in the system are **fixed,** and in the second step the meaning of the formulas is **defined** (29, p.56). Such a view, however, is incompatible with knowledge representation; translated into syntactic pattern recognition, this would mean first defining a grammar and then going to look for the patterns which could be described by it - a senseless undertaking. In artificial intelligence, a similar misunderstanding can be found. Knowledge representation is done here using a fixed formalism supplied mostly by the programming language selected. It is assumed that the formalism is general enough to hold all relevant knowledge. But such an approach is doomed to failure:

The form must be fitted to the content, not vice versa.

Where this principle is not observed, repairing mechanisms such as non-monotonic logic have to be installed.

According to a widespread view, LEIBNIZ intended his characteristica universalis to be an all-embracing logical calculus. This misinterpretation of his intentions rest on the unclear idea of knowledge representation outlined above but also on the ambiguous meaning of the word *general:* Characteristica universalis understood as a general artificial language for representing knowledge, can be interpreted in three ways: (1) as a general formal tool like the formalism of formal language, where special grammars must be inferred to represent the knowledge of a special domain; it can, however, also be interpreted (2) as a special grammar representing general, high-level knowledge. These interpretations do not contradict one another, because in the first one *general* is an attribute of the formalisms used, whereas in the second one it is an attribute of the knowledge to be represented. With respect to LEIBNIZ both interpretations are relevant: he describes a general approach, but he also attempts to carry it out with respect to numerous special domains, among them, the domain of logic. However, because LEIBNIZ intended his formalism to open up new experience, he could hardly start by developing a calculus without reference to experience. Thus, however general might be the domain he studied, the calculi he uses are always content related; they must never be interpreted posterior to their being established. There is, nevertheless a third meaning to *general*, namely that of an all-embracing logical calculus. This idea is frequently attributed to LEIBNIZ, but in fact it is nowhere to be found in his works.

It was apparently SCHLEIERMACHER[16] who introduced the frequently repeated claim, that LEIBNIZ's intention was to formalize natural language after the model of a mathematical calculus[17]. However, there is no evidence in LEIBNIZ's work for such a naive and utopian goal, doomed to failure from the start. Moreover, this interpretation is inconsistent with his writings on the German language[18], which, unfortunately, are largely ignored by the philosophers of language. Perhaps this erroneous view derives in part at least from LEIBNIZ's ill-advised attempts to create an „arithmetical language", an approach going back to DESCARTES' ideas[19]. In this approach, LEIBNIZ lets numbers function as words and multiplication as „grammar", and assigns to the numbers artificial syllables for the purpose of communication (20, p.277-279). The question, *can natural language be reduced to a calculus*? is answered in the negative by v. WEISZÄCKER and other authors, on the grounds, that, however desirable it might be for scientific purposes to state natural language more precisely, this cannot be done using an artificial one, because such a language always requires a natural language as a meta-language[20]. Of course, this argumentation is correct, but it does not go to the heart of the matter:

Not languages, only content can be formalized.

LEIBNIZ intention was to represent in artifical language the knowledge hitherto expressed in natural language; thus it is simply a matter of translation from one language into another, albeit that the target language must first be invented. This is a typical task a theorist is faced with in the course of his day-to-day scientific work.

Such translation is necessary in order to attain a language consisting of sentences which represent all and only all true sentences of a specific domain. In such a language, one can operate with symbols as representatives of real things, events or thoughts. Since grammar rules refer only to syntactic structures; operations with symbols are performed in a purely formal way, i.e., without, **during the formal operations**, taking into account the meaning of the symbols[21]. Because the philosophical view focussed only on this formal aspect, it concluded that the formalism as such must be contentless. The next step then was to conclude, that the formal system be completely abstract without any inherent meaning. But to represent knowledge, the formal language must be constructed in such a way that a „mechanical" manipulation of symbols is possible:

The schematic, formal use of symbols is not a presupposition of formalization, but rather its consequence.

If exactly all true sentences of a domain are represented by a formal language (that means especially, there is no sentence in the formal language which does not belong to the true sentences of the domain) then the domain is represented by this formal language without redundancy; it is a formalism optimally fitted to the content. In this sense v. WEIZSÄCKER calls such a formalism *pure information* (29, p.55):

When a formalization of a domain's knowledge is carried out correctly by means of a formal language, then syntax is identical with semantics.

Here *formal* does not mean *abstract* in its pejorative sense, rather it means: *judged according to (formal) rules*.

Many authors emphasize the richness of natural and the poorness of formal languages. They regard formal languages as an atrophied versions of natural languages, and argue that complete formalization of knowledge would „kill" language; i.e.: it would thwart communication. Such argumentation confuses *communication* and knowledge *representation*. Their distinction parallels the distinction between thinking and ratiocinatio: Communication requires a language capable of describing (nearly) all possible contents; for a language to have such capacity, among other things, syntax and semantics must (nearly) be decoupled. It is a direct consequence of this feature that in such a language errors and nonesense can also be expressed, since grammatical correctness no longer guarantees meaningfulness. In order to be free to express a wide range of content, one must risk making mistakes. Real knowledge is always unambiguous; thus there is no room for an interpretation, and by formalizing it, no disadvantage arises. If there is no redundancy, there can be no errors. Ratiocinatio is bound to the content of the formal language under consideration. Thinking may go astray, but ratiocinatio cannot[22]. Natural languages and formal languages should not be played off against each other; they serve different functions:

Language:	natural language	formal language
Goal:	communication	knowledge representation
Degree of coupling between syntax and semantics:	low	100%
Range:	nearly all possible contents	exactly one domain can be included

Although contrasting with another, these functions are part of in science; and, because of their contrast, they require different kinds of language.

The hope of remedying the natural language's inadequacies by substituting for it an exact logical language is thus a fatal error, and it is WITTGENSTEIN's tragedy that he fell victim to this error in attempting to solve problems of knowledge representation by means of logic. In his early *Tractatus logico-philosophicus*, he called for an artificial logic-oriented language. However, by its very nature, there can be no language problems in a formal language; and in natural languages the real problems are not linguistic but content related, since in natural language syntax and semantics are but loosely coupled. What needs to be clarified, is not the language but rather the content contained in the human mind, and that is definitely not a language problem. In a formal language, as described above, the structure of the represented domain corresponds to the structure of language. However, WITTGENSTEIN's reverse assertion *the structure of the world corresponds to the structure of the language* is mistaken, for language must always be fitted to content. On the supposition that language precedes reality, WITTGENSTEIN's „world" is dissected into things and facts in order to fit the requirements of the language. The later WITTGENSTEIN recognized the error of his earlier approach, but, in his *Philosophical Investigations*, he goes to the opposite extreme, reducing philosophy now to natural language. Both approaches represent the classical way out, to escape he problem of knowledge representation. Because this problem is prevalent in sciences, both schools of WITTGENSTEIN's followers, the advocates of logical empiricism and ideal language philosophy on the one hand, and the advocates of ordinary language philosophy on the other, miss the mark and fail to meet the real needs of contemporary science. In order to exercise the ars iudicandi and the ars inveniendi in a language, syntax and semantics must be identical. However, as explained above, then this language would be unsuitable for communication. LEIBNIZ needed therefore in addition to his characteristica universalis another language appropriate for scientific communication[23]. Natural languages are based on quite sophisticated grammars, and they include some inconsistencies so that it is justified to look for a more regular language. Based mainly on Latin, LEIBNIZ dealt with the development of such languages which he called *lingua philosophica, lingua rationis, lingua universalis*[24]. It should be not a formal, but a simplified natural language open for each content. His intentions are realized in our times in three quite different fields all characterized by using a standardized language: (1) in the field of artificial universal languages for communication like ESPERANTO or UNITARIO[25]; (short-hand-systems also belong to this lineage); (2) in the field of computerized knowledge representation found in formalisms like semantical networks, or rule-based logical systems, and (3) in the field of Analytical Philosophy as so-called logical grammar (17, p.222ff).

7. Summary and Conclusion

Against the background of formal languages and syntactic pattern recognition, seven elementary principles have been introduced for representing knowledge in an artificial language:

An analysis of the domain under study has to be performed to get the basic elements and their relations (principle 1, primitive selection). In assigning corresponding characters to them, the supposition is to compose complex objects from simple ones observing isomorphy (principle 2). The essential step in representation is to distinguish a subset from a carrier set (principle 3); in the formal language approach the distinction is done by a grammar. However, above all in order to make possible a representation, the questionable content must have some structure (principle 5). The structure of the valid combinations is represented in rules so that a finite number of characters together with a finite number of rules include all the knowledge of a domain. To permit formal operations, the artificial language must be developed in such a way that syntax and semantics are identical (principle 6), and for recursivity and because knowledge is characterized by different kinds of ordering relations, the formalism must allow for distinguishing entities of different levels of abstractions (principle 7). Finally, concerning the use of the represented knowledge, clear conditions for starting and stopping must be defined, and each pre-text must give information about how the immediately following characters are be interpreted (principle 4, parsing requirements).

In discussing the LEIBNIZ project in the context of syntactic pattern recognition, we demonstrated that LEIBNIZ had recognized all these principles, with the possible exception of principle 7, and that his project deals in fact with knowledge representation. Syntactic pattern recognition, as an example for the latter, can therefore be seen as a proof that, at least within a specific domain, the LEIBNIZ project can indeed be realized. Admittedly, the domains of knowledge involved here are very small. In order to include more extensive domains, obviously more expressive representation tools are needed such as are found especially in mathematics. The latter could be applied particularly successful in physics, so that it can be said that the LEIBNIZ project is realized today in the theories of physics. The principles of such kinds of knowledge representation, the role of algorithms and the problem of undecidability must be left for a subsequent paper. For the present, our discussion of the elementary principles must suffice to correct some widespread misunderstandings in the context of LEIBNIZ's characteristica universalis. Nothing was misunderstood in philosophy so completely and for a so long period of time than the role of knowledge representation in epistemology which can best be seen in the way the LEIBNIZ project was adopted.

On the one hand, reinforced now by the celebration of his 350th birthday, LEIBNIZ is praised as one of the great philosophical geniuses of all time. On the other hand, he is accused of quite simple errors incompatible with philosophical genius. In fact, such contradictions should lead scholars to take a criticical look at their own positions. Many of their objections are derived from a narrow, lopsided point of view, failing to take into account that LEIBNIZ was concerned with the whole spectrum of knowledge in his age. Although, by comparison to our own times, the sciences LEIBNIZ knew were still in their nacency, one does no justice to his work if it is jugded and interpreted by means of special philosophical doctrines ignoring, in particular, the results of temporary (computer) sciences. LEIBNIZ had to content himself with theoretical studies. However, it requires little phantasy to imagine how many things he would have realized with a modern computer.

It is hardly conceivable that LEIBNIZ should have devoted about fifty years of his life to pursuing a philosophical phantom. It is quite dubious to understand his project as a problem like the FERMAT's conjecture, for the proof of which lifetimes have been spent in vain. LEIBNIZ himself considered his representation concept to be an invention, and he attempted to use it in all domains. In fact, it forms a leitmotif, directing his research in specific directions, leading him to pursue certain lines of study and to avoid others. In this it is rather like the law of conservation of energy. Once such a law is recognized by scientists, it acts as a guideline for their subsequent work, influencing both thinking and behavior, e.g., in avoiding projects like the search for a perpetuum mobile. Even where such regulative ideas are not explicitly mentioned in texts, they can well be at work. Probably in this way LEIBNIZ's representation concept has to be understood. It would be an attractive task to pursue the influences of this concept in the diverse areas of his thinking. It would be interesting, for instance, to investigate the ways the concept underlies his factorization of the basic arithmetical operations into elementary mechanical operations for constructing his four-species machine. His monadology is another area possibly influenced by his representation concept and not vice versa as sometimes asserted. Indeed, LEIBNIZ's ideas here prove to be so central to his thinking, that it can well be asked, if they are not in fact the real driving force for his immense creative power? If this be the case, then possibly even today these ideas can be a source of creative impetus well worth listening to.

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Notes

1 The author could not be ascertained.
2 Against this principle it might be objected that thoughts are not discursive and therefore cannot be dissected. This may be true in non-scientific domains; but language is of its very nature discursive. Thus, either the thoughts must be fitted to the language requirements or their representation must be abandoned. On the other hand, it is argued (sometimes by the same people who made the above objection) that thinking would be determined by language. They do not realize that from the discursive nature of thinking, and, as a consequence, the discursive nature of thoughts follows from their objection. The representation principle 1 makes no general assumption about either the nature of thoughts, or of thinking; it supposes only that there can be discursive thoughts.
3 "I call a character a visible sign representing a thought. Ars characteristica is the art of creating and arranging characters in such a way that they reflect thoughts, i.e., that the characters are related one another in the same manner as the thoughts are related to each other. A term [of such an artificial language] is the concatenation of characters which stands for the object to be represented. The law for representation is: Just as the thought of a [complex] object to be represented is composed of the thoughts of those [primitive] objects, so also the term of the [complex] object must be composed of the characters assigned to those [primitive] objects1" (1, p.80f; similar: 5, p.192).
4 There are no clues in the literature for the need for further representation principles; by and large, the isomorphy principle is taken to be the only principle needed (16 p.68, p.105, p.148 and passim; 3, p.10; 27, p.112; 26, p.313; etc.).
5 With the aid of the transmission principle the objection of psychologism can be refused as mentioned, e.g., by (17, p.41f). It is impossible to speak about language without speaking about the procedures the language elements process. One can convince oneself of the correctness of this assertion by attempting to model language understanding on a computer.
7 The loose coupling has a direct link to the linguistic relativity thesis held by v. HUMBOLDT, SAPIR und WHORF.
8 For more details see the textbooks, for instance (7 or 28).
9 String representations are adequate for describing objects or other entities whose structure is based on relatively simple connections of primitives. Alternative representations of pattern structures are, e.g., trees and webs.
10 For more details see, e.g., (4, 10).
11 With respect to concepts: (22, p.15f; p.24f; 18.1, p.192-200); with respect to geometry: investigations on the analysis situs (6, p.141-171, p.178-183).
12 (20, 155). Quite absurd is WITTGENSTEIN's paraphrase: "If we speak about the location where thinking takes place, we are entitled to say that this location is the paper on which we write, or the mouth which is speaking" (30, p.23).
13 "We can perceive the world only through symbolic representations" (12, p.12).
According to KRÄMER, the epistemological idea of the LEIBNIZ project consists in: "All thinking is carried out in the medium of signs ... The steps of thinking realize themselves as stepwise construction and reconstruction of signs" (16, p.138).
More examples are found in(3, p.9; 26, p.315, p.318; 22, p.11●; etc.).
14 (5, p.31; similar 5, p.204; 20, p.155).
15 In the *Dialogus de connexione inter res et verba* LEIBNIZ writes: "Imo si characteres abessent, nunquam quicquam distincte cogitaremus, neque ratiocinaremus", i.e., he distinguishes very well between *cogitatio* and *ratiocinatio.*
16 In his speech in the academy on July 7, 1831 (possibly influenced by HEGEL). See also: (23, p.275).
17 (23, p.249f, p.250, p.275 et passim; 14, p.141; 29, p.48).
18 „Unvorgreiffliche gedancken, betreffend die ausübung und verbesserung der teutschen Sprache" sowie „Ermahnung an die Teutsche, ihren Verstand und Sprache beßer zu üben, samt beigefügten Vorschlag einer Teutschgesinten Gesellschaft", published, e.g., in (19).
19 DESCARTES's letter to MERSENNES from Nov. 20, 1629.
20 (29, p.56, similarly: p.59; 23, p.294 et passim).
21 (16, p.2, p. 57, similarly: 16, p.68, p.86, p.138 et passim).
22 One is reminded here of SCHILLER's: „Where much freedom there is much room to move, but certain is the narrow way of duty."
23 The philosophical language is often equated with the characteristica universalis (e.g., 3, p. p.10f, p.25). COHEN (2) has tried to show that LEIBNIZ was not so original as he is normally made out to be. COHEN calls attention to LEIBNIZ's predecessors, who like DALGARNO and WILKINS had before him invented universal languages. But COHEN fails to realize that LEIBNIZ was not primarily concerned with languages of this type and is therefore surprised to find that LEIBNIZ appears not to take the writings of DALGARNO and WILKINS seriously. According to LEIBNIZ, DALGARNO and WILKINS had not sufficiently grasped either the magnitude of the matter or its true use, "for their language or character achieves but one thing alone, convenient communication between those separated by language, but, as I conceive it, the true characteristica realis, would be thought of as one of the most apt instruments of the human mind, bearing an invincible power for discovery, memory and judgement" (5, p.7).
24 E.g., 20, p.280-282, p.288-290, p.432-435. The fragment (20, p.351-354) deals at first with the characteristica universalis and changes then abruptly to the philosophical language. It appears that the editors here merged two unconnected fragments into a single text.
25 Recently, automated translating became interested in such languages to reduce translation programs: instead of translating n languages into n-1 other languages consuming $n \cdot (n-1)$ programs, only $2 \cdot n$ programs are required when using an artificial language as a mediator. Thus, for example, a German text is translated first into an artificial language, from which it can then be translated into all other languages.

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