Computational Explication
of Intensionality

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Summary

An obvious requirement for a language understanding system of practical use is that the system tells "the truth and only the truth", and so called "intensionality" of natural languages is one of the main obstacles on the way to formulate a strict definition of truth for natural languages. Although it may be possible to account for it using the apparatus of formal logic, in the present state of art it seems more useful to describe this property of natural languages in the terms of computer science. The paper presents the problem of intensionality, shows its relation to some aspects of programming languages and outlines the way in which the intensionality is to be accounted for in the "multiple environments model of natural language" which is being developed by the author.
**Introduction**

Computational linguistics has already achieved such a stage of development that it is feasible to construct systems capable of conversing with humans on subjects restricted to narrow, specific domains. Although there is still much to be done as far as efficiency and other features are concerned, it seems to be the time for considering the problem of reliability in strictly logical sense, i.e. the problem of truth. The importance of the trustworthiness of a system can be hardly underestimated. The problem of truth has been discussed by philosophers since centuries; one of the fundamental difficulties encountered by them on the way to define precisely the notion of truth was so called intensionality of natural languages. There are several aspects of intensionality. The most discussed one is the fact that there are sentences which change their logical value to the opposite when a sub-expression of such a sentence is substituted by another expression but with the same referent.

The present paper aims at explaining the nature of this and similar facts in the framework of the multiple environments model of natural language which is being developed by the author. The basic ideas of this approach have been presented in (Bien 1975) and (Bien 1976); the reader is not assumed to be familiar with those papers.

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**The problem of intensionality**

The problem of intensionality has been introduced into the modern philosophy of language by Frege (1892). He suggested to distinguish the sense (meaning, in German "Sinn") and the denotation (nominatum, in German "Bedeutung") of a name and he noticed that for the truth-values of some sentences both the sense and the denotation of their constituents are relevant. He used "the Morning Star" and "the Evening Star" as an example of expressions which have the same denotations (i.e. the planet Venus) but differ in their senses; therefore the problem is also known as the paradox of the Morning Star and the Evening Star. Frege's solution was to recognize sentences which create the "oblique context", and to assume that a denotation of a name in an oblique context consists of its sense. In other words, substitution of
a name in an oblique context by a name with the same proper denotation does not change the truth-value of the sentence in question only if the names has also identical senses. This is quite a good rule-of-thumb for handling "oblique sentences", but unfortunately the notion of sense is still very difficult to formalize; this made some philosophers to reject Frege’s theory. Among them was Bertrand Russell, who discussed the problem of intensionality first in (1905), formulating his famous example (referring to an authentic fact), quoted here in the version of Church (1965:5)

(1) George IV once demanded to know whether Scott was the author of "Waverley".

(2) George IV once demanded to know whether Scott was Scott.

It is evident that (1) and (2) has different truth-values, although the only difference between them consists only in the substitution of the expression "the author of Waverley" for an expression with the same denotation, i.e. "Scott". Russell developed a radically different theory to account for the facts pointed out by Frege; this theory was applied e.g. in "Principia Mathematica" (Whitehead, Russell 1910). In this work some properties of a function of propositional functions has been defined (1910:72). One of them, called extensionality, consisted of the possibility to substitute the arguments of a function by any "formally equivalent" (i.e. possessing the same denotation) expressions. The property of being non-extensional was called intensionality; the term is derived from the Latin word "intensio" i.e. "meaning", "content". As far as I know, this is the first use of the term "intensionality"; the term has become popular and it is used also in other languages (e.g. Polish "intensjo-nalność"), although not always in exactly the same sense. I use it in the sense of Russell as generalized by Ajdukiewicz (1967:63) "The expression Ε₁, which contains no free variables, is an intensional expression if it can be transformed into a non-equivalent expression Ε₂ by replacing one of its members by an expression which is equivalent with that member".

"The expression Ε₁, which contains one or more free variables, is an intensional expression if two non-equivalent expressions can be obtained from it by substituting for each of these variables two different but equivalent constant expressions".
The equivalence of expressions is understood here as the equality of denotations and "member" means a sub-expression recognized in a given expression according to the rules of syntax.

Because of the lack of formal apparatus suitable to handle intensional expressions, the effort was first of all devoted to avoiding them in formal languages being constructed as well as in formal analysis of natural languages. It resulted in stating more and more subtle conditions sufficient for preserving the truth value of an expression during substitutions for its member. One of the early approaches (e.g. Carnap 1934) consisted in treating the entire phrase in the oblique context as a name; it means practically disallowing any substitution in such a context, because every change inside it generates quite a new name. This was obviously not adequate, because it gave no clue why sentences usually preserve their truth values if the substitution does not change the sense of a member. This inadequacy was realized early by Quine (1953) who stated more carefully that such phrases are only similar to names created by means of quotation marks; the similarity consists in the "referentially opaque" use of the names in both cases, while outside the "opaque contexts" the names are used "purely referentially". Quine did not suggest any solution of his own, and his treatment of examples was rather simplistic. In particular, he made strong and sometimes strange assumptions about the persons mentioned in examples, e.g. he said (Quine 1953:141) that

(3) Philip is unaware that Cicero denounced Catiline.

is "no doubt false". Similarly, he considered

(4) Philip believes that the capital of Honduras is in Nicaragua

to be always false, while at least three interpretations of (4) allow it to be true. First, Philip may be a child, who does not know that a capital of a country always is on the territory of the country. Secondly, Philip may not be aware that Honduras is a country and not a province of Nicaragua. The third interpretation is disputable, but it is possible to use (4) to transmit the relevant part of the message

(5) Philip believes that Tegucigalpa is in Nicaragua

to a person with poor knowledge of geography, where the relevant
part is that Philip has a highly erroneous belief about some important town.

An attempt to formulate a relatively precise criterion for allowing and disallowing substitutions in oblique contexts, was made by Carnap (1956, cf. Pelc 1960), who introduced the notion of \textit{intensional isomorphism}, defined in the following way (1956:56): "if two sentences are built in the same way out of designators ..., such that any two corresponding designators are L-equivalent, then we say that the two sentences are intensionally isomorphic". By the L-equivalence of designators Carnap means that the equality of objects designated by them follows from the rules of the given language, and is not the matter of empirical facts (in other words, the L-equivalence is a special case of synonymy). Carnap applies the notion to one of the most important type of intensional sentences, i.e. to belief-sentences of the type:

"John believes that D" in language S which are explicated in the following way (1956:62):

"There is a sentence $s_1$ in a semantic system $S'$ such that

a) $s_1$ in $S'$ is intensionally isomorphic to D in S and

b) John is disposed to an affirmative response to $s_1$ as a sentence of $S'$".

In the above-given explication Carnap aimed at two goals. The first one was to account for cases when John does not know language S; it was achieved by introducing the semantic system $S'$. The second goal was to reflect the fact that we are not permanently aware of all our beliefs; however, the formulation, "is disposed to an affirmative response" does not, in my opinion, solve the problem.

From the explication it follows that a condition sufficient for preserving the truth-value after the substitution of $D'$ for D is:

if "John believes that D" is true and $D'$ is intensionally isomorphic with D then "John believes that $D'$" is also true. Carnap's (1956) method is much better approximation of the solution than that of (Carnap 1934) and (Quine 1953) but it is still unsatisfactory. What we would really like to have is the condition both sufficient and necessary. From the following example, quoted after Ajdukiewicz (1959), it can be seen that none of the above-mentioned solutions, including that of Frege, states the necessary condition for changing the truth values of sentences:
(6) Caesar knew that Rome lies on the Tiber.
(7) Caesar knew that the capital of the Republic lies on the Tiber.

The sentences (6) and (7) are both true, although the respective clauses in the oblique context are neither intensionally isomorphic nor have the same sense.

The problem of sufficient and necessary condition for preserving the truth value during a substitution is only one aspect of intensionality. Another, more subtle one is related to the ambiguity of intensional sentences. The ambiguity was already noted by Russell (1905) who distinguished primary and secondary use of a denoting expression. In the primary use

(8) I thought your yacht was larger then it is.

means

(9) The dimensions which I thought your yacht had are greater then the dimensions which your yacht really has.

while in the secondary use, which is assumed in the ironic answer

(10) No, my yacht is not larger then it is.

the sentence (8) is understood as

(11) I thought that the dimensions of your yacht are greater than the dimensions of your yacht.

The ambiguity was realised later by Quine who discussed (1960:142) two interpretations of the sentence

(12) The commissioner is looking for the chairman of the hospital board.

If the dean by recent appointment and unknown to the commissioner is the chairman of the hospital board, the sentence (12) is considered respectively as equivalent or not equivalent to

(13) The commissioner is looking for the dean.

Ajdukiewicz (1959, 1961) argued that such ambiguity is systematic; he attributed two interpretations, with the truth value respectively true and false, even to the sentence

(14) Caesar knew that the capital of the Popes lies an the Tiber.

McCawley (1967) also considered the ambiguity to be systematic; he correctly recognized it as a case of the "de re" and "de dicto" distinction, applied usually to modal sentences. The distinction, which was introduced in Middle Ages, can be traced back to Aristotle, who has discussed the following examples, quoted after (Kneale 1962):
It is possible for a man who is sitting to walk.

It is possible for a man who is not writing to write.

The fact that the "de re" and "de dicto" distinction may be applied also to non-modal sentences was illustrated by McCawley in the following examples:

(17) Boris said that he didn't kiss the girl who he kissed.

(18) Willy said that he has seen the woman who lives at 219 Main St. but the woman he had in mind really lives in Pine St.

(19) Willy said that he has seen the woman who lives at 219 Main St. but he doesn't know that she lives there.

Most of the authors mentioned above attributed the ambiguity to the two different readings of the verb, the rest of them did not discuss the problem at all.

The essential progress was made by the works of Montague (Montague 1972, Thomason 1974), he realised that intensionality is an intrinsic feature of natural language and it is useless to try to avoid it. In consequence, he developed a formal intensional language such that natural language expressions can be translated into it. As it has been noticed by Hintikka (1973:209), the Montague grammar accounts correctly for the "de re" versus "de dicto" ambiguity, allowing the $2^n$-fold ambiguity for a sentence with $n$ noun phrases in the scope of an oblique context. Actually, the grammar handles properly also nested oblique contexts; allowing e.g. 3 noun phrase interpretation for a noun phrase embedded in two oblique context (Juškaszewicz 1982). Our arguments against the Montague's approach are of three kinds. First, the Montague grammar does not account for all the ambiguities, because it does not allow to split a complex noun phrase into different possible words; cf. the discussion of (32) below. Secondly, all present-day logic approaches to natural language does not explicate correctly the notion of belief: it is always assumed that if $A$ believes that $X$ and $X$ is logically equivalent to $Y$, then $A$ believes that $Y$. Actually, there may be several reasons why $A$, who is aware of $X$, will not be "disposed to an affirmative response" to $Y$; e.g. the inference required may be too sophisticated or time-consuming. Last but not least, although the task of constructing a model of natural language expressed in formal logic is very appealing, I am afraid that it is not feasible as yet. It should be remembered that e.g. in mathematics there were centuries of
research before theoretically solid foundations of mathematics have been successfully created. Therefore, although the research in formal linguistics is not to be neglected, the main effort should be aimed rather at the linguistic models of immediate practical importance. As the conceptual framework for such a model I propose computer science, and one of the reasons is the intensionality of programming languages.

In the present paper we will limit our discussion to the above listed cases of intensionality, because they are crucial ones and every adequate solution of these problems in easily extensible to cover also "names with empty denotation", "quantifying in" and other similar problems.

Intensionality of programming languages

The Ajdukiewicz definition of intensionality is relative to the notion of equivalence. It is quite natural to consider two programming language expressions as extensionally equivalent if and only if they deliver the same value when evaluated.

Evaluation of an expression is always performed in some environment (Wegner 1968), which specifies variables which can be accessed during the evaluation and the values of these variables. Most expressions are open, i.e. they contain free variables and therefore they are sensitive to the environment which they are evaluated in. On the other hand, environments are also sensitive to expression evaluation because the values of variables may be changed during the evaluation; such a change is called the side-effect of the evaluation. Obviously, two extensionally equivalent expressions may differ in their side-effects. For example, the following two expressions of Algol 68 (Lindsey, Meulen 1971) both evaluate to 4, but differ in their side-effects; the first one sets the variable i to 4, the second one - to 2.

\[
\begin{align*}
(i := 4) \\
(i := 2) \times 2
\end{align*}
\]

Now it is intuitively clear when a programming language expression is intensional. It is sufficient for it that there exists at least one open subexpression which is preceded by at least one subexpression. Let us call A the open subexpression, and B the subexpression preceding it. If we substitute a new expression C for B, and C is extensionally equivalent to B but it has different side-effect on the very variable to which A is sensitive, then the who-
le expression will change the value; that means that the expression is intensional. It is not easy to formalise the rule given above; establishing for a given expression to which variable it is sensitive or which variable is affected by it, may require the analysis of many possible flows of control during the evaluation of the expression. This task resembles to some measure the "stop problem" and it is quite possible that in general the problem of intensionality is in this sense undecidable. Nevertheless, for practical purposes it is sufficient to discuss only special cases of the problem, e.g. the case of such expressions for which only one flow of control is possible. I shall call such expressions non-alternating. For the sake of simplicity, it is reasonable to demand that the expressions under consideration are also non-redundant, i.e. that every variable influences the value of the expression. For the non-alternating and non-redundant expressions it is possible to recognise statically the relevant properties. In particular, it is possible to establish the input and output nomenclatures of the expression. By the nomenclature of an expression I mean all names of variables, procedures etc. contained in it; by the nomenclature of the program point occupied by an expression I mean all the names accessible by the expression. By the input nomenclature of an expression I mean all the names, which are used to pass values to the expression under consideration; by the output nomenclature I mean the names of all objects (usually variables) which receive a value during the expression evaluation. We need additionally the notion of the sensitivity nomenclature of a subexpression of a given expression or a respective program point; it is the union of the input nomenclatures of all those subexpressions, which are to be evaluated after the subexpression under consideration.

For example, in the Algol 68 closed clause

\[
\begin{align*}
\text{int } i, j, k; \\
\text{\ldots} \\
(j := j + k) * (i + 10) * k
\end{align*}
\]

the nomenclature of the program point occupied by the expression \((i := j + k)\) consists in the variables \(i, j\) and \(k\); its sensitivity nomenclature - in the variables \(i\) and \(k\); the input nomenclature of the expression consists in the variables \(j\) and \(k\), its output nomenclature - in the variable \(i\).
Let $A$ be a non-alternating and non-redundant expression, $X$ a non-alternating and non-redundant subexpression of $A$, $Y$ another non-alternating and non-redundant expression, and $B$ the expression obtained from $A$ by substituting $Y$ for $X$. If the nomenclature of the program point occupied by $Y$ contains the nomenclature of $Y$, then it is possible to evaluate $Y$ successfully and to check whether $X$ and $Y$ are extensionally equivalent. If the values of $X$ and $Y$ are equal, then the expressions $A$ and $B$ are extensionally equivalent on the following condition, which is both sufficient and necessary:

If the name of a variable belongs both to the input nomenclature of $Y$ and to the sensitivity nomenclature of the program point occupied by $X$, then its value after the evaluation of $Y$ is the same as its value after the evaluation of $X$. In other words, if the value of a variable is changed as a side-effect of the $X$ evaluation and this side-effect is relevant for the evaluation of the rest of $A$, then the evaluation of $Y$ should produce the same side-effect on this variable to ensure the equality of values delivered by the evaluations of $A$ and $B$.

For example, substituting for $(i := j+k)$ the expression $(i := j+k+1; j+k)$ will change the value of the clause under consideration, while substituting for it the expression $(i := k+j)$ will preserve the value.

The programming languages used for Artificial Intelligence research have specific primitives for environments manipulation, like contexts of associative data bases or filters of pattern matching processes. The notions introduced above can be easily redefined also for these languages; therefore we can use our rule for preserving the value under a substitution also for expressions coded in such languages as e.g. FLANNER, QA4 etc. (Bobrow, Wegbreit 1974).

Multiple environments model of natural language

There is a widely accepted assumption that a sentence refers directly to some state of affairs in the real world, and only in a secondary way carries some information about the sender. This assumptions underlies e.g. the Morris (1938) definition of syntactics, semantics and pragmatics, where semantics is just the intermediary stage between syntax and pragmatics. In reality an utterance transmits exclusively some data about its sender, in particular about his beliefs or pretense. We interprete an
utterance as a description of some aspects of the real world only on the basis of additional assumption, e.g. that the sender is in a position to know the facts described in the utterance, that he does not lie etc. Therefore it is quite conceivable that a theory of language is divided into syntactics, pragmatics and semantics in this very order, where semantics is considered as the description of general aspects of speech acts performed according to the rules of pragmatics.

One of the main features of the multiple environments model (Bień 1976a) is that it is based on this way of thinking about communication acts. It means in practice that we are to keep track of the beliefs and their changes for all the participants of the communication act. For every utterance we have to consider at least the state of minds of the sender and the addressee; in some cases it is necessary to take into account also the state of minds of persons mentioned in the utterance. As we follow the approach of Davies and Isard (1972) of treating utterances as programs, the minds of persons are represented by different environments in the computer science sense. The process of understanding an utterance is treated as the evaluation of the utterance in respective environments. The meaning of an utterance is represented as some relationships holding between some objects. The surface representation of a relation (usually a verb) I shall call the pivot, and the representations of objects (usually nouns or noun phrases) I shall call designators. The objects in question may be images of real physical objects as well as abstract or fictitious notions. Designators can be either elementary or compound. Every designator has its meaning, i.e. a procedure representing the characteristic function of the set of its denotations. The meaning of a designator can be assigned to it in several ways.

In every society there are some objects of great importance for it, and this causes the need for designators referring to these objects. The meaning of such designators has to be rather stable; usually all the society members know it, and the great part of such designators is learned in the childhood. On the other hand, objects important enough for a society to deserve their own designators usually are numerous members of relatively homogenous classes; in such cases the meaning of the designator consists in listing the characteristic features of the whole class.
designators are traditionally called common names and they form the majority of the designators used in natural languages. Common names have two uses, relatively clearly separated. They can be used to refer to a particular object of the class, or to any object of it. The first use is often called referential, and the second one attributive; The phenomenon is also referred to as the specific versus non-specific distinction. For example

(20) Jack wanted a kitten.

may mean that Jack wanted a particular kitten, e.g. that owned by Bill, or that Jack wanted to keep any kitten he could get. Similarly, in the utterance

(21) The electric lamp is a useful invention.

"the electric lamp" may mean a particular device talked about, or the whole class of electric lamps.

We account easily for the difference between referential and attributive use of designators, assuming that the meaning of a designator is evaluated in an incremental way. By the incremental evaluation I mean such a process of computation, which may be suspended any time when some prerequisite conditions are not fulfilled. If the evaluation of a designator is completed, then we have a case of its referential use. If the evaluation is not even started for some reasons, then it is the case of strictly attributive use.

Besides of common names there also proper names. Following Kripke (1972), we consider the necessity of fixing the reference to be the essential feature of proper names. Because proper names usually refer to objects or persons not known by the majority of the society, they do not have any generally accepted meaning. If we are to understand e.g.

(22) John has come.

we need to have the referent of "John" already fixed. To be strict, "John" has some residual meaning, which is available even completely out of context: that it designates an object referred in some milieu by "John", that the object is probably called "John", that it is probably human and probably male. This explains why it is sometimes reasonable to use proper names attributively, e.g.

(23) Mount Everest is Chomolungma.

If an individual is largely known in the society, then his
proper name may have quite rich meaning, which situates it on
the borderline between proper and common names, like e.g.
"Napoleon" in

(24) He is a little Napoleon.

All the above discussion of elementary designators is basically
valid also for compound designators, usually called descriptions.
They are usually created ad hoc, although some of them are
lexicalised proper names, e.g. Holy Roman Empire, or common
names, e.g. "letter-box". They can be used both attributively
and referentially, e.g.

(25) The Smith murderer is insane.

may concern a particular person guilty of the murder or it may
concern anybody who has murdered Smith.
The evaluation of compound designators is additionally complica-
ted, because such designators can be decomposed into parts in
such a way that every part is to be evaluated in a different
environment.
For the sake of completeness of the discussion it should be
mentioned that pronouns can be interpreted as a special kind of
proper names, which require fixing the reference again and again
for almost every occurrence of a pronoun.

Intensionality and multiple environments

We will discuss several examples of intensionality and observe
when and how the value of a sentence is changed by a denotation
preserving substitution.

(26) The commissioner met the chairman of the hospital board.

(27) The commissioner met Jones.

(28) Smith met the chairman of the hospital board.

(29) Smith met Jones.

Assuming that Smith is the commissioner and Jones is the chairman
of the hospital board, we have above the results of denotation
preserving substitutions. If the sender knows the names of the
commissioner and the chairman, the all the utterances carry the
same information about the sender. If the addressee trusts the
sender, then he updates his beliefs to be in accord with the
state of affairs represented by the utterance. For the purpose
of updating he evaluates the utterance, in particular its
designators. If he knows that Smith is the commissioner, then
both "Smith" and "the commissioner" evaluate to Smith;
therefore e.g. (26) and (28) are for him equivalent. Analogically, if he knows that Jones is the chairman of the hospital board, then e.g. (26) and (27) are for him equivalent. The Quine's example

(30) The commissioner is looking for the chairman of the hospital board.

is more complicated due to the two readings of the verb "look for". One of them I call objective; it means "to perform an action aimed at finding an object". I call the second reading subjective; it means "to intend to find an object", and this requires that the person in question has a mental image or the object looked for, but it does not presuppose the existence of the object. According to the first reading (30) and (31)

(31) The commissioner is looking for the dean.

are equivalent as long as both the sender and the addressee know that the chairman is the dean. According to the second reading the utterances (30) and (31) are obviously different, because looking for anybody who is the dean is quite different from looking for anybody who is the chairman of the hospital board. Our next example is

(32) Philip believes that the capital of Honduras is in Nicaragua.

Here we have to consider three environments: the beliefs of the sender, the beliefs of the addressee and the beliefs of Philip. The pivot of the main clause, i.e. "believes", is to be evaluated primarily in the sender's environment and secondarily in the environment of the addressee, and the pivot of the subordinate clause is to be evaluated in the Philip environment. The choice of the suitable environment for the designators is much more complicated. The utterance (32) may be intended to mean that Philip realises what is Honduras and what is a capital, but nevertheless he believes that the capital of Honduras is in Nicaragua because of his erroneous beliefs about Nicaragua. On the other hand, Philip may know what is Nicaragua and what is a capital, but he may know nothing about Honduras, and therefore he may see no contradiction in his belief. The next possibility is that Philip believes that Tegucigalpa is in Nicaragua, but he does not know that it is the capital of Honduras while the sender, on the contrary, does not remember the name of the capital of Honduras but he knows that Philip
believes this town to be in Nicaragua. There are still some possibilities left, but it is enough to see what they come from. All the different interpretations discussed above are derived by different ways of evaluating the designators. The first interpretation assumes that "the capital of Honduras" is evaluated in the Philip's environment, what presupposes the respective knowledge on the part of Philip, and the proper name "Nicaragua" in the sender's environment; in consequence, the Philip's environment need not contain the knowledge that Nicaragua is a country.

Next, we can assume that "the capital of Honduras" is divided between two environments and to evaluate "the capital of" in the Philip environment and the "Honduras" in the sender's environment; respectively, the Philip's environment need not contain the knowledge that Honduras is a country. Next, we can evaluate the whole phrase "the capital of Honduras" in the sender environment etc.

Obviously, some of the interpretations are more natural than others; out of context, those two interpretations are particularly preferred, which are equivalent to the "de re" and "de dicto" interpretations. Our next and the last examples are the Ajdukiewicz's sentences

(33) Caesar knew that the capital of the Republic lies on the Tiber.

(34) Caesar knew that the capital of the Popes lies on the Tiber.

Because "know" is a factive verb, the pivot of the subordinate clause is to be evaluated in both the environment of Caesar and the sender. There are several possibilities for evaluating the designators, but all the possibilities which assume the evaluation of "the Popes" in the environment of Caesar are bound to fail because "Popes" simply lack any meaning in the Caesar's environment.

Conclusions

I hope to have shown that the earlier treatment of the intensionality was too simplicistic. In fact, an utterance taken out of context has practically always several interpretations. Their number depends not only on the number of designators and the number of environments available for the evaluation of designators (these factors were recognised already by Montague), but also on the complexity of designators.
The problem is obscured by the fact that we rarely discuss an utterance really out of context. Usually we assume that it is uttered by an adult with a typical cultural background etc. Such implicit assumptions rule out some interpretations and cause some interpretations to collapse into single readings (if some of them happen to be incorrect, usually a misunderstanding occurs). Nevertheless, from the theoretical as well as from the practical point of view all the possible interpretations should be taken into account.
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