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What is Formal in Formal Semantics?

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ABSTRACT

Formal semantics is understood either as a formal analysis of semantical features of natural language or as model-theoretic semantics of formal(ized) languages. This paper focuses on the second understanding. The problem is how to identify the formal aspects of formal semantics, if we understand 'formal' as 'independent of content'. This is done by showing that the form of semantical interpretation of a language L is given by its syntax and the parallelism of the signature of L and its interpretative structure SI. However, the content of interpretation, that is, the way of correlating of L-expressions with extralinguistic items depends of informal factors. The discussion shows that semantics is prior to syntax.

There are currently two uses of the term 'formal semantics'. The first, becoming more and more popular among linguists, refers to a formal (mathematical) treatment of natural language (see Cann 1993, pp. 1-2) and of its relation to the world. This approach accepts the following theses: (a) the Chomsky thesis – natural language is a formal system; (b) the Montague thesis – there is no principal difference between formal and natural language. Yet the real scope of the validity of (a) and (b) is still disputed. Hence, it is not clear to what extent speaking about the formal semantics of natural language is justified. Since I will not discuss this question, let me immediately pass to the second issue according to which formal semantics is a mathematical treatment of formal languages and their semantical features, like truth, reference, etc. Formal semantics in this sense is the same as model theory. Roughly speaking, to give a semantical characterization of a language L means to point out the class of models $C(M)$ of L, that is, the class of algebraic structures which L is about.[1] Apparently, everything is clear here. We have L as a formal language and $C(M)$ as a formal set-theoretical object. Since both are mathe-

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[1] The phrase 'the class of algebraic structures which L is about' means 'the class of algebraic structures in which sentences of L are true'.

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matically characterized, everything is formal in formal semantics of formal languages. I will argue that this picture is essentially simplified.

Four contrasts applied to languages are relevant to our problem: (A) natural – artificial; (B) informal – formal; (C) unformalized – formalized; (D) interpreted – uninterpreted. For the first look, it might seem that members of the sequence 'natural, informal, unformalized, interpreted' express the same property, which can be also pointed out as 'ordinary', 'colloquial', etc.[2] Consequently, the words 'artificial', 'formal', 'formalized' and 'uninterpreted' seem to refer to the same feature. However, a closer inspection shows that these extensional identifications are dubious. If we say that a language is artificial, we usually have in mind that it was created for performing special tasks. Although an artificial language contains special symbols, it does not need to be formalized. According to a basic intuition, a language is formal if it can be described independently of the content of its expressions and by appeal only to their syntactic form. Finally, a formalized language is a result of a special process or operation, called formalization. Nothing precludes that a formalized language arose as a formalization of an informal one. For instance, formal mathematics arises by formalization of more or less informal mathematics. Furthermore, nothing precludes that a formalized language is interpreted. This was strongly stressed by Tarski:

> It remains perhaps to add that we are not interested here in 'formal' languages in sciences in one special sense of the word 'formal', namely sciences to the signs and expressions of which no material sense is attached. For such sciences the problem here discussed [the problem of truth] has no relevance, it is not even meaningful. We shall always ascribe quite concrete and, for us, intelligible meanings to the signs which occur in the language we shall consider. The expressions which we call sentences still remain sentences after the signs which occur in them have been translated into colloquial language. The sentences which are distinguished as axioms seem to us materially true, and in choosing rules of inference we are always guided by the principle that when such rules are applied to true sentences the sentences obtained by their use should also be true. (Tarski 1933, pp. 166-167; page-reference to Eng. tr.)

For Tarski, doing formal semantics for *L* requires that the language in question is interpreted, although formalized.[3] Perhaps it is the most important outcome of the foregoing discussion that 'formalized' and 'interpreted' can coexist.

[2] My treatment of (A) and (B) is considerably influenced by Ryle (1964). In particular, Ryle's observation that the adjective 'ordinary' in the phrase 'the ordinary use of expressions' means something different than 'ordinary' in the phrase 'the use of ordinary expressions' is very relevant here. Ryle points out that 'ordinary' in the first case can replaced by 'standard'. Hence, the expressions of non-ordinary, for instance, mathematical language have their ordinary, that is, standard use, although they not belong to ordinary, that is, colloquial language.

[3] Tarski himself offers a very general characterization of formalized languages: „These can be roughly characterized as artificially constructed languages in which the sense of every expression is unambiguously determined by its form." (Tarski 1933, pp. 165-166)

Contemporary mathematical linguistics succeeded in a very general description of formal languages (see Mateescu and Salomaa 1997). Let G be an arbitrary non-empty set with an associative operation • and the neutral element 0 (which means that for any $g \in G$, $g \bullet 0 = g$). Thus, algebraically speaking, G is a monoid (a free semigroup). The elements of G are elementary strings (the alphabet), the operation • is interpreted as concatenation (in particular, we have that $g_i \bullet g_j = g_i\, g_j$) and 0 is the empty word. Every finite sequence of strings over the alphabet is counted as a word. Finally, a language L is a set of words over the (finite or infinite) alphabet G.

There is no restriction as to the nature of strings and words. Arbitrary objects (tables, chairs, English words, electric impulses, symbols of a vocabulary of the propositional calculus, etc.) can be building blocks of a language. Hence, languages understood as sets of words over alphabets are perfect instantiations of the concept of formal language. Yet we find the following comment:

> What is a language? By consulting a dictionary one finds, among others, the following explanations:
> 1. The body of words and systems for their use in common to people who are of the same community or nation, the same geographical area, or the same cultural tradition;
> 2. Any set or system of signs or symbols used in a more or less uniform fashion by a number of people who are thus enabled to communicate intelligibly with one another.
> 3. Any system of formalized symbols, signs, gestures, or the like, used or conceived as means of communicating thought, emotion, etc.
>
> The definitions 1-3 reflect a notion of "language" general and neutral enough for our purposes.
>
> Further explanations are more closely associated with the spoken language [...]. When speaking of formal languages, we want to construct formal grammars for defining language rather than to consider a language as a body of words somehow given to us or common to a group of people. Indeed, we will view a *language* as a set of finite strings of symbols from a finite alphabet. Formal *grammars* will be devices for defining specific languages. Depending on the context, the finite strings constituting a language can be also referred to as *words, sentences, programs,* etc. Such a formal idea of a language is compatible with the definitions 1-3, although it neglects all semantic issues and is restricted to *written* languages.
>
> The idea of a *formal language* being a set of finite strings of symbols from a finite alphabet constitutes the core of this Handbook. Certainly all written languages: the natural, programming or any other *kind*, are contained in this idea. (Mateescu and Salomaa 1997, p. 1)

The last quotation concurs with that taken from Tarski. Although Mateescu and Salomaa explicitly say that the definition of formal language drops all semantical issues, it is intended to serve as a formal representation of languages understood, particularly, as sets of sentences.

As I have already noted, formal semantics is a formal (mathematical) treatment of relations holding between a language and the world. I will discuss so called first-order languages, that is languages based on first-order logic. Let L be such a language (for simplicity, without identity). As a formal language it satisfies the algebraic definition. However, logicians proceed in a less abstract way. The first step in the description of L consists in the specification of its alphabet. It has logical constants (propositional connectives, quantifiers); a countably infinite stock *VAR* (the set of individual variables): x_1, x_2, x_3,...; a countable (possibly empty) stock *CONT* (the set of individual constants): a_1, a_2, a_3,...; a countable (possibly empty) stock *FUN* (the set of functions symbols) of the type $f_{i,j}$, where the first index indicates the arity of f and the second its place on the list of all function symbol of a given arity (for example, $f_{1,2}$ denotes the second monadic function symbol), and a countable (non-empty) stock *PRED* (the set of predicate letters or predicates) of the type $P_{k,l}$ (the use of indexes is analogous to the case of function symbols). The definition of a well-formed formula (wff) of L is standard. In some case, it is convenient to consider individual constants as functions of zero arity (zero-ary functions), for example, $f_{0,1} = a_1$.

L (and every similar language) has a definite signature. From the intuitive point of view, the signature displays the number of individual constants in L and its stock of functions and predicates, both of a definite arity. Suppose that the alphabet of L consists of (we drop the variables) a_1, a_2, $f_{1,2}$, $P_{1,4}$, $P_{2,2}$. It has the signature $<0, 0; 1; 1, 2>$. Hence, we derive the following information: L has two individual constants, one monadic function and two predicates, one monadic and one dyadic. The general definition of indexes belonging to the signature treats them as objects of the type $s(i)$, where for any $i \in In$ (the set of indexes) $s(i) \in N$ (the set of natural numbers) if we have to do with indexes of functions, but $s(i) \in N - \{0\}$ if we have to do with indexes for predicates. Since functions are convertible to relations, there is no need to define their indexes in a different way than it is done for predicates.

In order to speak about semantical relations, we have to define an interpretation of L. We start with an interpretative structure $IS = <U, CT, FN, PD>$, where U is a non-empty set of objects (the carrier of IS), CT is a countable (possibly empty) set of objects distinguished from U, FN is a countable (possibly empty) set of functions over U, that is, entities of the type $fn_{i,j}$ (indexes play the same role as in the case of elements of the sets *FUN* and *PRED*), and PD is a countable (non-empty) set of attributes, that is, the entities of the type $Pr_{i,j}$; moreover, $Pr_{i,j} \subseteq U^i$, that is an attribute $Pr_{i,j}$ is a subset of the i^{th} Cartesian power of U.[4] For example, if we have to do with the attribute $Pr_{1,j}$, then $Pr_{1,j} = U_j$, where $U_j \subseteq U$, but in the case of $Pr_{2,j}$, we have that $Pr_{2,j} \subseteq U \times U$. Thus, monadic attributes are subsets of U, but n-ary attributes are n-ary relations defined on U. The signature of *IS* is defined in the same manner as the signature of L.

It is not true that a purely formal language (at least, defined as our L) does not yield any information about its possible interpretative structures. Since the signature of the alphabet is given univocally, it also decides about some structural properties of *IS*. If the signature of L is <0, 0; 1; 1, 2>, we know in advance that *SI* for L must contain at least one distinguished object (since v is not a bijection, more than one name can refer to the same object), one function and two attributes, one monadic and one dyadic. The converse dependence is even stronger. If the signature of *SI* is <0, 0; 1; 1, 2>, L must have two individual constants (because v is a function), one function symbol and two predicate letters, one monadic and one dyadic. Thus, information to be derived from L about the structure of *IS* is weaker than the message in the reverse direction.

However, links between languages and their possible interpretative structures generated by the signatures do not yield interpretations. An interpretation of L is given by a function v such that $v(x_m) \in U$, $v(a_n) = u_n$, $v(f_{i,j}) = fn_{i,j}$ and $v(P_{k,l}) = Pr_{k,l}$. Thus, the function v ascribes: arbitrary but fixed objects taken from U to variables, distinguished elements of U to individual constants, functions to function symbols, and attributes to predicates. The function v interprets the alphabet, but this suffices for the interpretation of the whole L, provided that it is compositional. Compositionality means here that the semantic value of a complex expression is the value of some function, denoted by v, of the semantic values of their explicit components. This is the case if composite expressions are formed by applications (of concatenation) of propositional connectives and quantifiers to already constructed items. The operation • also behaves compositionally. Consequently, the function v preserves compositionality, that is, constructs interpretations of the composites from the interpretations of their elements. For example, the expression $P_{1,1}(x) \vee P_{1,2}(x)$ is interpreted by the attribute $Pr_{1,1} \cup Pr_{1,2}$, and the expression $P_{1,1}(x) \wedge P_{1,2}(x)$ by the attribute $Pr_{1,1} \cap Pr_{1,2}$. One might maintain that the requirement of compositionality is too strong, because it yields problems for the mathematical analysis of intensional contexts which are not compositional in many cases. This is true, but it also explains notorious difficulties to be meet in formal analysis of modal propositions or epistemic reports. In fact, compositionality

[4] There is an ambiguity in the use of the term 'interpretation'. Sometimes it refers to *SI*, sometimes to the process of interpreting L, sometimes to the result of that process. It stems from the fact that interpretation can be arbitrary or it can preserve some earlier intuition. I will speak about interpretation in the second meaning.

displays an essential feature of formal semantics. Languages and interpretative structures should be handled by mathematical devices operating according to recursive procedures. This requires parallel properties of both correlate entities, that is, languages and their interpretative structures. Additionally, compositionality allows applications of recursive and inductive procedures to syntax and semantics.[5]

The introduced apparatus is not sufficient for the interpretation of sentences. This is a serious defect, because languages are sets of sentences. Let $X \subseteq L$. We add new objects to *IS*, namely *1* (truth) and *0* (falsehood) and assume that if $A \in X$, then $v(A) = 1$ or $v(A) = 0$. *IS* is now extended to $IS' = \langle U, CT, FN, PD, 1, 0 \rangle$. Now, if for every $A \in X$, we have $v(A) = 1$, then *IS'* is a model of *X*. Truth is not defined by this construction, but taken as a new primitive concept.[6] Following Tarski, we can define the concept of truth in a well-known way, that is, as satisfaction of a sentence by all infinite sequences of objects. Briefly: the Tarski-style truth definition requires *IS* and the definition of satisfaction. *1* and *0* can be dropped from *IS* in this situation. *A* model *M* of a set *X* of sentences ($X \subseteq L$) is an interpretative structure *IS* such that every $A \in X$ is true in the Tarskian sense.[7]

The foregoing analysis shows that *L, IS, v* and satisfaction are necessary components of any *L*-semantics. In particular, the function *v* provides a correlation between expressions and appropriate items from *IS*. What is formal in it? Of course, the answer depends of how 'formal' is understood. Suppose that something is formal if it is just independent of content, but solely dependent of form. This old meaning is useful, although not quite precise. The matter is simple as far as *L* is concerned, because its structure and signature are given

[5] These remarks are not intended as a general protest against non-compositional syntax or semantics. All attempts to extend mathematical methods in order to develop semantics of intensional contexts are welcomed. In this respect, Montague's semantics or Hintikka's game-theoretical semantics and independent-friendly logic are important proposals. Consequently, there is no reason to limit formal semantics to the model theory of classical logic. However, I claim that compositionality is too often rejected without rethinking its consequences for the formal analysis of language.

[6] Formally speaking, *1* and *0* can be considered zero-ary attributes. See the next footnote.

[7] We have here an important difference between Tarski's semantics and Frege's semantics. Frege considered logical values as objects (zero-ary attributes in our terminology), but Tarski defined them. If we assume that *1* and *0* satisfy the rules of Boolean algebra, formal consequences of both approaches are exactly the same. However, the comparison of both approaches suggests that Frege's thesis about the undefinability of truth is not correct. Moreover, the Tarskian approach has an advantage over Frege's account, which is of some importance here. If we add *1* and *0* as new attributes to *IS*, the signature parallelism between it and *L* is lost in the general case. Due to the Tarski undefinability result, it is impossible to introduce consistently the truth-predicate into languages sufficient for arithmetic. I do not suggest that the parallelism in question is a necessary condition for semantics. Yet it leads to more elegant constructions.

purely syntactically. The meaning (sense) of expressions of L is not relevant here. Since we assume the signature parallelism of L and *IS*, the formal structure of the latter is displayed by the signature. Let us say that, for some given language L, its syntax and its signature display the form of interpretation given by the function v. On the other, v itself is not formal, because it depends of how expressions of L are understood. Take once more L with the alphabet a_1, a_2, $f_{1,2}$, $P_{1,4}$, $P_{2,2}$. Assume that: U = the set of philosophers, a_1 = 'Plato' a_2 = 'Aristotle', $f_{1,2}$ = 'the teacher of', $P_{1,4}$ = 'is a rationalist', $P_{2,2}$ = 'is older than'. The interpretation which is faithful to the history of philosophy correlates Plato with 'Plato', 'Aristotle' with Aristotle. Plato is the value of the function *the teacher of* for Aristotle as the argument, the sentence 'Plato is a rationalist' is true, the sentence 'Aristotle is a rationalist' false, the sentence 'Plato is older than Aristotle' true, and the sentence 'Aristotle is older than Plato' false. We can describe other interpretations in which matters look differently, for example, possible worlds in which Plato was younger than Aristotle was, but the former still taught the latter. However, independently of whether our interpretations are faithful to empirical data or ordinary language, the function v behaves accordingly to some contents. Thus, we can say that the content of an interpretation is given by the way of correlating L with *IS* by the function v. Even if we say that it is formal to some extent, because it is described by mathematical devices, like functions, sets, relations, etc., the meaning of 'formal' is different here.[8] Anyway, one is entitled to say that the content of interpretation is given informally as compared with the form of interpretation.

A general framework of the relation between the form and the content of an interpre-tation can be outlined by appealing to one point in Tarski's construction of the truth-definition. It concerns the T-scheme, that is, the equivalence

(T) S is true if and only if S*,

where the letter S denotes a name of the sentence in question and the symbol S^* denotes a metalinguistic translation of the sentence denoted by 'S'. If the sentence denoted by 'S' belongs to L, the appropriate specification of (T) is part of *ML*, that is, the metalanguage of L. The rule is this: if L is formal (formalized), *ML* is not. There is no other way to establish interpretation than to use more or less informal metalanguage.[9] Thus, the content of interpretation goes from the top to the bottom, that is from *ML* to L. Beth once remarked:

[8] Let me remark that I do not consider various operations on models or interpretative structures, like extensions, restrictions, embeddings, direct products, etc. They are formal in the sense that they are generated by algebraic operations. I also omit a discussion of partial interpretations. These technical problems have no particular significance for the general perspective outlined in this paper.

> By *semantics* I mean a rigorously deductive treatment of the connections between the logical and mathematical symbols and the objects which they denote. An informal discussion of the same subject is denoted as *hermeneutics*. (Beth 1962, p. XIV).

Beth, as it follows from his further remarks on pp. 67, 72 and others, considers hermeneutics to be an informal discussion faithful to ordinary (mathematical) intuitions. My proposal sharpens this view in the way that (a) hermeneutics consists in any decision how to correlate *L* and *IS* or, equivalently, how to translate *L* into *ML*, and (b) it is impossible to do formal semantics without a certain amount of hermeneutics; formal semantics is always embedded into hermeneutics.[10]

The discussion above additionally supports the view that semantics is prior to syntax. This thesis has its justification in the limitative theorems of Gödel and Tarski, which show that there are true, but unprovable sentences or that the concept of truth is undefinable in rich languages. Now we have a more philosophical perspective. If we accept it, the following manner of speaking about logic

> From time to time in the following chapters we shall interrupt the rigorous treatment of a logistic system in order to make an informal semantical aside. Though in studying a logistic system we shall wish to hold its interpretation open, such semantical explanations about a system may serve in particular to show a motivation for consideration of it by indicating its principal interpretation. (Church 1956, p. 67-68)

is incorrect, because it means that semantics is secondary to syntax. Philosophically speaking, the former is transcendental with respect to the latter (see Woleński 1997 for further remarks).

The relation between syntax and semantics has some general consequences, significant for the philosophy of logic. Suppose that one considers logic as the sum of syntax and semantics. It is clear that this whole is not homogeneous. Syntax or logistic systems (in the sense of Church) are given effectively.[11] This means that there is an effective procedure (algorithm) deciding in a finite number of steps whether a given syntactic construction is correct or not. Due to the parallelism of syntax and semantics the effectivity property also hold for the latter, but only partially. Some semantical properties, at least in classical logic, require infinitary methods of proof. For example, the completeness the-

[9] This is reminiscent of the relation between formal and informal mathematics. We need the latter in order to speak about the former.

[10] It seems that even a syntactic description of a language is embedded into some hermeneutics, because it is also done in an informal *ML*. For example, the treatment of languages as sets of sentences is governed by some informal intuitions. However, I do not enter into this problem.

[11] It does not matter whether we work with classical or constructive logic. Recall also that we consider only languages with finitely long formulas.

orem for first-order logic is not provable by finitary methods. Hence, the model-theoretic proofs of consistency of rich formal theories go beyond devices admissible for constructivists. Even if one will formalize semantics in a complete way, this situation comes back on the level of metasemantics.

Suppose that one wants to justify a logistic system (in the sense of Church), that is, a deductive machinery by appealing to semantical properties. This is usually done by proving that some given logic is sound (its rules lead to true conclusions, provided that the premises are true) and complete (every tautology is provable). However, this justification must use methods going beyond the part of logic which is justified. Thus, logic as a syntactic and thereby effective construction (that is, constructed according to recursive procedures)[12] is justified by less effective constructions. On the other hand, it is difficult to imagine a purely syntactic way of proving that some logic is sound and complete.[13] I do not say that it is a paradox.[14] Yet philosophers of logic should remember what is going on with semantical justification of logic.

I would like to illustrate the last point by an important historical example. Husserl (see Husserl 1929, §§14-15) distinguishes consequence-logic and truth-logic. He writes (pp. 54-55; page-reference to Eng. tr.):

> It is an important insight, that questions concerning consequence and inconsistency can be asked about judgments *in forma*, without involving the least inquiry into truth or falsity and therefore without ever bringing the concepts of truth and falsity, or their derivatives into the *theme*. In view of this possibility, we distinguish a level of formal logic that we call *consequence-logic* or *logic of non-contradiction*. [...]. The fundamental concepts of pure analytics [= consequence-logic – J. W.] in the pregnant sense include, *as fundamental concepts of validity* (norm-concepts), *only analytic consequence and analytic contradiction;* as already said, *truth and falsity,* along with their modalities, are not present among them. This must be rightly understood: They are not present as fundamental concepts pertaining to the *thematic* sphere. Therefore, in this pure analytics, they play only the role that is theirs in all the science, so far as all sciences strive for truths and consequently talk about truth and falsity; but that is not to say that truth and falsity belong to the "fundamental concepts" of every science, the concepts pertaining to the proper essence of its particular scientific *province.* [...]
> Inquiry for formal laws of possible *truth* and its modalities would be of a higher logical inquiry, *after* the isolation of pure analytics. If a logic restricts itself to the bare form of the significations of statements – that is, the judgement-forms – what means does it have of becoming a genuine logic of truth? One can see fortwith that *non-contradiction* is an essential condition for possible *truth*, but also that mere analytics be-

[12] This problem requires a further discussion as far as it concerns some logics beyond first-order predicate calculus.

[13] Unless we restrict logic to propositional calculus.

[14] The situation is similar to that with causal explanation, which explains known facts by appealing to causes, perhaps not entirely unknown, but certainly further from experience than explananda.

> comes converted into a *formal truth-logic* only by virtue of a *connexion* between these intrinsically separable concepts, a connexion that determines an eidetic law and, in logic, *must be formulated separately.*

I will not enter into an exegesis of Husserl's views about logic. It is sufficient to observe that the logic of non-contradiction is syntactic in its nature, but that truth-logic plays the role of semantics. Further, Husserl stresses that pure analytics should be supplemented by a formal truth-logic, because the latter goes beyond the former. These views fairly concur with contemporary views about the relation between syntax and semantics. On the other hand, it is unclear whether Husserl applies the adjective 'formal' in the same sense, when he speaks about pure formal analytics as when he speaks about the formal logic of truth. As I tried to show, one should sharply distinguish these things. Perhaps a more important question concerns Husserl's view about the justification of logic. He maintained that the eidetic analysis would be necessary for this task. Thus, we have three levels: (a) pure formal analytics (syntax); (b) the formal logic of truth (formal semantics); (c) the eidetics (perhaps: transcendental logic). According to Husserl, the analysis performed on the level (c) is the strongest and it is reliable from the methodological point of view. However, even if one claims that logic requires a justification by appealing to its philosophical (in my scheme, metasemantical) foundations, it cannot be stronger than the justification available on the levels (a) and (b). I guess that this is a mistake of all conceptions of logic considering transcendental logic as prior to formal logic.[15]

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