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Tarski, truth and natural languages

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Abstract

The first part of the paper traces the history of the relationship between logic and linguistics with particular emphasis on the contributions of Tarski and Ajdukiewicz. In the second part we give a brief review of current work on formal semantics for natural language systems and argue for the need for a richer geometric structure on the semantic model space.

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The relationship between logic and language has always been a complex affair. They have been inseparably intertwined in the European intellectual tradition. It was not an easy relationship, but there were always issues of substance whether they were friends or foes. This is not the place to trace the whole story; for a somewhat personal view of the development see Fenstad [14]. We shall on this occasion, the centenary of the birth of Alfred Tarski, take the mid-1930s as our starting point and look at the situation from the perspectives of the Vienna Circle and the *Unity of Science* movement.

The Vienna Circle was a driving force behind the Unity of Science movement. A congress in Praha in 1934 had laid the plans for a series of future conferences devoted to the unity of science. An impressive International Committee had been formed to further these aims; we recognize the names of three Nobel prize winners in physics (Bohr, Bridgeman, and Perrin), several of the leading mathematicians of the time (e.g. Cartan, Fréchet, and Hadamard), and, of course, all the great names of the "new" philosophy, Carnap, Dewey, Lukasiewicz, von Mieses, Reichenbach, and Russell. There were some names from the social sciences, and almost none from the biological sciences. Physics, mathematics, logic and "exact" philosophy were the standard bearers.

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This lead to the third congress in Paris 1937, which was devoted to the project of organizing an *International Encyclopedia of Unified Science*, where the foundation for science and rationality was once and for all to be inscribed; see Neurath [26], one of the leaders of the movement, for a personal and very interesting account.

Linguistics was part of the unity of science project, and the well-known American linguist Leonard Bloomfield was to be its representative. The development of linguistics is an important, but sometimes a somewhat neglected part of our intellectual history. The study of languages covers a wide spectrum of topics, ranging all the way from the neural basis, via speech analysis and grammar formalisms, to the interpretation of metaphors. We shall be interested in the relationship between logic and linguistics.

Let us start by making a few remarks on the situation in linguistics in the mid-1930s. The historical and comparative school, which dominated by the end of the 19th century, had by that time been replaced by a structural approach going back to the great Swiss linguist Ferdinand Saussure. In the mid-1930s Bloomfield occupied a central position in the field. Philosophically he was close to the Unity of Science movement, being at the same time both a firm believer in the empiricism of the Vienna Circle and a committed behaviorist. This is very much in evidence in an article, *Linguistic Aspects of Science*, which he contributed to the new *International Encyclopedia of Unified Science*; [5]. He is severely critical of the latin tradition in the study of grammar for the many mistakes caused by the "metaphysical", and hence un-scientific, definitions and *a priori* constructions found in this tradition. He recommended that linguistics as a science should seek its roots in the newly rediscovered grammar for Sanscrit. In this tradition we see, according to Bloomfield, a descriptive, even scientific, grammar rid of the metaphysics and a priorism of the Latin tradition. This set an example for the description of native Indian languages in the US and gave a historical justification for the data-driven and inductive methods of structural linguistics. If we believed in Bloomfield's account in the *Encyclopedia*, this was the final theory. But read on the background of current insight in the cognitive sciences, his behavioristic foundation for linguistics was a remarkably primitive construction.

Natural languages had, however, a very low status within the Vienna Circle. No one denied that it was something existing in space and time which had to be studied and classified by the proper (i.e. Bloomfieldian) methods. But it was not something to be used for insight and understanding. In the same *Encyclopedia*, devoted to the unity of science, we find the following programmatic declaration by C.W. Morris that "it has become clear to many persons today that man—including scientific man—must free himself from the web of words which he has spun and that language—including scientific language—is greatly in need of purification, simplification, and systematization"; Morris [25]. Tarski is an explicit source for Morris. And the source is, of course, the famous article *Der Wahrheitsbegriff in den formalisierten Sprachen*, reprinted in the collection Tarski [34], where we read on page 165:

> " ... the very possibility of a consistent use of the expression 'true sentence' which is in harmony with the laws of logic and the spirit of everyday language seems to be very questionable, and consequently the same doubt attaches to the possibility of constructing a correct definition of this expression".

The way out for the unity of science movement was to turn away from everyday language as a medium for scientific understanding and to construct a new and purified logical syntax and semantics for the "scientific man" of the future. It was left to Carnap to be the architect for the new edifice, where his *Logische Syntax der Sprache* [8] was to be the central element of the new structure.

I do not know whether Bloomfield, Carnap and Tarski ever sat down together and discussed logic and language in the light of the doctrines of the *Einheitswissenschaft*. What I do know is that the future always likes to confound those who believe that the last battle has been fought and won. The interaction between logic and language did not at all develop as was prescribed in the *International Encyclopedia of Unified Science*. We recall a few facts.

American structural linguistics looked upon itself as the culmination of linguistics as a science. And the book that was intended as the last stone to the structure, was *Methods in Structural Linguistics* [18] by Zellig Harris from 1951. The book was severely inductive in approach. Any description of a language must be based on an extensive occurrence analysis. The structure must emerge from observed regularities. General linguistics seemed to be reduced to a methodology for language description and experimental design. There is no universal grammar. And meaning is a stimulus–response added-on. (I deliberately used the word "seemed" above; as explained in Fenstad [14], there is much more to Harris than this crude descriptivism.) Such was the leading paradigm up to the appearance of Chomsky's *Syntactic Structures* in 1957 [10]. Chomsky was a revolution within linguistics, and no one can deny the importance of what he did. Much has been written about this. I shall add some remarks about the logic–linguistic interface.

Tarski denied that his logical analysis in *Wahrheitsbegriff* had any relevance for the understanding of truth and meaning in natural languages. This may be true. Tarski's analysis in *Wahrheitsbegriff* has remained a cornerstone in formal semantics; for a recent up-date on truth and partiality, see the author's article *Partiality* in the *Handbook of Logic and Linguistics* [4]. But if we are concerned with the broader interaction between logic and linguistics, we see a missed opportunity. What had happened if Tarski had paid attention to what his Warsaw colleague Ajdukiewicz tried to do in his article *Die Syntaktische Konnexität* [1] from 1935? Tarski and Ajdukiewicz belonged to the same group of logicians in Poland in the mid 1930s. In the two papers mentioned above there are mutual references. Tarski has several references to Ajdukiewicz, also inside the section where he discusses "colloquial" languages (see footnote 1 on page 161 in Tarski [34]), but not to *Die Syntaktische Konnexität*. Ajdukiewicz has a reference to the *Wahrheitsbegriff* paper (see footnote 1 on page 209 of Ajdukiewicz [1]) where he notes the similarity between his theory of semantic categories and the hierarchy of logical types. Indeed, there are similarities. Both systems derive from the Russell–Whitehead theory of types; directly in Tarski's *Wahrheitsbegriff* and indirectly via Lesniewski [23] in Ajdukiewicz's *Syntaktische Konnexität*. The link is—in hindsight—all too obvious. The categorial grammar of Ajdukiewicz is an applicative system corresponding to higher order logic. It was precisely for these logic systems that Tarski developed his concept of truth. Contrary to both Tarski and Bloomfield (and their fellow travellers Morris and Carnap), it would have been possible in the 1930s to build a viable link between logic and linguistics. We could have had a modern version of the great synthesis of the medieval *modistae*; see the *Grammatica Speculativa* by Thomas of Erfurt [36] from 1315. But both the methodological dogmas of the Vienna Circle and the strict inductive methodology of American structural linguistics forbade such speculations.

Not everyone followed the party line. Hans Reichenbach made use of higher order logic in a chapter on conversational languages in his text book *Symbolic Logic* [30] from 1947, and in particular his analysis of the concept of time in natural languages has become a standard part of linguistic semantics. But there were no traces of a syntactic analysis in Reichenbach [30]. This we find in a paper by H.B. Curry, *Some Logical Aspects of Grammatical Structure* [12], from the late 1940s. Curry's paper was published in 1961 and was almost universally neglected by linguists. The breakthrough came first in the late 1960s with the work of Richard Montague; see the reprint of Montague's papers in Thomason [35]. Montague got his Ph.D. from Tarski in Berkeley, but that was on the metamathematics of set theory. I have no information if logic and natural languages ever was a topic of serious intellectual interchange between Tarski and his student.

Both Chomsky and Reichenbach–Curry–Montague worked at the interface between logic and linguistics. Chomsky entered the stage before semantics really became a standard part of the logic tool-box. He made use of the links between logic–formal languages–computer science and it is syntax which occupies the front stage. And since he does not have a workable theory of semantics, we can see how he "overloads" the syntactic component in his model building. Formal semantics came relatively late, a major influence was the Tarski school in Berkeley in the 1950s. Montague was a product of this school, so it was natural for him to have both syntax and semantics as formal parts of his model of (fragments of) natural language. Reichenbach as a very accomplished logician handled his semantics in a somewhat informal way, as was usual of the logicians of the early part of the 19th century; we may, as an example, recall how Skolem used an informal understanding of the semantics—even in his constructions of countable models of set theory and nonstandard models of arithmetic. Curry was more precise. He was a remarkably original logician, at times several steps in advance of his more well-known colleagues. Both in computer science and in theoretical linguistics he merits much greater recognition for his pioneering work.

Why was Montague and not Curry recognized for their work in linguistics? We can speculate. Curry worked in isolation and at odds with the ruling points of view. The time span from Harris in 1951 [18] and Chomsky in 1957 [10] is admittedly rather short, but it was soon recognized that structuralism had its limits—a theory of experimental design is not a theory of the subject matter itself—and that the new approach of Chomsky with its clean mathematical foundation and links to computer science was a promise for the future. Reichenbach and Curry with their insistence on logic and linguistics seemed to be a throw-back to an old-fashioned *a priorism* and unscientific metaphysics.

But Montague succeeded. The mathematics of Curry and Montague are comparable, and some may even prefer to read Curry rather than struggle with the formalism of Montague. But Montague had something which Curry did not—an interpreter. Barbara

Hall Partee was—and still is—a leading American linguist. She was a professor in the Linguistic Department of the University of California at Los Angeles at the same time Montague was a professor of philosophy there, and she became acquainted with his work. She soon saw the relevance of it for the study of natural languages. She made his work accessible to the linguistic community and added significant new contributions herself. With her stamp of approval linguists had to take note. (For more details on the history of the interaction of mathematics and linguistics see Fenstad [14].)

Logic and grammar: It is time to fill in some technical details. The theory of grammar was never a unified science. There seems, however, to be one shared assumption. Most theoretical linguists will subscribe to the following point of view expressed by the Dutch linguist Jan Koster in a lecture some years ago; Koster [21]:

> "... we have to make a distinction between a computational structure and a more or less independent conceptual structure ... The conceptual module includes what is often referred to as knowledge of the world, common sense and beyond. It also includes logical knowledge and knowledge of predicate-argument structure. The computational module concerns the constraints on our actual organization of discrete units, like morphemes and words, into phrases and constraints on relation between phrases (Koster [21, p. 593])".

Later he adds (Koster [21, p. 598])—and this is not a view universally accepted by linguists:

> If the two basic modules are autonomous and radically different in architecture and evolutionary origin, there must be ... an interface ... My hypothesis is that the interface we are looking for is the lexicon ....

A major part of post-Chomsky linguistic theory has been devoted to the investigation of the computational module. Post Montague we have seen an increased interest in the conceptual module, or semantic space. In a certain sense the computational module of the linguist corresponds to syntax as used by the logician and the conceptual module corresponds to the use of semantics or model concept. This is a rough indication and the usage may differ between different authors.

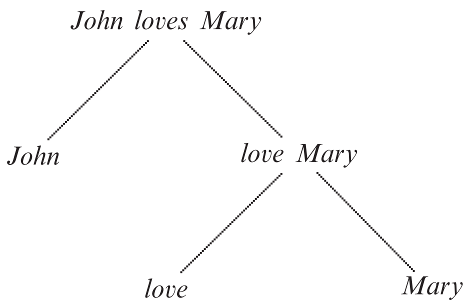
Both in Curry [12] and Montague [24] we have two major parts to the model: One is an *extended categorial grammar*, corresponding to the computational module of Koster, which gives a syntactic analysis of a well-defined fragment of a natural language. The second part, which corresponds to the conceptual module of Koster, consists of a *translation* into a system of higher order (intensional) logic. The translation is required to observe the principle of *compositionality*, which means that it is (in an appropriate sense) a *homomorphism* between the syntactic "algebra" and the semantic "algebra".

In his analysis Montague implicitly used the notion of *generalized quantifier* to give a uniform treatment of *noun phrase*; see Fenstad [13] and Barwise and Cooper [2]. Thus if *john* and *mary* are items of the lexicon, they will not be translated as constants j and m of individual type, but be translated as:

john	translates to	$\lambda P.P(j)$,
mary	translates to	$\lambda Q.Q(m)$.

The term $\lambda P.P(j)$ corresponds in the semantic interpretation to the set $\{X : j' \in X\}$ in the model, where j' is the value of the constant j. Note that for simplicity we use an extensional version of higher order logic.

The sentence *john loves mary* has in the Montague model the following syntactic analysis:



Compositionality, or the homomorphism criterion, demands a translation of *love mary* as an application of the translation of *love* to the translation of *mary*,

$$\textit{love mary} \qquad \text{translates to} \qquad \textit{love}'(\lambda Q.Q(m)),$$

where *love*' is an appropriate constant of the logic as translation of the lexical item *love* of the natural language fragment. In the next step compositionality dictates the following translation:

$$\textit{john loves mary} \qquad \text{translates to} \qquad (\lambda P.P(j))(\textit{love}'(\lambda Q.Q(m))).$$

Compositionality requires that every node in the syntactic tree has an associated object in the logic and the semantic algebra. And the syntactic analysis tells us which type to assign to the associated object. Thus the primary translation *love*' is no longer a relation between individuals, but a more abstract function. Not everyone in love would be happy with this analysis!

There is an answer that some people has taken to be a success of the Montague analysis; see Fenstad [13]. The logic may have a basic constant $love^*$ denoting a relation between individuals. Using lambda-abstraction we can then define a new constant *love*' of the appropriate type by

$$\textit{love}'(\mathbf{P})(x) \qquad \text{if and only if} \qquad \mathbf{P}(\lambda y.\textit{love}^*(x, y)).$$

This “lifted” *love*' has the correct type to match the syntactic analysis:

$$\begin{array}{lll} \textit{love}'(\lambda Q.Q(m))(j) & \text{conv. to} & (\lambda Q.Q(m))(\lambda y.\textit{love}^*(j, y)) \\ & \text{conv. to} & (\lambda y.\textit{love}^*(j, y))(m) \\ & \text{conv. to} & \textit{love}^*(j, m) \end{array}$$

This is what Tarski and Ajdukiewicz could have done in the mid 1930s. Everything was in Curry [12], a paper which was written in the late 1940s, but largely neglected.

We had to wait for Montague in the late 1960s to see the modern equivalent of Thomas of Erfurt [36] and the revival of the link between logic and linguistics. It is outside the scope of this lecture to follow the more recent developments. A good source for this is the *Handbook of Logic and Language* [4]. The reader curious for more details on type theory and its applications to linguistics may also consult Carpenter [9].

The notion of *the connecting sign* was a central element of Koster's analysis. And, indeed, the nature of the *syntax–semantics interface* has been a major issue in recent linguistic theory. In early Chomsky (see his *Aspects of the Theory of Syntax* from 1965 [11]) the connecting sign between grammatical deep structure and semantical representation was basically an arrow decorated with a name (a so-called projection rule)—but with no particular content; we noted above that formal semantics was not well developed at the time when Chomsky started his work. With Montague, a student of Tarski, semantics is part of the tool-box, and, as we have seen above, in his model the connecting sign is most readily identified as the translating formula in higher order intensional logic.

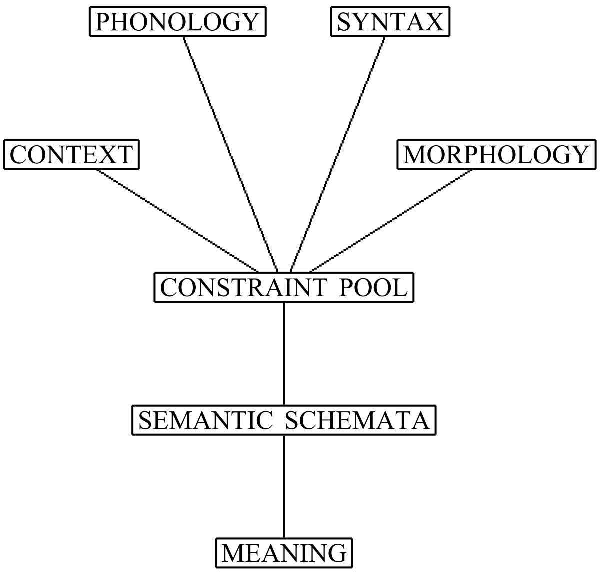
A major alternative to formulas as connecting signs is the use of attribute-value structures. This is an approach which in a very concrete sense uses a lexical sign as the connecting element between the computational and conceptual modules. An early and important example of such a theory is the *Lexical-functional grammar* (LFG) developed by Kaplan and Bresnan [20]. This format was extended to include semantical attributes in *Situations, Language and Logic* [16]. A closely related theory is the system of *Head Driven Phrase Structure Grammar* (HPSG) developed by Pollard and Sag [28]. *The Discourse Representation Structures* theory developed by H. Kamp (see the exposition in Kamp and Reyle [19]) gives another example of a connecting sign bearing some similarity to attribute-value theories. And within AI we have seen a number of proposals in the form of trees, frames, scripts, etc.

Every theory of language has as its ultimate goal an account of the link between linguistic structure and meaning. But different theories differ as to where to locate the connecting sign along the syntax–semantics axis. Chomsky's *Aspects* is biased toward the syntax end. To a certain extent this is also true of classical LFG. HPSG is more balanced between the two components. From our point of view Montague's theory is above all a theory of the connecting sign. The grammar is simple and the theory makes almost no use of the model structure. Much early theory in the Montague tradition consisted in the manipulation of lambda-terms. At this point we should remind the reader that the *Situation Semantics* developed by Barwise and Perry [3] has emerged as a major alternative to the standard Tarski-type semantics; see several articles in the *Handbook of Logic and Language* [4]. It was also a system of situation semantics that was used in Fenstad et al. [16] to add a meaning component to LFG; see the paragraph above.

Cognitive Grammar is an interesting exception to this tradition. Here we see a shift from the syntax to the semantics end of the connecting axis; for a development of this theory see Langacker [22]. In the earlier forms of the theory we still recognize two components, one phonological and one semantical. There is also a connecting symbolic structure, which in some sense is a pictorial attribute-value structure. In a purer version of the theory the phonological module is subsumed under the semantic one: " … phonological space should instead be regarded as a subregion of semantic space (Langacker [22, p. 78])". Cognitive grammar is a minority view in linguistics, but it may have a valid point in its revolt against the combinatorial dominance within current linguistic theory; for a discussion of this point and the geometrization of thought see Gärdenfors [17].

Contrary to cognitive grammar the standard view in linguistics has been that syntax is the only input to semantic interpretation. This is particularly true of categorial grammar and theories in the Montague tradition which are based on type theoretic formalisms. In these theories meaning is a homomorphic image of the syntax in a very precise sense: the interpretation function is a homomorphism (i.e. a structure preserving) map between the algebra of formulas and the set-valued algebra generated by the model as explained in the example above. The world is what can be expressed in your language.

We can read a different philosophy behind the attribute-value formalism. This formalism can be looked upon as a constraint-based view of the relationship between linguistic form and meaning.



In this view all aspects of linguistic form, such as phonology, syntax, and morphology as well as context contribute to a combined set of constraints, which in turn determines the meaning of an utterance. In theories of the LFG variety the constraints are given in form of equations and the resulting linguistic sign or attribute-value matrix represents a consistent solution to the constraint equations; for an extended discussion see Chapter II of *Situations, Language and Logic* [16].

Let us pause for a moment and reproduce the canonical LFG example of a linguistic sign. The sentence is

a girl handed the baby a toy

Following tradition we simplify and look at syntax alone as the source for constraint equations. In this case the attribute-value matrix is:

$$\begin{bmatrix} SUBJ & \begin{bmatrix} SPEC & A \\ NUM & SG \\ PRED & \text{`}GIRL\text{'} \end{bmatrix} \\ TENSE & PAST \\ PRED & \text{`}HAND\langle(\uparrow SUBJ)(\uparrow OBJ2)(\uparrow OBJ)\rangle\text{'} \\ OBJ & \begin{bmatrix} SPEC & THE \\ NUM & SG \\ PRED & \text{`}BABY\text{'} \end{bmatrix} \\ OBJ2 & \begin{bmatrix} SPEC & A \\ NUM & SG \\ PRED & \text{`}TOY\text{'} \end{bmatrix} \end{bmatrix}$$

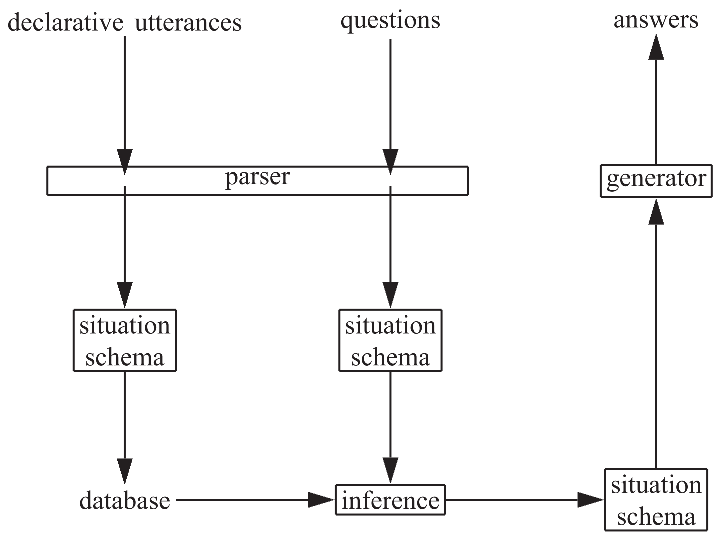
This is a very simple example and tells us only that the theory is pointed in the right direction. There are various noteworthy points. Let me just draw attention to the attributes *SUBJ*, *OBJ*, and *OBJ2*. In one direction they represent a noun phrase, in another a generalized quantifier—the link between the two is, in fact, a true link between language and logic. As pointed out above this link is implicit in Montague [24], but it took some time to excavate this fact from his formalism.

The matrix above is a lexical sign. A sentence such as *a girl handed the baby a toy* gives us a complete sign, a verb phrase alone would determine an incomplete sign where only the attributes *PRED* and *TENSE* would have values, but the sign calls for values of the three other attributes *SUBJ*, *OBJ* and *OBJ2*. In simple situations like this one everything works out perfectly. But when the theory is called upon to serve in more complex situations, where context is important for understanding, we need a more elaborate structure theory for lexical signs. This is a focus for much work today and an extended theory for lexical signs is an absolute necessity for viable language engineering applications.

A useful review of current work is given in Blutner [6] *Lexical semantics and pragmatics* (to appear, for a preprint version see http://www.blutner.de). After discussing the defects of current theories Blutner points to two ways out. One way is represented by a theory of *The Generative Lexicon* as developed by Pustejovsky [29]. This approach aims to enrich the lexicon with new generative mechanisms while staying as close as possible to current linguistic technology. The advantage of this is that it keeps the changes close to the existing computable structures and is therefore computationally tractable. Pustejovsky's presentation of his theory is not easy to understand and leaves some doubts to the technical coherence of parts of his work. In a recent Oslo thesis *Leksikalsk semantikk* Knut Skrindo [32] has presented part of the theory in a consistent way within the framework of *Situations, Language and Logic* [16]. Skrindo's thesis also gives a useful review of much current work.

Blutner argues against the generative position adopted by Pustejovsky and presents a pragmatic alternative, pointing to the need for mechanisms of contextual enrichment (i.e. a pragmatic strengthening based on contextual and encyclopedic knowledge). But much remains to be done to translate this view into a workable theory and efficient computational praxis.

We remarked above that much of current theory is a theory of the connecting sign and that little attention is paid to the structure of semantic space. In Montague's theory the semantic model is there, but it is almost never used. In Pustejovsky's theory one is still close to the attribute-value matrix format. There is a model structure, but not more than can be written into the representational form. Seen from the point of view of language engineering this is not necessarily a criticism. Any application—take any question–answering system as an example—reduces necessarily the semantics to a database representation.



This example is taken from Vestre [37], but is quite typical in overall structure for applications where "model = data base" is a valid equation.

Formal semantics, which is a name used for much of the work at the interface between logic and language, has in my view been a major influence on theoretical linguistics. But there are limits. Computational linguistics never was and is not an applied branch of theoretical linguistics. There are many useful links and the equation "model = data base" is a useful starting point, but computational linguistics and language engineering need to draw upon many sources. To be very brief and somewhat polemical, when you are given the task to design a dictation system for journal keeping to be used by doctors in the health system, you do not start out by consulting a manual of higher order intensional logic. This is a situation not very different from the traditional relationship between basic physics and, say, electrical engineering. Few, if any, actual design tasks would start from the Maxwell equations. There have, however, been important changes in the physics–engineering relationship. In many parts of material technology, applications today are in a very direct sense applied science. Will we see a similar development in computational linguistics and language engineering? We recommend two collections of papers for further reflection, *Computational linguistics and formal semantics* [31] and *Computers, language and speech: formal theories and statistical data* [33].

We have noted some limits in the relationship between the science of language and language technology. There are also major challenges in the relationship between the science of language and the broader cognitive sciences; for an overview see the article *Formal semantics, geometry and mind* [15] and P. Gärdenfors' recent book, *Conceptual spaces: The geometry of thought* [17]. Formal semantics must proceed beyond the equation "model = data base" in order to serve as a link between language and mind. The challenge is to understand how language and cognition are rooted in the behavior of large and complex assemblies of nerve cells in the brain. Much of current linguistic theory proceeds at the level of symbol manipulation, such as sorting, ordering and comparing symbols. But, as was implicit in Blutner's discussion of pragmatics and the lexicon, we need to proceed beyond this level. A first step is a geometrization of model theory as a basis for a phenomenological model of mind. The next is to understand how the dynamics of brain cell interaction generates this geometry. Much is already known, but much remains before we have a firm understanding of this double task.

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