

Postscript

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In this postscript I wish to suggest to the reader, who in most cases will probably be a linguist, a certain approach to the present monograph by L. Nebeský, concerning in particular its linguistic relevance. Hereby I hope to elucidate the fact that an essentially mathematical work is being published in a series of philological monographs, which some ten years ago was scarcely conceivable. (After all, in an era of wide collaboration between formerly self-contained scientific disciplines, an era which also gives rise to new borderline disciplines, a proper amount of broadmindedness which makes the publishing of various kinds of "experimental" works possible is not out of place.)

The work was originally intended as a contribution to deeper knowledge of the so-called dependency conception in syntax. We shall see, however, that it may be of more general significance. Having touched upon some problems of the formal study of the dependency conception, I shall characterize, in 1, the author's general approach to such a study in comparison with other possible approaches, then I shall survey and discuss the results of the work, first, in 2, those whose linguistic significance is immediate, and then, in 3, some others. If need be I shall comment on general questions of the relationship between mathematics and linguistics *quà* empirical science.

1. In contradistinction to the immediate constituent conception, which because of its distributionalist and antisemantical origin within American descriptivism permitted a relatively easy formal-

ization (Chomsky 59, 147, Postal 64, ch. 3), the formal reconstruction of the dependency conception meets with many more obstacles.¹⁾ It has come to be known in modern Western linguistics (regarded from the standpoint of this country) only through the fundamental book by Tesnière (59) and from the automatic syntactic analysis of Russian by Harper and Hays (60) but it originated and has been cultivated in Slavonic countries throughout a long tradition of syntactical scholarship, in a setting with a different standard of precision in presenting the results of research. Here syntax has always been conceived of as a study of sentence meaning (cf. Bauer 52) -mostly oriented explicitly or implicitly towards sentence parsing as practised at schools- and only recently have the semantic and formally combinatorial aspects of sentence structure begun to be distinguished (Dokulil-Daneš 58, Hausenblas 58). Consequently, it is quite natural that the dependency conception began to be formalized later and in a more difficult way than the immediate constituent conception, and that its further substantial elaboration is accompanied by independent attempts at its formal clarification, and, conversely, attempts at its formalization give impulses to its further substantial elaboration (cf. Daneš 64, Sgall 67 and Shaumyan — Soboleva 63).

In principle it is clear that dependency relation as used by grammarians reflects, in a not yet fully understood manner, purely combinatorial (distributional), morphological and semantical facts about word forms (Revzin 67). (Referring to the so-called linguistic intuition in the case of dependency relation seems to be unjustifiable. If anything is intuitively clear in this field of language experience, it is a certain interdependency relation (Figure 1). Next, even if any claim were to be made for the intuitive clearness of the dependency relation (cf. Mel'chuk 64, 18), we would not be relieved of the duty of explaining this intuitive clearness.) It goes without saying that a formal reconstruction of the dependency conception would be incomplete with the exclusion of sentence semantics.

Nebeský is not the first mathematician to be interested in the dependency conception, especially in its central notion of dependency.

¹⁾ We shall always differentiate between an informal syntactical conception and its formalizations, called theories (the latter item being, in turn, opposed to concrete grammars constructed in accordance with a theory).

He uses, however, a procedure different from that used so far. He is not trying to explicate the dependency relation, which is current in the so-called analytical trend of algebraic linguistics (Nebeský 62, Revzin 63, Nebeský 65, Marcus 67, Revzin 67), nor does he treat it in the way prevailing at present in the specifying (generative or recognition) trend, i.e. simply by taking it as one of the so-called

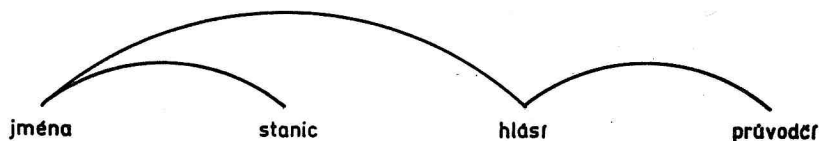


Figure 1. ("The names of the stops are announced by the conductor".)

formal universals (Gaifman 65, Fitialov 62, cf. Katz 67, 127), but having observed the role played in the dependency conception by the notion of projective tree,²⁾ he has investigated, in an abstract mathematical manner, the main components of this rather involved mathematical notion, namely the tree, the root and the condition of projectivity in their connexions. A programmatic stress is placed on the due discerning of the first two components.

When one wishes to give a linguistic appraisal of Nebeský's results one is faced with a situation different from the more usual one where one is putting concrete questions stimulated by empirical research to mathematics. In the latter, an *a priori* application of mathematics, we are concerned, in a sense, with translating linguistic problems into problems of mathematics and solving them as such (cf. Karush 63, Kemeny-Snell 63, Čulík 65, Čulík 67a). Of course, different types of situations may arise: a corresponding mathematical system may have already been developed or it may still have to be set up; the given problem may already have been solved or it may be being tackled for the first time; the problem may be solvable or

²⁾ If we compare the rooted tree diagrams used by various authors we would find some differences among them caused by different ways of simplifying the complicated linguistic reality or by problems so far unsolved. However, in view of solution proposed by Shreider (64) for integrating the coordination in the framework of dependency conception we may not give an otherwise obligatory warning that our discussion does not apply to coordination.

it may not (and various combinations of these possibilities). The former case, with which we are confronted just now, is of a kind that has been christened *a posteriori* application of mathematics to an empirical science (Čulík 65). Certain results in tree theory have been obtained and we are trying to estimate their linguistic relevance. In such cases we must firstly realize what questions we would like to be answered and, perhaps be ready to reconstruct further possible questions answered by the mathematical theory under consideration, further to answer questions put to us explicitly and to discover questions put to us only implicitly, and finally ourselves to ask further questions.

Clearly, both types of situations, i.e. the *a priori* and the *a posteriori* applications, are not mutually exclusive.

2. Nebeský's monograph itself proceeds from the general subject matter to the specific; we shall, however, be proceeding conversely. Let us begin with the discussion of the results of Chapter Four, the linguistic relevance of which is immediately clear. In this chapter the author is dealing with the so-called projectivity (see Corollary 4.8.), a condition laid down within the dependency conception for the relationship between dependency relation and word order. There are various wordings of it, most of them having been proved to be equivalent (Marcus 67, 219 seq.). The first formulations appeared in connexion with automatic syntactic analysis and were needed for the simplification of the retrieval of dependency links between discontinuous word forms within sentence.

It has been proved (Theorem 4.9.) that the condition of projectivity may be split, so to speak, into two subconditions. In the first of them only tree and word order are concerned, that is to say, any mention of the notion of root is omitted, whereas in the second only three vertices, one of them being the root, are involved. Throughout Chapter Four an essential use is made of the so-called intersection vertex operation (see p. 17).

The splitting of the notion of projectivity has twofold meaning. First, three directions for generalizing this notion suggest themselves immediately: 1) subcondition one, 2) subcondition two, and 3) either subcondition one or subcondition two. Such generalizations are needed on account of the following considerations. A few languages have been investigated from the standpoint of projectivity. In all

of them most of the sentences (utterances) are projective, but not all (Marcus 67, 231). It is this which raises the problem of classifying the nonprojective sentences and of stating their relationship to the projective ones. In a recent study (Uhlířová, forthcoming) nonprojective constructions in Czech have been analysed; I have been unable to find there any cases satisfying neither of the two subconditions, which might show that Nebeský's generalizations lie in the right direction.

Secondly, it has often been repeated that the condition of projectivity is a counterpart of the condition of continuity of constituents within another conception of syntax, namely the immediate constituent conception, but the parallelism of the two conditions has been shown more precisely only by Nebeský's result. It is clear now that it is the first subcondition of projectivity which is formally almost identical with the condition of continuity of constituents (to put it briefly, all the constituents being marked by the left and right brackets in the usual way the scopes of all the appropriate pairs of brackets must not overlap). Moreover, the split of the original notion of projectivity gives an independent motivation to the further study of trees in the context of the dependency conception.

3. The linguistic relevance of the first two chapters seems to be of a different nature.

3.1. The main result is the establishment of the equivalence of the notions of tree and tree algebra on the one hand and rooted tree and tree semilattice on the other hand (equivalence in the same sense as if we were speaking about equivalence of different definitions of the notion of group or lattice; strictly speaking, several different notions are defined and their mutual derivability is proved). In other words, it has been proved that there is a one-to-one correspondence between the set of all trees and the set of all tree algebras ensured by two mutually converse relations 'being a proper algebra of' and 'being induced by' (see Definition 1. 4.) and similarly for rooted trees and tree algebras. In more details: Every tree has exactly one proper algebra (by Theorem 1.1. and Definition 1.4.). Let A be a tree algebra, and G_1, G_2 be two trees such that A is their proper algebra, then $G_1 = G_2$ (by Theorem 1.7.). For every tree algebra A there exists a tree G such that A is a proper algebra

of G (by Theorem 1.6. and 1.7.). Every tree algebra induces exactly one tree (by Definition 1.3, 1.4 and Corollary 1.3.). Let G be a tree and A_1, A_2 be two tree algebras such that G is induced by them, then $A_1 = A_2$ (Lemma 1.14.). For every tree G there exists a tree algebra A such that G is induced by A (Theorem 1.7.). Let G be a tree, and A its proper algebra, then G is induced by A (Theorem 1.6.). Here again, the notion of intersectional vertex operation plays an important role. Similar statements could be made for rooted trees and semilattices.

3.2. As noted already, Nebeský proceeds from more general topics to less general ones. In order to facilitate the further discussion of his results I shall now sketch an alternative development of the main ideas of Chapter One and Two, proceeding mostly in the opposite direction. All that will be said in the following two paragraphs can be proved on the basis of Nebeský's results. However, it is conjectured that it all can be achieved quite independently as well. Taking the notion of rooted tree $G = (M, H, z)$ as starting point one may introduce a binary operation on M as follows. We shall denote by $x \circ y$ (or by $x \underset{G}{\circ} y$) the unique vertex that lies on the path from the root z to x , from z to y and that has the largest distance from z . Then we may prove the properties I.—IV. of Definition 2.1. for this operation, define the notion of tree semilattice as in the same definition, and prove the equivalence of the rooted tree and the tree semilattices. This would be on lines exactly parallel to Chapter One.

But, starting again with the notion of rooted tree, one might investigate properties of its transitive closure, and possibly the partial order that may be uniquely assigned to it, and in this way one could obtain the partial order approach to semilattices quite analogous to partial order approach to lattices (cf. Hermes 55).

As for the trees and the tree algebras, one can observe that determining the transitive closure of a tree leads to the so-called complete graph from which one cannot reconstruct the original relation, thus this way of development is excluded from our considerations. But there is another possibility. Given a tree $G = (M, H)$ one may determine for every $x, y, z \in M$ three rooted trees as follows $G_1 = (M, H, x)$, $G_2 = (M, H, y)$ and $G_3 = (M, H, z)$; then it holds that $y \underset{G_1}{\circ} z = x \underset{G_2}{\circ} z = x \underset{G_3}{\circ} y$. This shows that if one ommits, in

a rooted tree, the direction of arrows, one may introduce, as a substitute, a ternary operation in place of the binary one, the uniqueness of the operation being preserved at this cost. Originally, this was a motivation for introducing the notion of intersectional vertex operation.

Again, one may conceive of the contents of Chapters One and Two as an attempt to study the relationship of the notions tree and rooted tree — which, in terms of graph theory, is quite clear (the root induces, in a unique manner, a change of edges to arrows, as shown in Figure 2) — by a *détour*, namely via equivalences with the notions of tree algebra and tree semilattice, respectively.



Figure 2

3.3. The time has come to turn to the issue of the possible linguistic relevance of these results. Attempts have been made in two directions, to use the two operations (binary and ternary ones) in formulation of grammatical rules of modified dependency theories and to find out new facts about sentence structure stated in terms of the operations and some other notions of theory of graphs. I am sorry to report that nothing has been achieved.

But on closer examination, there is nothing here to cause surprise. To begin with, let us recall a theorem on trees (Berge 58): Let G be a graph with $n \geq 2$ vertices. The following propositions are pairwise equivalent: (1) G is connected and without cycles, (2) G has no cycle and admits $n - 1$ edges, (3) G is connected and admits $n - 1$ edges, (4) G has no cycle, but if we add an edge, we obtain a cycle, (5) G is connected, but it becomes nonconnected if we remove an edge, (6) given two vertices a and b of G , there exist a unique chain starting in a and arriving in b . The theorem — more generally, any other of this type, that is to say of the biconditional form — says that whatever portion of experience satisfies one of the conditions, it necessarily satisfies all the other ones as well. Essentially, the same lesson may be drawn from the results of Nebeský.

Here we may say quite similarly that whatever may be described as satisfying the condition of being a tree (and named accordingly), necessarily may be described as satisfying the condition of being a tree algebra (and named so). But, in contradistinction to all the conditions of Berge's theorem, here both conditions are formulated in terms of different types of mathematical structure (an algebra and a relational system). Therefore, we need a guide to lead us from one manner of looking at the portion of reality to the other manner. And this is exactly provided by Nebeský. Thus, given a description of a certain object, situation etc. from the standpoint of one system, it is possible to construct, in an entirely formal fashion, a description in terms of the other system.

3.4 The question is whether all the ways of describing, looking at object and situations which are made possible by what has just been mentioned, are of the same utility, importance, informative value for each purpose, for each application. For instance, do the new ways of looking at sentence structure (e.g. in terms of intersectional vertex operation) reveal to us new, interesting aspects of this structure?

Examples given in the sequel suggest a negative answer to the general question (cf. also Garvin-Karush 63, 368). Some of the formulation may be easier to grasp intuitively, others more convenient in practical manipulation, others more adequate for an over-all description of the subject matter being considered, still others of a heuristic value etc. etc. These are entirely empirical questions. Of the same nature is, of course, the question which of the possible formulations of dependency relation (conceived of as rooted tree, its transitive closure, tree semialgebra) is more suited to the statement of grammatical rules within the dependency conception.

It is to be noted at this point that frequent assertions on the simplifying, "roughening", impoverishing, schematic nature of mathematical models of bodies of experience express one half of the truth only. It is true, on the one hand, that mathematical models reflect only some aspects of their originals, but, on the other hand, they are or may be richer than their originals in other respects, that is to say, they may possess features which are for adequate knowledge of the reality under consideration quite dispensable or, though this is not the case with us, features, without any empirical counter-

parts. Simply, a mathematical theory is at our disposal for various applications, but not all notions and theorems of the theory are needed for each application.

Let us adduce a few examples. Undoubtedly, the condition of projectivity may be formulated either in terms of rooted tree or in terms of its transitive closure, but the latter wording will be somewhat simpler. Now let us consider the item 2 and 3 in Berge's theorem. They do not seem to have any direct connexion with other features of sentence structure. Nevertheless, they have proved useful as a controlling tool for our schoolchildren, who in doing their parsing exercises are never sure whether the lists of syntactical pairs (head-dependent) given by them are complete.

Again, consider points 4 and 5 of the same theorem, which say us that the tree is the most economical connected graph (in terms of number of edges; by the addition of a single edge it ceases to be most economical, by deleting a single edge it ceases to be connected).

3.5 This property of trees can lead us to respect this economy, to work with these graphs and not work with less economical ones unless there are good reasons for so doing. It has been shown (Novák 66) that the so-called double dependency (occurring at "nominal predicate") is superfluous, if we do not mix binarity of the dependency relation with the fact that in most grammars of Slavonic languages attention is confined to pairs of possible heads and dependents and if we are willing to formulate rules which take into account more dependents of the same head. We shall make use of this property of trees still later, in a chain of reasoning ending with a question of possible conceptions of syntactical description. In order to be precise to a satisfactory degree, the question must be expressed in terms of formalizations of syntactical conceptions, not in terms of the conceptions themselves. First I shall recall some well-known results obtained in mathematical linguistics.

Within the specifying trend of algebraic linguistics there are two distinct kinds of formalization of the immediate constituent conception, namely context-free phrase-structure theory (Chomsky 59) and categorial theory (Bar-Hillel-Gaifman-Shamir 60). As for the dependency conception the most important formalization is that of Gaifman (65) and that of Fitialov (62). Each of the conceptions

(theories) reflects somewhat different aspects of syntactical structures. Context free theory and dependency theory may be studied generally or utilized in the description of languages either independently or as a basis for certain superstructures, transformational, stratificational and possibly others as well. So far categorial theory has not been considered as a basis for such superstructures.³⁾ The three theories are weakly equipotent, meaning that every language specifiable by a grammar of one kind is specifiable by a grammar of the other kinds as well (Bar-Hillel-Gaifman-Shamir 60, Gaifman 65, Hays 64, Fitialov 68).

Further, the structural characterization of sentences (strings specified) from the standpoint of grammars of each theory may be given by making use of ordered rooted trees, but in a different way in each theory. Modifying, in a way, observations made by Lecerf (61) and Čulík (63) we may say that within context-free theory the vertices of ordered rooted trees are labelled by terminal symbols (word forms) or by nonterminal symbols (grammatical categories), more precisely, terminal vertices by terminal symbols, the other vertices by nonterminal symbols (Figure 3), whereas within depen-

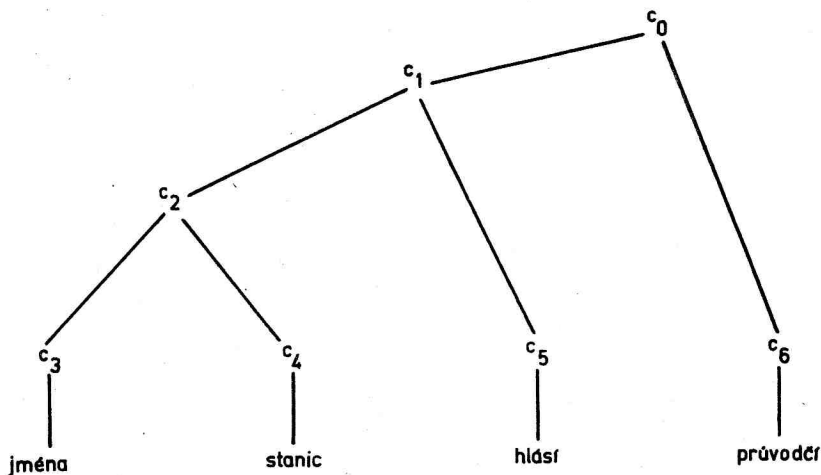


Figure 3

³⁾ For a different approach to the basic conceptions of syntactical description see (Hiž 60). For categorial theory cf. also Ajdukiewicz 35 and Curry-Feys-Craig 58.

dency theory all the vertices are labelled by pairs consisting of a word form and an appropriate grammatical category symbol (Figure 4). In categorial theory even two distinct uses of ordered rooted trees are possible, that is to say in both ways just mentioned (cf. Figure 5 according to Bar-Hillel 60, Figure 6 according to Suszko 58).⁴⁾ In Figures 3—6 the V- and H-conventions (see pp. 38 and 62) are adopted.

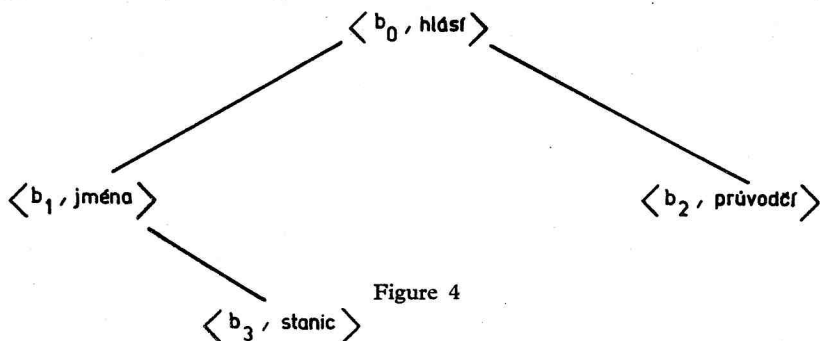


Figure 4

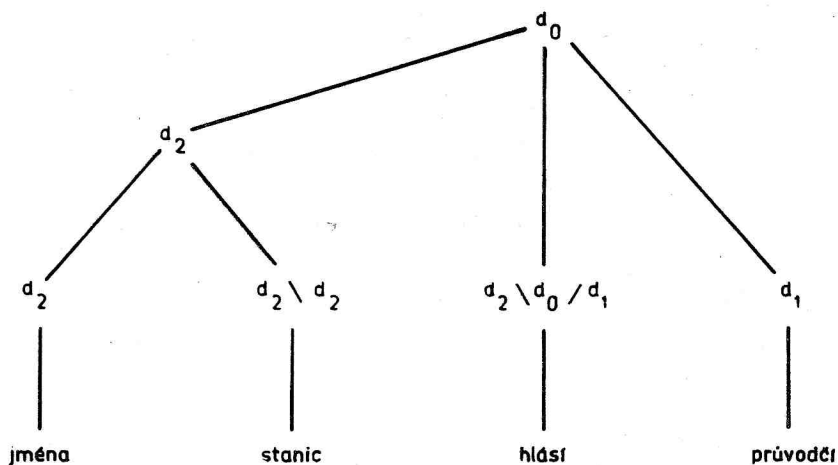


Figure 5

⁴⁾ More precisely, with Suszko the vertices are labelled by ordered triples of symbols, but it is tied up with the fact that Suszko analyses an artificial language of logic and not natural languages.

At this point one may ask whether such utilization of ordered rooted trees in all the three theories is merely “accidental” or whether this fact may be given an explanation. We should not overlook the economical nature, mentioned in 3.4, of rooted trees *qua* trees. In this the fact that the sentence is a whole organized in a rather economical way may be reflected. Not being able to say anything else on this topic, let us try to ask more specific questions.

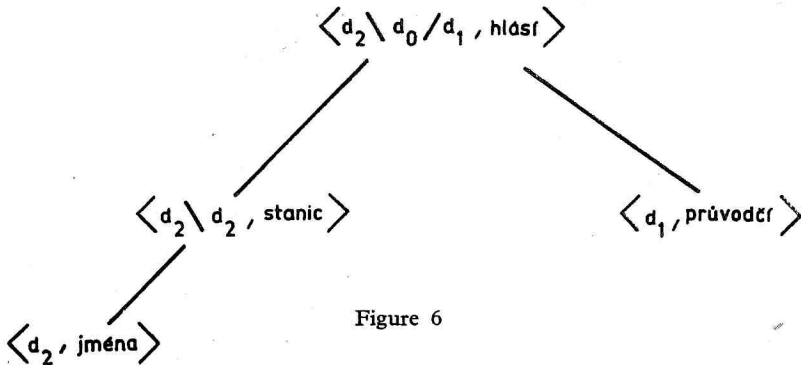


Figure 6

In Chapter Two we have learnt that there exist other structures so far unknown that may be represented by rooted trees. By this, in spite of our failure to apply the results in question to the language description, the possibility has emerged of the existence of still other structures that might be represented by rooted trees.

These considerations lead us to the formulation of our final question. (*) Are there any other kinds of specifying theories weakly equipotent to, say, context-free theory, from the point of view of which the syntactical structure of sentences specified may be represented by means of labelled (ordered) rooted trees?

To answer this question we have to state whether any other, and if any, which structures may be represented by (ordered) rooted tree and whether grammatical rules may be formulated by means of terms typical of these structures (cf. e.g. the notion of intersection vertex operation). If the question may be answered in the affirmative, about which I am rather sceptical, four possibilities may in principle occur, according to whether the “grammatical” rules in question would describe some new aspects of the syntactical structure of sentences or not, and whether the specifying theories would be

equipotent with the three kinds of specifying theories. It might be pertinent in this connection to examine on what assumptions one could arrive, given one of the so far known syntactical theories, say, dependency theory, only with paper and pen in one's hands, at the two others.

In any case, an answer to the question (*) or to any of its modifications which suggest themselves seems to be of considerable importance, because it might lead to a better understanding of what in our description of natural languages is given by properties of the languages and what is motivated by properties of our conceptual apparatus(es).

3.6 It seems to me that the preceding considerations give a hint for a terminological remark. If the expression 'application of mathematics' is understood simply as interpretation of some part of it (Čulík 65), a need is felt of a term for a more pragmatical notion. The word 'utilization' may serve this task. We may then say that utilization of results of mathematics in linguistics may be of various kinds and therefore we should not be surprised to meet, in linguistics, situations of a rather unusual kind. Of course, I do not insist on the terminology, but on due differentiation between the notions.

4. In conclusion, if we had to say what might be taken in Nebeský's monograph as linguistically relevant we could mention the following points: first, it either offers directly a solution to a linguistic problem (generalization of the notion of productivity) or gives rise, in a suitable context, to a very general and interesting problem (of the possible basic conceptions in syntax), second, it is also of tutorial value: a linguist has very seldom the opportunity to study a mathematical theory which deals with a notion which seems familiar to him, a theory which is worked out to quite a great depth and which requires at the beginning really minimal mathematical knowledge.

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