PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Procedural Theories of Linguistic Performance [and Discussion]

H. C. Longuet-Higgins and J. G. Wolff

Phil. Trans. R. Soc. Lond. B 1981 **295**, 297-304
doi: 10.1098/rstb.1981.0141

Phil. Trans. R. Soc. Lond. B **295**, 297–304 (1981)
Printed in Great Britain

Procedural theories of linguistic performance

By H. C. Longuet-Higgins, F.R.S.

Centre for Research in Perception and Cognition, Laboratory of Experimental Psychology, University of Sussex, Brighton, BN1 9QG, U.K.

In the modern theory of language it has been found useful to distinguish between questions of 'competence' and questions of 'performance'. The distinction has at least two aspects. First, it recognizes that the description of a language as such is logically distinct from an account of the way in which particular people use that language, but, secondly, it separates questions of grammaticality from questions about naturalness or intelligibility. It is argued that, while the former distinction is valuable, the latter has now outlived its usefulness. A generative grammar can be regarded as an adequate model of the ideal speaker's competence only if it is accompanied by a specification of processes by which ideas could be encoded in words, and these words subsequently decoded by the hearer. Examples are given of effective procedures, implemented as computer programs, for the performance of specific linguistic tasks; one of these, due to A. C. Davey, is a model of the production of connected English discourse; another, due to R. J. D. Power and myself, is a device that learns, from representative number–numeral pairs, the numeral systems of a variety of natural languages.

Introduction

In present-day discussions of language it is customary, as we have seen, to distinguish between questions of 'competence' and questions of 'performance'. The distinction has at least two aspects. First, it recognizes that the description of a language as such is logically distinct from an account of the way in which particular people use that language, but, secondly, it has been taken to imply that the cognitive processes that mediate the production and comprehension of utterances are a matter of indifference to linguistic theory. The former proposition needs no defence, but the latter, I shall argue, demands serious reconsideration.

The argument hinges on the concept of linguistic knowledge. Undoubtedly grammatical knowledge must count as an integral part of linguistic knowledge, because competent language users largely agree in their judgements of grammaticality. But to qualify as a competent speaker–listener a person must not only know *that* his language provides such-and-such grammatical resources; he must also know *how* to deploy these resources in communicating with other members of his linguistic community. 'Knowledge how' is no less essential to competence than 'knowledge that'; in the last resort we judge a person's linguistic competence by his ability to express himself coherently, and to understand what other people say.

A speaker's grammatical knowledge, according to Chomskyan theory (Chomsky 1956, 1965), can be represented by a generative grammar – an abstract automaton that generates an infinite set of linguistic expressions, together with their structural descriptions. On this view the generation of a sentence is a succession of mappings between syntactic structures, and it is the structural antecedents of a sentence that indicate its meaning, not just the words of which it is composed. The connection between linguistic expressions and their meanings is therefore indirect; it is only when a linguistic expression has been successfully generated, as it were, that the possibility arises of assigning a meaning to it.

It has often been stressed that a generative grammar is not to be regarded as a model of production or comprehension, and it is easy to see why. In actually producing a sentence, a speaker will have at least some idea of what he wants to say before he begins to speak. But we cannot suppose that he has to search through an infinite set of well-formed expressions for one that suits his meaning; clearly, he must have access to a systematic encoding procedure of some sort. The listener is faced with a converse problem, that of assigning a structural description to the sequence of words uttered by the speaker. But he, likewise, would get nowhere by blindly enumerating the sentences of the language in the hope of finding one with the right words in the right order; surely, he must have some way of parsing particular expressions – of proceeding from the words themselves to an appropriate structural description.

In short: if the theoretical linguist accepts the obligation of describing the ideal speaker–listener's competence; if he allows that linguistic competence includes the ability to say what one means and to attach meaning to what other people say; and if, as we can agree, a generative grammar has nothing to tell us about these matters; then standard linguistic theory is to that extent seriously incomplete, and we may feel entitled to ask the theoretical linguist for clear proposals as to how natural utterances might *in principle* be produced and understood.

The standard response is to issue a counter-challenge. If one wishes to regard a language as a code for the communication of meanings, then how is one to give an independent account of the meanings of linguistic expressions? In the absence of such an account we must conclude, it is said, that semantic concepts are of little or no use, either in the formulation of linguistic theory, or in the acquisition of language by real babies. (Syntax, like bath water, is so much easier to deal with.) A more constructive approach is to examine a semantically restricted area of linguistic communication and see what it might have to tell us about language in general. This is what I propose to do in this paper; my first example is one in which the problems of meaning are unusually tractable, and the grammatical phenomena relatively easy to describe, namely the numeral systems of natural languages.

Numeral systems

Numeral systems provide the linguist with a compact microcosm of language as a whole. They have been widely documented, and they vary considerably in the ways in which they represent the natural numbers. Table 1 shows how the natural number 97 is represented by the numeral systems of English, French, Mixtec and Biblical Welsh respectively.

Table 1

English	*ninety seven*	$(9\times 10)+7$
French	*quatre-vingt dix-sept*	$(4\times 20)+(10+7)$
Mixtec	*kuu siko siaqu uu*	$(4\times 20)+(15+2)$
Biblical Welsh	*onid dri cant*	$-3+100$

In his book *The linguistic theory of numerals*, Hurford (1975) discusses a variety of numeral systems within the framework of transformational grammar, and arrives at a number of broad generalizations about them.

1. The base grammars of all known numeral systems are highly recursive phrase structure grammars.

2. Unless further constrained, all numeral grammars generate a plethora of ill-formed

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

numerals such as *forty nineteen* or *sept vingt treize*; Hurford deals with this problem by invoking a constraint called the Packing Strategy, which uses *arithmetical* criteria for choosing between alternative expressions such as *forty nineteen* and *fifty nine*.

3. Any numeral containing an ill-formed constituent numeral is itself ill-formed.

The generality of these observations prompted Richard Power and myself to consider how a learner might actually acquire a natural numeral system from a representative list of number–numeral pairs presented in succession (Power & Longuet-Higgins 1978). Dictionaries normally provide exactly this kind of information, and leave it to the reader to induce the grammar for himself. The question immediately arose: what exactly does a person learn when he acquires a numeral system? What he learns, surely, is not just a set of rules for generating well-formed numerals and assigning arithmetical interpretations to them; he learns how to

Table 2

lexicon		rule	semantic component *M*		*N*	syntactic component
1	*ii*					
2	*uu*	(1)	10	+	(1...4)	⟨*M*⟩ ⟨*N*⟩
3	*uni*	(2)	15	+	(1...4)	⟨*M*⟩ ⟨*N*⟩
4	*kuu*	(3)	20	+	(1...19)	⟨*M*⟩ ⟨*N*⟩
5	*usu*	(4)	20	×	(2...19)	⟨*N*⟩ *siko*
6	*inu*	(5)	20 × (2...19)	+	(1...19)	⟨*M*⟩ ⟨*N*⟩
7	*uha*	(6)	400	×	(1...19)	⟨*N*⟩ *tuu*
8	*una*	(7)	400 × (1...19)	+	(1...399)	⟨*M*⟩ ⟨*N*⟩
9	*ee*					
10	*usi*					
15	*siaqu*					
20	*oko*					

express any number he pleases in words. A few numbers, of course, have single-word names that must be learned by rote; it is all the other numbers that make the problem interesting. Here the significance of Hurford's three generalizations becomes apparent: a nameless number must be systematically decomposed into numbers for which single-word names are available. Every numeral system has its own rules of decomposition, but they are inescapably arithmetical in nature. Both the decomposition rules and the corresponding syntactic forms must of course be learned in the process of acquiring the system.

Table 2 presents, in these terms, part of the Mixtec numeral system. (The orthography is a simplified version of that adopted by Merrifield (1968).) The lexicon is self-explanatory, but the rules deserve comment. First, each rule has both a syntactic and a semantic component. The semantic component is an arithmetical formula involving a major term M and a minor term N ($<M$), which are to be added or multiplied together as the case may be. The syntactic component indicates how the resulting number is to be realized syntactically; the symbols $\langle M \rangle$ and $\langle N \rangle$ denote the numerals corresponding to the major term and the minor term respectively. The symbols M and N themselves do not refer to grammatical categories, because a number that is the major term in one formula may be the minor term in another; this is a significant point of departure from Hurford's formalism, but in no way reflects upon his linguistic observations.

The information presented in table 2 suggests, almost explicitly, an algorithm for the encoding of numbers into numerals. Take for example the number 97. It belongs to the set of numbers specified in rule (5), with $M = (20 \times 4)$ and $N = 17$; its name is therefore given by the relation

$$\langle 97 \rangle = \langle 20 \times 4 \rangle \langle 17 \rangle .$$

The number 20×4 is, in turn, generated by the semantic component of rule (4), with $M = 20$, $N = 4$; and so

$$\langle 20 \times 4 \rangle = \langle 4 \rangle \textit{ siko} = \textit{kuu siko}.$$

17, on the other hand, is generated by rule (2) with $M = 15$, $N = 2$; the corresponding numeral is therefore

$$\langle 17 \rangle = \langle 15 \rangle \langle 2 \rangle = \textit{siaqu uu}.$$

Putting all these facts together, we finally obtain

$$\langle 97 \rangle = \textit{kuu siko siaqu uu}.$$

It is, of course, an open question whether the various steps in this derivation bear any close relation to the thoughts which pass through the mind of a Mixtec speaker when he tells another Mixtec speaker the number of counters in a pile. The point that I wish to stress is that a grammar that simply listed the syntactic forms of the numerals and the associated arithmetic operations would be quite useless to a speaker who wanted to put a particular number into words, if only because, as Hurford points out, such a grammar would generate far more ill-formed numerals than well-formed ones. It would, of course, be possible to capture all the *syntactic* information contained in table 2 by introducing a sufficient number of uninterpreted syntactic categories, but to do so would obscure the underlying rationale of the system: the fact that the arithmetic formulas specified by the rules are just sufficient to generate all the numbers from 1 to 7999 without leaving any gaps. Some languages – English among them – supply more than one numeral for a given number – *two dozen*, *four score* and *nineteen hundred* are obvious examples – but such superfluous expressions raise no issues of principle; they can be identified either as vestigial forms or as occasionally useful options.

It appears, then, that a grammar that incorporates semantic information can throw light on the process of production by showing how a given semantic entity such as a number must be structurally represented if it is to be realized by a linguistic expression. It is no surprise that different languages should solve this problem in different ways, though it would, of course, be a mistake to assume in advance that absolutely any meaning can be expressed in any language.

So much, then, for the production of numerals; what can be said about their comprehension? As Dr Gazdar has already reminded us, context-free languages, to which numeral systems approximate, are susceptible to a general parsing algorithm; but unfortunately the requisite number of steps is of order n^3, where n is the number of words in a typical string. Was it possible, we wondered, to find an algorithm that could parse the numerals of a natural language in a number of steps comparable with the *first* power of n? The existence of such an algorithm was by no means assured, but eventually we discovered one that succeeds in parsing the numerals of a wide variety of uninflected systems. Some of its features are, I think, relevant to the present discussion.

Unlike some other types of linguistic expression, numerals are (almost without exception) unambiguous; there is just one legitimate way of bracketing together the substrings of a many-word numeral. To operate as efficiently as possible, a parser, once it has inserted a pair of brackets, must never find it necessary to remove them. Since numerals exhibit both left- and right-branching constructions, the ideal parser cannot, therefore, work exclusively from left to right. Nor, for a different reason, can the parser insert outer brackets before inner ones; if it did, then a learner would be unable to discover constructions that make their first appearance at the highest level of a phrase marker, as in the numeral ((*one hundred*) *and one*). (This point should become clearer in a moment.)

The parsing algorithm that we eventually uncovered is, accordingly, a 'bottom-up' parser. It relies on the fact that in a given numeral each pair of brackets must embrace a major term and a minor term, but relatively few numbers can play the role of the major term in a sum or a product. In building the phrase marker – or rather, in evaluating a given numeral – the parser therefore looks for the smallest potential major term, and attempts to combine it, in this role, with one of its neighbours. The attempt may fail, or succeed with just one of the neighbours; but, if either mode of combination is possible, then multiplication takes precedence over addition or subtraction: ((*deux cent*) *trois*) not (*deux* (*cent trois*)). As soon as such a union is consummated, the resulting number becomes available, of course, for combination at the next level.

I mention these details as supporting evidence for the view that semantics may succeed, where syntax fails, in keeping a parser on course and thereby enhancing both its speed and its reliability. Numeral systems are, of course, much simpler in their semantics than other domains of discourse, but if semantic concepts, such as the relative magnitude of two numbers or the precedence of multiplication over addition, can be of such assistance in the parsing of numerals, might they not be of equal value in the comprehension of other types of utterance?

Having satisfied ourselves that arithmetical concepts could help to explain the production and comprehension of numerals, Power and I were still faced with one major challenge: could we discover an effective – and efficient – procedure for acquiring an unfamiliar numeral system from a representative but limited set of number–numeral pairs, presented in succession?

The central problem was to define the circumstances under which a new rule could safely be added to an existing partial grammar; the solution that we arrived at can best be explained by a simple example. Imagine that a learner of Mixtec has been told the names of the numbers from 1 to 10 and is then presented with the pair 11/*usi ii*. His first task is to assess the reliability of this datum – a problem to which most discussions of language acquisition are oddly inattentive. He already knows that *usi* means 10 and *ii* means 1, so he will naturally ask whether there is any simple arithmetic operation which combines 10 and 1 to give 11. The fact that there is such an operation speaks for the authenticity of the information presented; the fact that the operation is one of addition implies that the numeral *usi ii* designates the sum of 10 and 1. And finally, if any significance is to be attached to word order, the syntactic form of the given numeral can be described as one that juxtaposes the names of the two terms in the sum, with the name of the larger term preceding the name of the smaller one. The learner has now the germ of a grammatical rule, which may be stated in the form

$$\begin{array}{l} M \quad N \\ 10+1 : \langle M\rangle \langle N\rangle, \end{array}$$

though the rule as stated applies to only one case. But, if the next pair to be presented is 14/*usi kuu*, the learner can draw a similar set of inferences; and it then requires no great inductive leap to interpolate between 11 and 14, and arrive at the first rule of the Mixtec system, namely

$$\begin{array}{lll} & M & N \\ 10+ & (1\ldots 4) & : \langle M\rangle\langle N\rangle. \end{array}$$

Whether interpolation is or is not used in the acquistion of numeral systems, is a matter for psychological investigation. But the credibility of linguistic evidence is a quite general problem for theories of language acquisition. We have suggested that a number–numeral pair will be accepted as valid evidence in favour of a new grammatical rule only if it 'makes sense'; but the concept of a linguistic expression 'making sense' is obviously not limited to numeral systems, and may well be the key to grammar discovery. On this view, unintelligible utterances provide no evidence for or against putative grammatical rules; it is only when the evident meaning of an utterance bears a discernible relation to the meaning of its constituents that there are any solid grounds for identifying their juxtaposition as a syntactic construction rather than an accident of performance.

It is now time to draw some of these threads together. I have argued that the distinction between competence and performance, originally introduced to promote the objective description of language as such, may have led to the undervaluation of questions about production and comprehension, which, though in one sense aspects of linguistic performance, are none the less crucial to the ideal language-user's competence. The correct opposition, surely, is not between competence and performance – between linguistic knowledge and its deployment – but between competence and incompetence, in whatever linguistic attainment that one wishes to consider. In so far as knowing how to produce and interpret utterances is an essential part of the ideal speaker–hearer's competence, the logical description of these processes must count as one of the main goals of linguistic enquiry, and one that can hardly fail to illuminate the more traditional areas of grammatical concern.

It may be felt that the example that I have used for illustration, the numeral systems of natural languages, is uncharacteristic of language as a whole, because of the exceptional clarity of its semantics. This clarity was, of course, the reason why Power and I used numerals as a paradigm of language acquisition, but one can, in fact, point to other semantic domains where the processes of production and comprehension have yielded to formally precise description. One such model, which addresses a number of further linguistic issues, is that of A. C. Davey, who developed a model of the production of connected English discourse and implemented it as a computer program. The universe of discourse was childishly simple – the game of noughts and crosses – but the discourse that the program generated was fully adult. I should stress, at this point, that every commentary that Davey's program produces is composed *de novo* from a lexicon and a systemic grammar, with the aid of a pragmatic component specially tailored to the rules and strategy of the game; and also that there are upwards of 20000 non-equivalent legal games of noughts and crosses, on any one of which the program will produce a coherent commentary. Here is one such commentary:

> I started the game by taking the middle of an edge, and you took an end of the opposite one. I threatened you by taking the square opposite the one I had just taken, but you blocked my line and threatened me. However, I blocked your diagonal and threatened you. If you

had blocked my edge, you would have forked me, but you took the middle of the one opposite the corner I had just taken and adjacent to mine and so I won by completing my edge.

The principles underlying the progam are fully described in Davey's book (Davey 1979). Here I can only draw attention to the orderly arrangement of the sentences, the felicitous uses of coordination and subordination, of definite and indefinite noun phrases, contrastive adverbs and conjunctions, of the counterfactual hypothetical, and of pronominal and other sorts of anaphoric reference.

I shall conclude with two general observations.

First, we may disagree as to whether or not linguistics is a branch of psychology; but, in so far as language is a manifestation of cognitive activity, the description of this activity is of no less concern to the linguist than to the psychologist, and it is difficult to see how one could describe the cognitive processes of production and comprehension in other than procedural terms.

Secondly, although vast areas of meaning and use still elude formal description – computers are much too stupid to appreciate them – teachers of language can convey to their pupils, in whatever meta-language suits the occasion, the semantic and pragmatic applications of particular constructions, and the conventions that govern the use of particular types of expression. So, while it is always reassuring to see a formal theory emerge unscathed from a computer implementation, it would certainly be overzealous to decree that what cannot be explained to a computer is, *ipso facto*, inexplicable.

I am indebted to P. N. Johnson-Laird for helpful comments, and to the Royal Society and the Science Research Council for research support.

Bibliography (Longuet-Higgins)

Chomsky, N. 1956 *Syntactic structures*. The Hague: Mouton.

Chomsky, N. 1965 *Aspects of the theory of syntax*. Cambridge, Massachusetts: M.I.T. Press.

Davey, A. C. 1979 *Discourse production*. Edinbugh University Press.

Davey, A. C. & Longuet-Higgins, H. C. 1978 A computational model of discourse production. In *Recent advances in the psychology of language* (ed. R. N. Campbell & P. T. Smith), vol. 3, part 4b, p. 125.

Hurford, J. R. 1975 *The linguistic theory of numerals*. Cambridge University Press.

Merrifield, W. R. 1968 In *Grammars for number names* (*Foundations of language, supplementary series*, vol. 7) (ed. H. B. Corstius), pp. 91–102. Dordrecht: Reidel.

Power, R. J. D. & Longuet-Higgins, H. C. 1978 Learning to count: a computational model of language acquisition. *Proc. R. Soc. Lond.* B **200**, 391–417.

Discussion

J. G. Wolff (*Department of Psychology, University of Dundee, U.K.*). I am sure that Professor Longuet-Higgins will agree that many ungrammatical utterances make perfectly good sense, and that some grammatical utterances do not – or, at least, are difficult to interpret. How can these facts be reconciled with the hypothesis that the learner uses 'making sense' as a criterion of grammaticality?

H. C. Longuet-Higgins. The point that I was trying to make is that a rule of grammar specifies not merely a syntactic form but also a type of semantic construct that can be expressed in that form; I was suggesting that a grammatical rule can only be discovered if the form and the

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

construct are simultaneously apparent to the learner. Unintelligible utterances therefore provide no evidence for or against grammatical rules, but intelligible utterances with a discernible (though anomalous) syntactic form may indeed be taken as evidence by the learner: children tend to pick up their parents' grammatical idiolects, just as they copy their 'accents'.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES