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Computer Programs for Translation

A simple model for sentence construction, devised as a first step toward mechanical translation, is beginning to show why English and other languages are so ingeniously complicated

by Victor H. Yngve

A schoolboy studying his first foreign language sometimes asks: "Why do they say it that way?" Often the reply is: "Because that's the way it is in the language. Don't ask why, just learn it." As a matter of fact in many cases nobody knows the answer to such a question. Recently, however, a possible answer to some of the questions as to why language is the way it is has come from an unsuspected quarter: research on the mechanical translation of languages by electronic computer.

As long as we keep to our native tongue and are not obliged to explain its quirks to others, we rarely appreciate just how complicated language is. It appears that even widely different languages are complicated to much the same extent. The usefulness of some of the complications is clear. Word order or case endings frequently serve to indicate whether a phrase is playing the role of a subject, an object or something else. But then there is a seemingly endless catalogue of other complications with no apparent utility, and the traditional grammar book does little to point out the reason for these complications. Faced with the many complexities of language, about the best a grammar or language textbook can do is to justify certain usages "as a matter of euphony" and to condemn others as "awkward" or "stylistically poor." Such vague explanations are of little help to the student who has not yet developed a feeling for the language. They are almost useless to someone who is trying to analyze a language rigorously, with a view to mechanical translation.

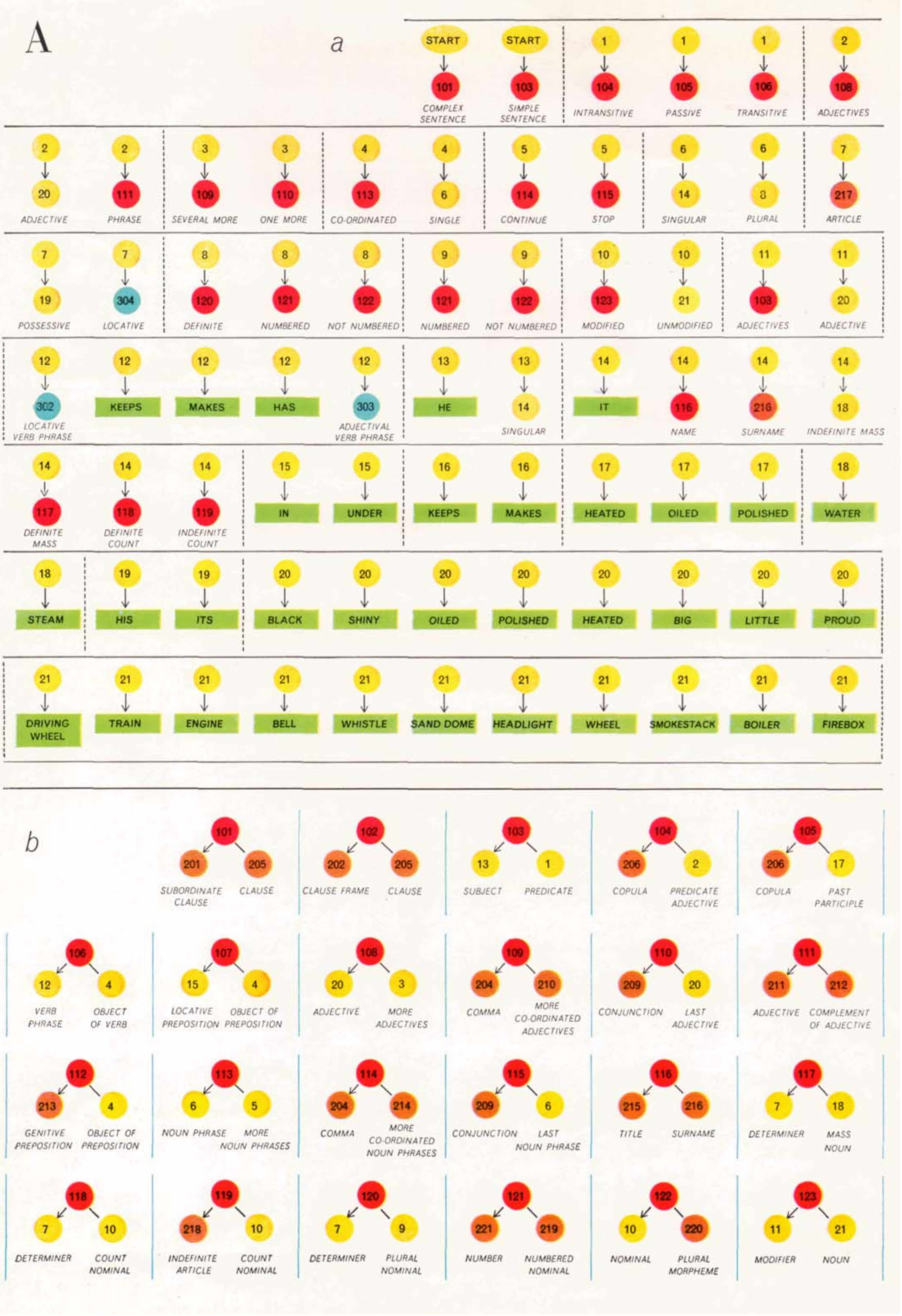
Why, for instance, do we say "He called *her up*" but not "He called *up her*," when we can say both "He called *the girl up*" and "He called *up the girl*"? Why do we have two ways of saying the same thing, for example, "He gave *the girl the candy*" and "He gave *the candy to the girl*"? Also we have "*The woodsman* chopped down *the tree*" and "*The tree* was chopped down by *the woodsman,*" where the passive sentence appears to have the same meaning as the active one. Other anomalies concern the placement of modifiers. Adjectives generally precede the noun, but relative clauses follow. We say "a *worn-out* car" and "a car *that is worn out.*" Some modifiers are actually split, part going before the noun and part after: "*too worn-out* a car *to drive,*" "a *more priceless* possession *than jewels*" and "*the best* friend *in the world.*" The list could fill a volume. It is remarkable that the human brain can cope with such a vast catalogue of complications. It sometimes seems as though language is just about as complex as it can be without making it impossible for an average individual to learn it in his preadult years.

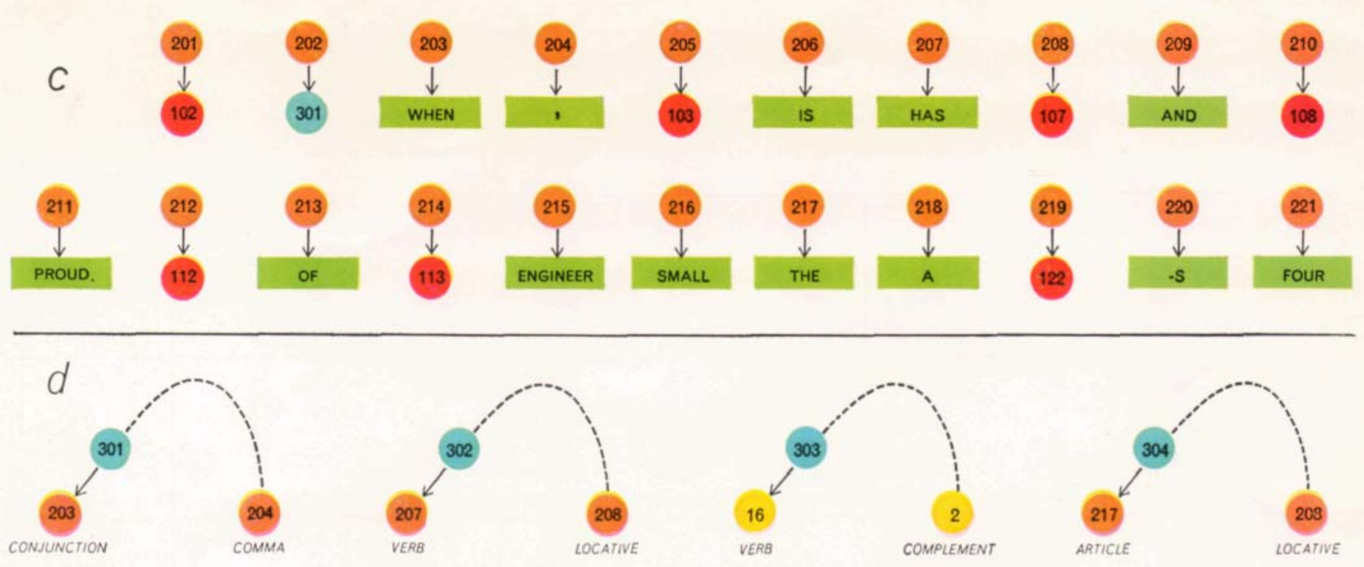
One would expect that a simpler language would have a utilitarian advantage. A basic puzzle is why English and other Western languages employ four major parts of speech: verbs, nouns, adjectives and adverbs. It can be shown by means of logical notation schemes that two parts of speech and a single rule for word order could provide, in principle, an artificial language as expressive as English. Why, then, is English so complicated? The usual explanation for the four main parts of speech does not stand up to careful examination. It is not invariably true that verbs express actions or states of being, that nouns are the names of persons, places or things, and so on. That is, even if one knows the semantic class of the thing referred to, one cannot invariably determine the correct part of speech to use. A given concept may at different times be referred to by different parts of speech: "They *projected* the pictures very clearly"; "The *projection* of the pictures was very clear"; "They were very clearly *projected* pictures."

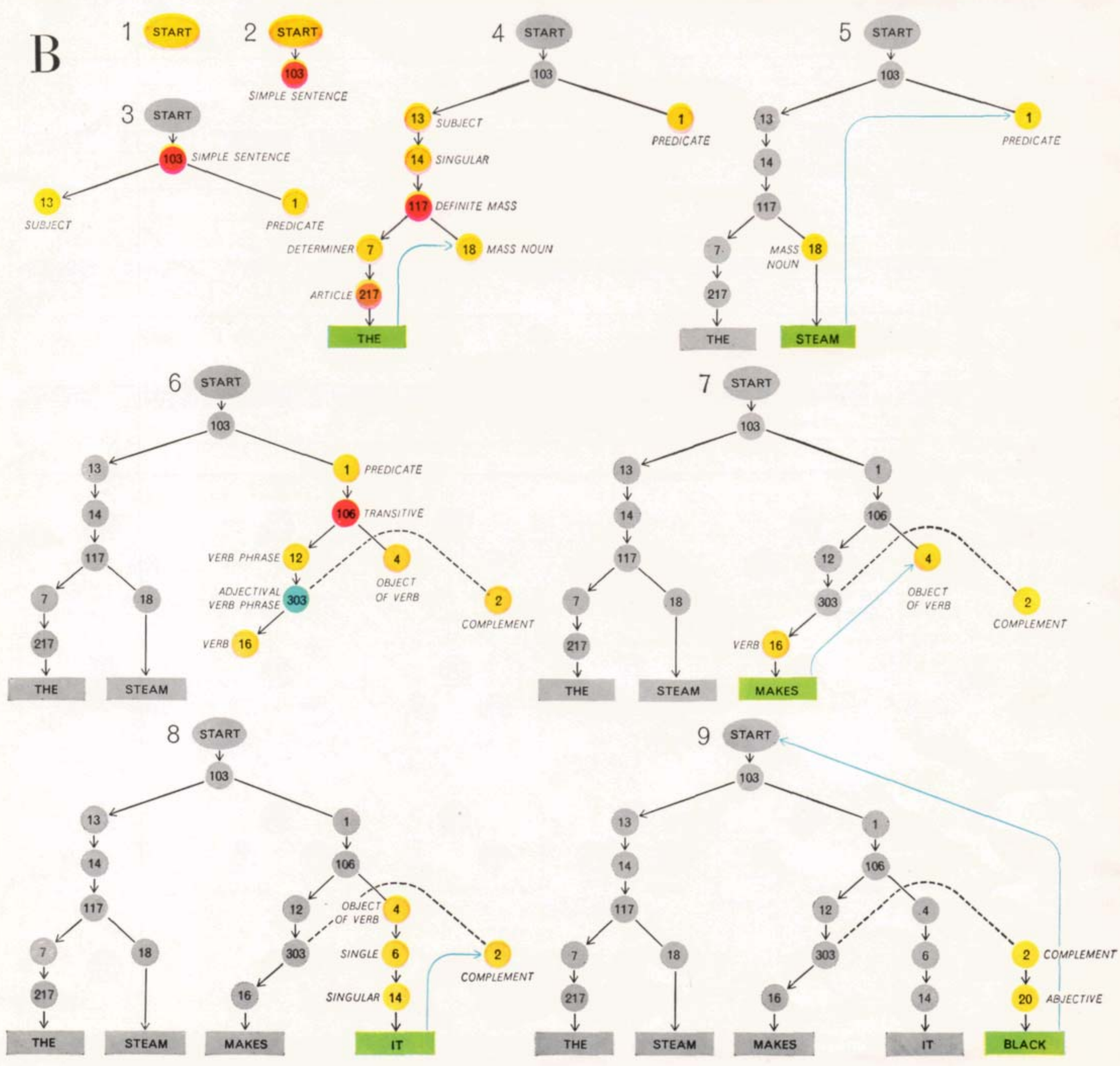
Our main schoolboy question, therefore, is whether all these complications serve a useful function in the language or whether they are sheer dead weight. It is this question that research in mechanical translation may have elucidated. An answer to the question would do more than satisfy our curiosity. In view of all the complications of language, it seems almost too much to hope that we will ever be able to program machines to handle human language adequately unless we can achieve a deeper understanding of how and why languages operate.

The possibility of applying machines of the digital-computer type to the twin problems of mechanical translation and information retrieval has spurred an increasing number of workers to reexamine language. If we could perfect a translating machine, a great stride would have been made toward removing language barriers. If we could perfect an information-retrieval machine, the

SIMPLE GRAMMAR sufficient for the first 10 sentences of a children's book is described in *A (four tables on opposite page and at the top of page 70)* in terms of a series of building blocks. Each arbitrarily numbered circle is a potential "node," controlling one step in the sentence-building process. Table *a* lists the nodes at which the computer can choose among several possibilities; *b* indicates the constituents of various grammatical constructions; *c* gives the nodes at which the computer has only one choice; *d* lists discontinuous constructions.


A
a
START 101 COMPLEX SENTENCE
START 103 SIMPLE SENTENCE
1 104 INTRANSITIVE
1 105 PASSIVE
1 106 TRANSITIVE
2 108 ADJECTIVES
2 20 ADJECTIVE
2 111 PHRASE
3 109 SEVERAL MORE
3 110 ONE MORE
4 113 CO-ORDINATED
4 6 SINGLE
5 114 CONTINUE
5 115 STOP
6 14 SINGULAR
6 8 PLURAL
7 217 ARTICLE
7 19 POSSESSIVE
7 304 LOCATIVE
8 120 DEFINITE
8 121 NUMBERED
8 122 NOT NUMBERED
9 121 NUMBERED
9 122 NOT NUMBERED
10 123 MODIFIED
10 21 UNMODIFIED
11 108 ADJECTIVES
11 20 ADJECTIVE
12 302 LOCATIVE VERB PHRASE
12 KEEPS
12 MAKES
12 HAS
12 303 ADJECTIVAL VERB PHRASE
13 HE
13 14 SINGULAR
14 IT
14 116 NAME
14 216 SURNAME
14 18 INDEFINITE MASS
14 117 DEFINITE MASS
14 118 DEFINITE COUNT
14 119 INDEFINITE COUNT
15 IN
15 UNDER
16 KEEPS
16 MAKES
17 HEATED
17 OILED
17 POLISHED
18 WATER
18 STEAM
19 HIS
19 ITS
20 BLACK
20 SHINY
20 OILED
20 POLISHED
20 HEATED
20 BIG
20 LITTLE
20 PROUD
21 DRIVING WHEEL
21 TRAIN
21 ENGINE
21 BELL
21 WHISTLE
21 SAND DOME
21 HEADLIGHT
21 WHEEL
21 SMOKESTACK
21 BOILER
21 FIREBOX
b
101 201 SUBORDINATE CLAUSE 205 CLAUSE
102 202 CLAUSE FRAME 205 CLAUSE
103 13 SUBJECT 1 PREDICATE
104 206 COPULA 2 PREDICATE ADJECTIVE
105 206 COPULA 17 PAST PARTICIPLE
106 12 VERB PHRASE 4 OBJECT OF VERB
107 15 LOCATIVE PREPOSITION 4 OBJECT OF PREPOSITION
108 20 ADJECTIVE 3 MORE ADJECTIVES
109 204 COMMA 210 MORE CO-ORDINATED ADJECTIVES
110 209 CONJUNCTION 20 LAST ADJECTIVE
111 211 ADJECTIVE 212 COMPLEMENT OF ADJECTIVE
112 213 GENITIVE PREPOSITION 4 OBJECT OF PREPOSITION
113 6 NOUN PHRASE 5 MORE NOUN PHRASES
114 204 COMMA 214 MORE CO-ORDINATED NOUN PHRASES
115 209 CONJUNCTION 6 LAST NOUN PHRASE
116 215 TITLE 216 SURNAME
117 7 DETERMINER 18 MASS NOUN
118 7 DETERMINER 10 COUNT NOMINAL
119 218 INDEFINITE ARTICLE 10 COUNT NOMINAL
120 7 DETERMINER 9 PLURAL NOMINAL
121 221 NUMBER 219 NUMBERED NOMINAL
122 10 NOMINAL 220 PLURAL MORPHEME
123 11 MODIFIER 21 NOUN


c
201 102
202 301
203 WHEN
204 ,
205 103
206 IS
207 HAS
208 107
209 AND
210 108
211 PROUD.
212 112
213 OF
214 113
215 ENGINEER
216 SMALL
217 THE
218 A
219 122
220 -S
221 FOUR
d
301 203 CONJUNCTION 204 COMMA
302 207 VERB 208 LOCATIVE
303 16 VERB 2 COMPLEMENT
304 217 ARTICLE 208 LOCATIVE


B
1 START
2 START 103 SIMPLE SENTENCE
3 START 103 SIMPLE SENTENCE 13 SUBJECT 1 PREDICATE
4 START 103 13 SUBJECT 14 SINGULAR 117 DEFINITE MASS DETERMINER 7 ARTICLE 217 THE 18 MASS NOUN 1 PREDICATE
5 START 103 13 14 117 7 217 THE MASS NOUN 18 STEAM 1 PREDICATE
6 START 103 13 14 117 7 217 THE 18 STEAM 1 PREDICATE 106 TRANSITIVE VERB PHRASE 12 ADJECTIVAL VERB PHRASE 303 VERB 16 4 OBJECT OF VERB 2 COMPLEMENT
7 START 103 13 14 117 7 217 THE 18 STEAM 1 106 12 303 VERB 16 MAKES 4 OBJECT OF VERB 2 COMPLEMENT
8 START 103 13 14 117 7 217 THE 18 STEAM 1 106 12 303 16 MAKES OBJECT OF VERB 4 SINGLE 6 SINGULAR 14 IT 2 COMPLEMENT
9 START 103 13 14 117 7 217 THE 18 STEAM 1 106 12 303 16 MAKES 4 6 14 IT 2 COMPLEMENT 20 ABJECTIVE BLACK

wisdom accumulated in the libraries of the world would be made much more readily available. Effective indexing, abstracting and retrieval may require a deeper understanding of the languages used than anyone now possesses.

The history of mechanical-translation research is brief. Much of the early work, some 10 years ago, contemplated little more than word-for-word substitution. It was hoped that the output of such a word-for-word device would be good enough to be of some use to the scientist who wanted to know what was in an article written in a foreign language [see "Translation by Machine," by William N. Locke; SCIENTIFIC AMERICAN, January, 1956]. Presumably the reader's general knowledge of the subject matter would let him fill in wherever the output of the machine was obscure. That hope collapsed when it became obvious that a mere word-for-word translation was so poor as to be nearly worthless. Another approach, still in progress, is a pragmatic effort to improve the word-for-word translation by fixing up its most serious shortcomings, using any measures that seem to work. Those employing this approach hope to obtain, within a reasonable time, translations of practical value for some purposes. The results of such programs are often impressive, but looks are deceiving: in the flow of English words there lie many hidden inaccuracies and mistakes. It is becoming clearer that although 80 per cent of the translation problems can be solved rather easily with these crude methods, the remaining 20 per cent are very difficult, and it is this 20 per cent that make all the difference between an acceptable and an unacceptable translation.

It looks as though there are no short cuts. Nothing less than a careful and thorough study of the basic problems of grammar and syntax will do. One needs a complete catalogue of the structure of each language, a catalogue with a degree of explicitness never before achieved. This is because information for the use of an unthinking machine must be more tediously explicit than information for human use. Every "feeling" about language that the computer is to display must be first understood by the human programmer, then broken down into its elements and written into the machine program. With such a program one can hope to obtain translations much better than any obtainable by a pragmatic approach.

As a first step in this direction, I began thinking some time ago how one could prepare a catalogue of the intricacies of sentence structure that would fit the needs of a computer. Of course, a description of a language is static, and a computer program for handling language is dynamic. It seemed reasonable that the two could be separated. The computer would be provided with a description of the linguistic facts, stored in lists or tables, together with a program capable of referring to the stored facts while the computer carried out its translating operations on the text it was processing.

The separation seemed attractive because linguists had already considered how a language might be described. Most of the proposed methods of description are variations of what are known as phrase-structure or immediate-constituent models, where a sentence is divided successively into smaller and smaller parts. Commonly an English sentence is viewed as having two parts: a subject and a predicate. Each of these parts is viewed in turn as having two (or more) parts, until one gets down to words or to morphemes, the smallest units that have meaning.

Such analytical methods work quite well most of the time but run into complications when they try to deal with discontinuous constituents. For example, two or more words that form a single construction are often separated by other words in the sentence. Examples are *called up* in "He *called* her *up*," *can see* in "Can he see through the fog?" *what for* in "*What* did he use it *for*?" and *best at any price* in "the best car at any *price*." One of the problems is to specify just how much material is enclosed between the first and second part of each discontinuous constituent.

I have adopted a system for describing the facts of a language that is close to the better traditional ways of representing linguistic structure. The description is composed of four tables, which are reproduced on page 69 and at the top of the opposite page. The first table (*a*) reflects the freedom of choice existing in the language—between singular and plural, for example. Other tables indicate various kinds of grammatical construction, together with their immediate constituents. The way to represent adequately discontinuous constituents, shown in table *d*, became clear only after I had decided how a computer could be programmed to construct relatively simple sentences using the basic description scheme. The tables shown, representing the first attempt at this method of description, include only enough of the structure of English to be able to handle the first 10 sentences of *The Little Train*, a well-known children's book written and illustrated by Lois Lenski.

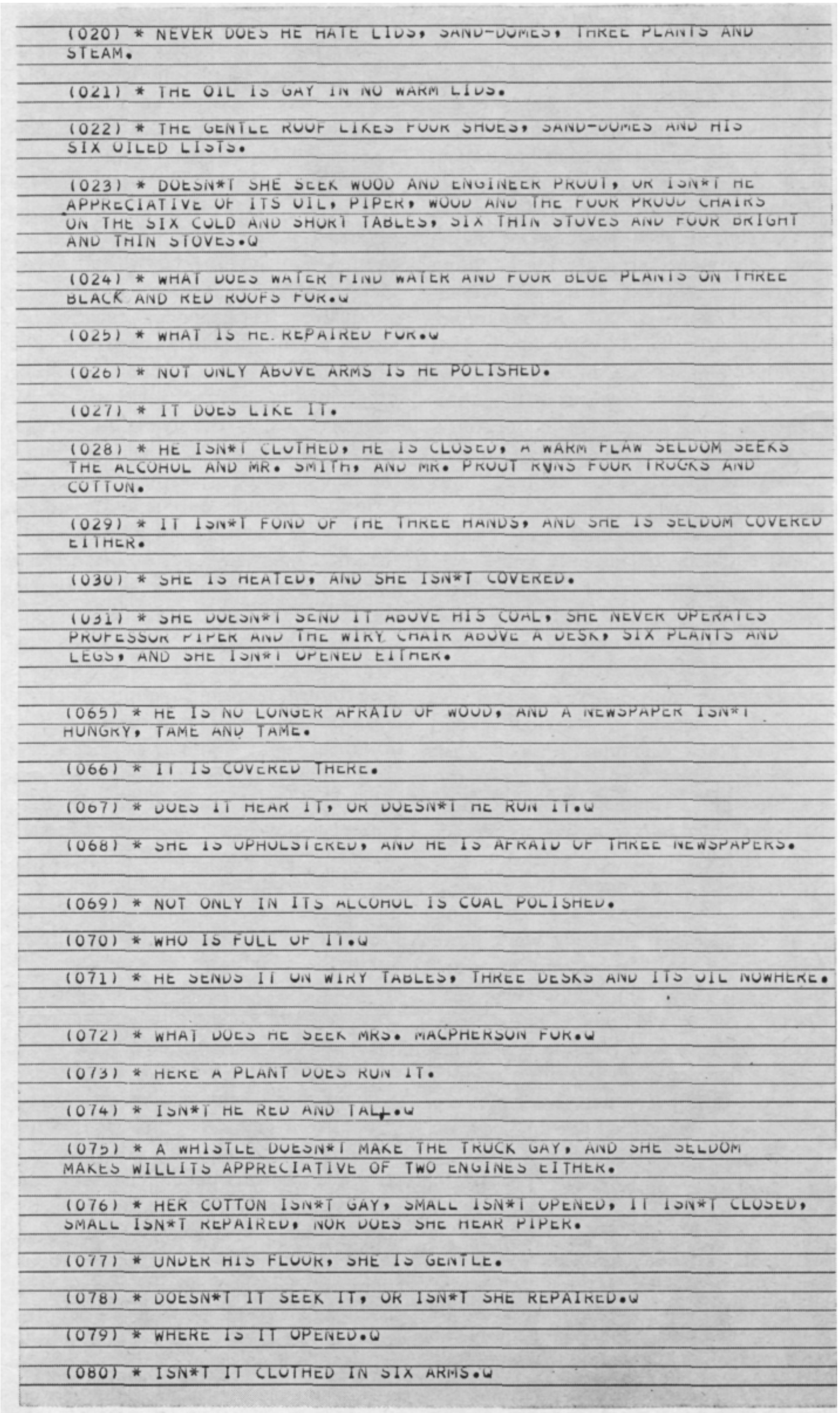
The program for constructing sentences, designed for use in a general-purpose digital computer, is straightforward and operates well [*see illustration B on opposite page*]. Whenever there is a choice point in the program, the computer chooses at random. The resulting sentences conform only to the grammatical constraints represented in the tables, and if the sentences appear to be ungrammatical, one can go back and correct the tables. The program therefore turns out to be a valuable research tool for checking the accuracy of the descriptions. Without some such check it is practically impossible to produce an accurate, error-free description of a language.

A number of sample sentences, produced by a computer provided with a vocabulary of about 225 words, appear on the following page. The sentences embody improvements in language description suggested largely by the work of Edward S. Klima and added to the program with the help of George Monroe. (Klima and Monroe have been working with me at the Massachusetts Institute of Technology.) The sentences are of course lacking in meaning because the program is concerned only with sentence structure. If the program were adapted for language translation, the word choices would be governed by the text being translated. A more advanced

COMPUTER CONSTRUCTS SENTENCE by working its way from node to node as shown in the numbered sequence of steps in B on the opposite page. There is always a "current node," which controls the next step. The reader can follow the computer's procedure by noting the color and number of the current node, referring to that node in the proper table in illustration *A* and choosing the corresponding lower node, which becomes the new current node. If the node is yellow, a choice is available; the machine makes this choice at random. If the node is orange, only one choice is provided. If the node is red, the lower left-hand node under it becomes the new current node and the one at the right is a "remembered node." If the node is blue, the procedure is the same except that the remembered node must be delayed until later in the sentence. Each word in a green rectangle is a word in the sentence; after it is in place the next current node is found by moving up and to the right (*blue lines*) until the next remembered node is encountered, or back to *START* to begin a new sentence.

program for French is being developed by David A. Dinneen, and a good beginning of a description of Arabic has been made by Arnold C. Satterthwait as a part of his experimental program for translating Arabic into English. Other members of our group are working on a German program, which is already more complete than the English one.

Close examination of the properties of such programs reveals some rather interesting points. Although the grammar consists of a finite number of rules, the program can produce a sentence of any length, and therefore any sentence chosen from an infinite set of sentences. It can do this by making choices in such a way that it repeatedly returns to the same node number. An example of such repetition is shown at the top of the opposite page, where the node 108 (adjectives) can give rise to a potentially infinite string of adjectives. Node 113 behaves similarly, as does node 117 in a slightly more complicated way to produce “the water under the wheels under the firebox under the boiler.” There are many examples of this sort of recursiveness in English (“I imagined him listening to the announcer reporting Bill catching Tom stealing third base”). Thus one sees that our grammar and program is satisfactory in this respect as a model for English.



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(020) * NEVER DOES HE HATE LIDS, SAND-DOMES, THREE PLANTS AND
STEAM.

(021) * THE OIL IS GAY IN NO WARM LIDS.

(022) * THE GENTLE ROOF LIKES FOUR SHOES, SAND-DOMES AND HIS
SIX OILED LISTS.

(023) * DOESN*T SHE SEEK WOOD AND ENGINEER PROUT, OR ISN*T HE
APPRECIATIVE OF ITS OIL, PIPER, WOOD AND THE FOUR PROUD CHAIRS
ON THE SIX COLD AND SHORT TABLES, SIX THIN STOVES AND FOUR BRIGHT
AND THIN STOVES.Q

(024) * WHAT DOES WATER FIND WATER AND FOUR BLUE PLANTS ON THREE
BLACK AND RED ROOFS FOR.Q

(025) * WHAT IS HE. REPAIRED FOR.Q

(026) * NOT ONLY ABOVE ARMS IS HE POLISHED.

(027) * IT DOES LIKE IT.

(028) * HE ISN*T CLOTHED, HE IS CLOSED, A WARM FLAW SELDOM SEEKS
THE ALCOHOL AND MR. SMITH, AND MR. PROUT RUNS FOUR TRUCKS AND
COTTON.

(029) * IT ISN*T FOND OF THE THREE HANDS, AND SHE IS SELDOM COVERED
EITHER.

(030) * SHE IS HEATED, AND SHE ISN*T COVERED.

(031) * SHE DOESN*T SEND IT ABOVE HIS COAL, SHE NEVER OPERATES
PROFESSOR PIPER AND THE WIRY CHAIR ABOVE A DESK, SIX PLANTS AND
LEGS, AND SHE ISN*T OPENED EITHER.


(065) * HE IS NO LONGER AFRAID OF WOOD, AND A NEWSPAPER ISN*T
HUNGRY, TAME AND TAME.

(066) * IT IS COVERED THERE.

(067) * DOES IT HEAR IT, OR DOESN*T HE RUN IT.Q

(068) * SHE IS UPHOLSTERED, AND HE IS AFRAID OF THREE NEWSPAPERS.


(069) * NOT ONLY IN ITS ALCOHOL IS COAL POLISHED.

(070) * WHO IS FULL OF IT.Q

(071) * HE SENDS IT ON WIRY TABLES, THREE DESKS AND ITS OIL NOWHERE.


(072) * WHAT DOES HE SEEK MRS. MACPHERSON FOR.Q

(073) * HERE A PLANT DOES RUN IT.

(074) * ISN*T HE RED AND TALL.Q

(075) * A WHISTLE DOESN*T MAKE THE TRUCK GAY, AND SHE SELDOM
MAKES WILLITS APPRECIATIVE OF TWO ENGINES EITHER.

(076) * HER COTTON ISN*T GAY, SMALL ISN*T OPENED, IT ISN*T CLOSED,
SMALL ISN*T REPAIRED, NOR DOES SHE HEAR PIPER.

(077) * UNDER HIS FLOOR, SHE IS GENTLE.

(078) * DOESN*T IT SEEK IT, OR ISN*T SHE REPAIRED.Q

(079) * WHERE IS IT OPENED.Q

(080) * ISN*T IT CLOTHED IN SIX ARMS.Q
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COMPUTER PROSE shown in this read-out was produced by a digital computer programed as in the illustrations on pages 69 and 70 but with a larger vocabulary and more advanced grammar. Many of the sentences are nonsensical, although grammatical, because the program was concerned only with sentence structure and words were selected at random.

It is probably clear from the illustrations that the program operates with remembered nodes. Each time the computer embarks on the beginning of a construction (for example, a subject) it stores a remembered node (such as a predicate) so that it will be sure to follow the first part of the construction by an appropriate second part. But if indefinitely long sentences can be produced, how much temporary memory will have to be provided in the computer for storing the remembered nodes? An unlimited amount? Let us examine this question. The bottom illustration on the opposite page contains at the left a “regressive" structure. We call it regressive because the machine has to go down the stem expanding *1, 2, 3, 4* and *5,* storing a number of nodes in its memory (here four); then it has to go back up, expanding in turn the branches growing from *a, b, c* and *d.* This regressive structure has a “depth” of four. The depth of a node is numerically equal to the number of remembered nodes when that node is about to be expanded. On the right side of the same illustration is a “progressive” structure. The machine can continue down the main stem, expanding as it goes, never retracing its steps and putting only one node away in its temporary memory at each step. After each expansion it returns to the main stem and expands the node remaining in its memory. It is clear that as regressive structures grow longer and longer they require more and more memory. Progressive structures, however, do not. They can continue indefinitely with a minimum of memory.

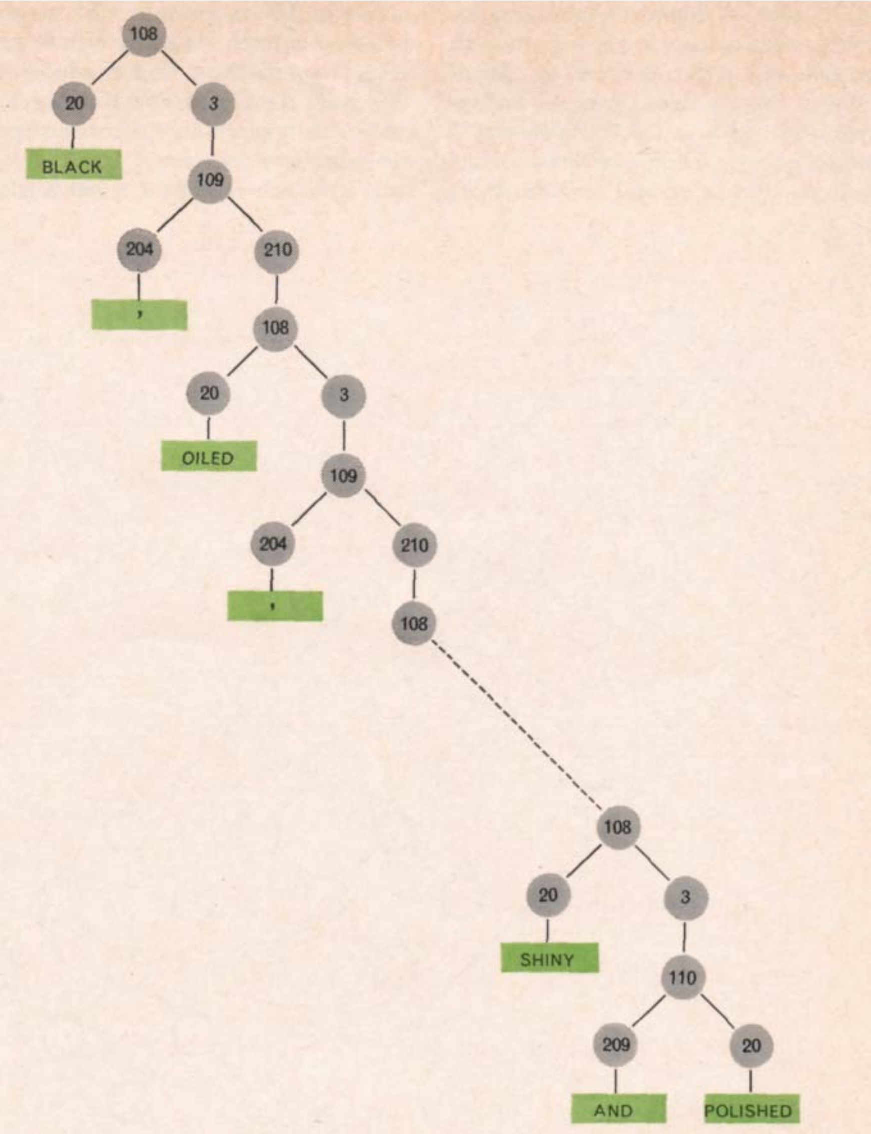
Let us consider what would happen if the memory had room for only three remembered nodes at a time. In this case it could produce the sort of structure shown in the upper illustration on the following page, but it would not be able to produce any structure that would penetrate the broken line. If the machine is to have a limited temporary memory, it will have to have some means of restricting its operation if it is to function correctly. One possibility would be to add to the program an alarm much like a typewriter bell that would give warning when the temporary memory was nearly full. At this point the freedom of choice in the grammar could be restricted so that no more remembered nodes would be produced until there was room again in the memory. Another possibility would be to leave the program as it is, without an alarm, and restrict the grammar in such a way that its rules can be reapplied to produce arbitrarily long sentences of the progressive type, but not those of the regressive type beyond a certain depth. Restrictions of this kind could lead to severe complications in the grammar.

In order to determine whether either of these possibilities or some other possibility would be reasonable, I looked again carefully at some of the constructions of English and discovered that many of the previously puzzling complications of the language fall into place as devices in the grammar for restricting the depth of sentences to about seven. Many other complications evidently serve to maintain the expressive power of the language in the face of this rather severe restriction of depth. I framed the hypothesis that all languages will have grammatical and syntactic complications to serve the same purposes.

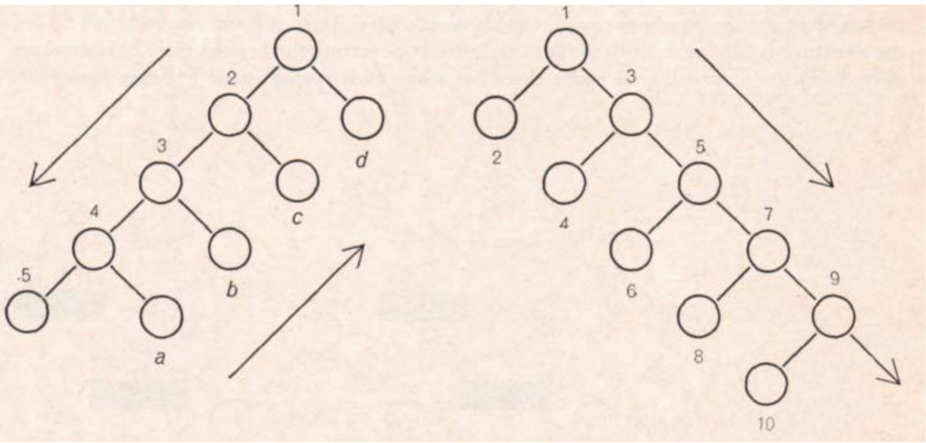
A limit of seven for the temporary memory in our model checks with the span of immediate memory measured by psychologists. We are able to memorize at a glance and repeat back correctly about seven random digits, or about seven nonsense words, or about seven items.

Such a depth limit would not apply to schemes of notation used in mathematics and logic because the mathematician or logician, working on paper, can look back at what he has written. He need not keep it all in his head. Thus workable mathematical and logical notations can have a simple structure.

There are many complications of English that appear to be related to a limited temporary memory. I shall discuss only a few illustrative examples. It is now possible to see the usefulness of the parts-of-speech system in English. It provides a method of tagging nodes to



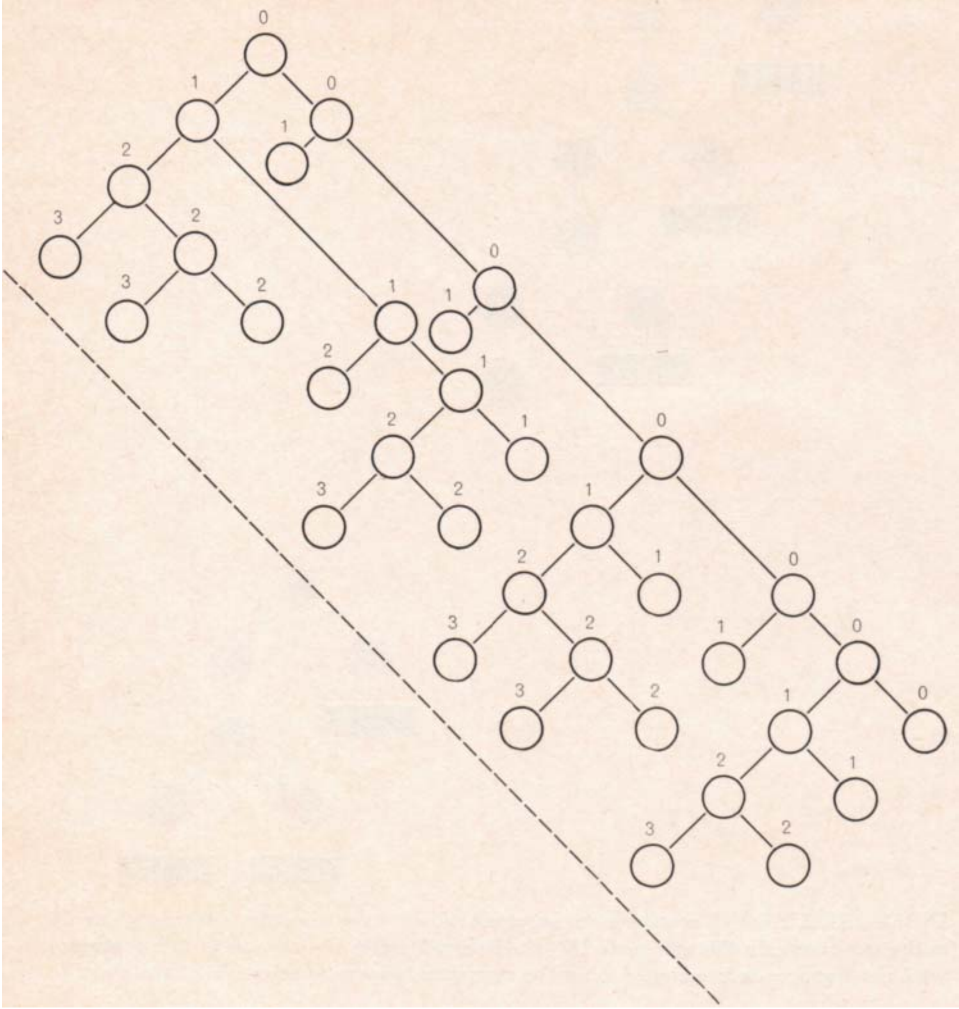
INDEFINITELY LONG sentences can be produced when the computer returns repeatedly to the same node. In this case node 108 ("adjectives") gives rise to a chain that continues until the sequence is interrupted when the computer happens to select 110 ("one more").



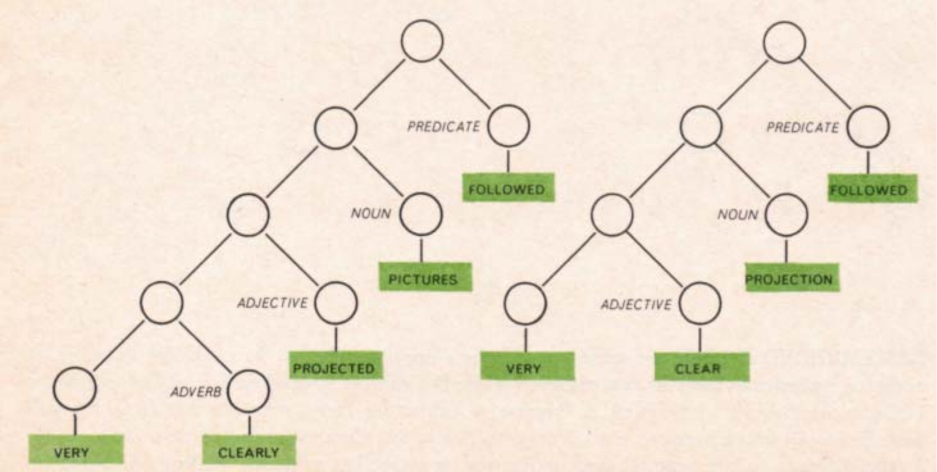
REMEMBERED NODES are stored to tell the computer what to do next. For example, a node for a predicate must be remembered while the subject is produced, a node for a noun while its modifiers are expanded. A "regressive" structure (*left*) requires that an additional node be stored in the memory with every step down, and then expanded in turn (*a, b, c, d*). At step 5 there are four remembered nodes; the structure has a "depth" of four. A "progressive" structure (*right*), on the other hand, never has more than one remembered node: a depth of one. (Vertical node-to-node lines are omitted in this diagram and the next one.)

keep track of depth. Construction can follow construction in the regressive direction only so far. One can say, for instance, "Very clearly projected pictures followed." Here a verb (*followed*) is preceded by a noun (*pictures*), which is in turn preceded and modified by an adjective. The adjective is itself preceded by an adverb, which is in turn preceded by a different kind of adverb. At this point the facilities of the language offer little opportunity for continuing in the regressive direction.

We can now see why it is that English allows object clauses within object clauses ("He knows what should have been included in what came with what he ordered") but does not allow subject clauses within subject clauses ("What what what he wanted cost in New York would buy in Germany was amazing"). The first is progressive; the second is regressive, and every new subject clause would introduce another predicate node into the temporary memory. There are apparently no nodes for producing it in the grammar. But when English does allow clauses within clauses in the regressive direction, a special device is used to count them out and prevent the number of remembered nodes from increasing indefinitely. We have "The family is leaving tomorrow"; "The family the woman told us about is leaving tomorrow"; "The family the woman we met yesterday told us about is leaving tomorrow." This is about as far as it can be carried. English uses special patterns of pitch, loudness, pause and speed in these cases to mark the regressive steps. The patterns allow for two or three regressive steps but no more.



DEPTH OF STRUCTURES that can be produced is limited by the number of nodes that can be stored in the temporary memory. In this case, with a limit of three remembered nodes, the structure is held to a depth of three and cannot penetrate the broken line. The numbers show how many remembered nodes there are when each current node is being expanded.



PARTS OF SPEECH provide a ladder for counting regressive steps and indicating the relations between words. The parts of speech change as words move up and down the ladder.

English also has various methods for conserving depth: getting as much expressive power as possible out of each regressive step. For example, when we say, "The boy loves the girl," we have the feeling—supported by linguistic analysis—that the sentence is divided into subject and predicate, and that the predicate (*loves the girl*) is then divided into verb and object [*see illustration on opposite page*]. The alternative of dividing the sentence immediately into three parts—subject, verb and object—would require in our model two remembered nodes (verb and object) rather than one (predicate). It has frequently been noted by linguists that language seems to prefer two-part rather than multipart constructions. This may be the reason.

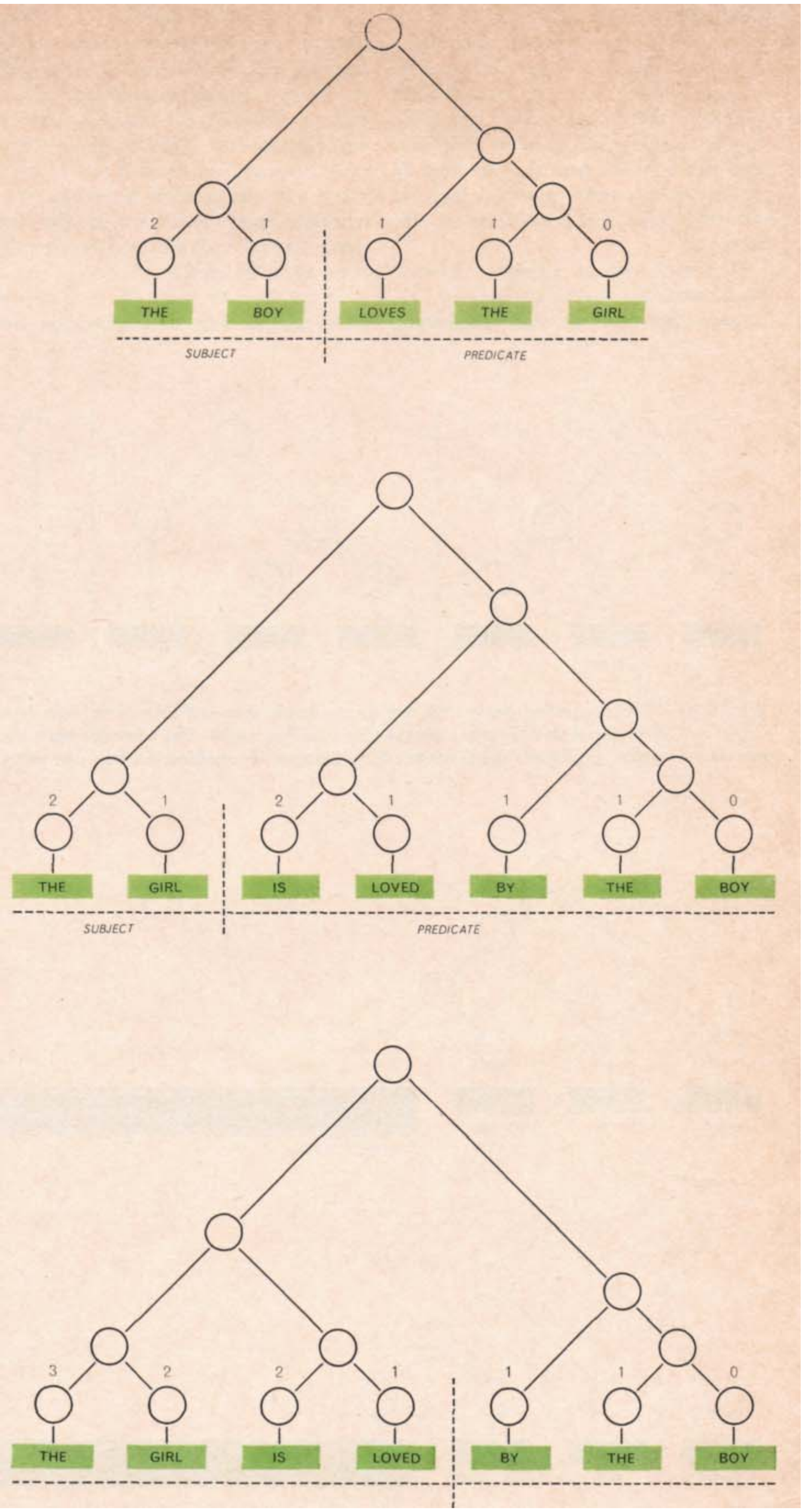
But when the sentence "The boy loves the girl" is changed to the passive sentence "The girl is loved by the boy," we do not retain the same connection between *girl* and *love* that we had in the active. The immediate constituents of the sentence are not *the girl is loved* and *by the boy*, which would require in our model that while the words *the girl* are being produced there would have to be two remembered nodes, one for *is loved* and one for *by the boy*. Instead the pattern of modification is changed back to the subject-predicate type, so that while *the girl* is being produced the program has to remember only one node for the entire predicate *is loved by the boy*.

Other means of conserving depth,

more prevalent in languages such as Turkish than in English or Chinese, are the phenomena of affixation and agglutination, which form long words out of various parts, including prefixes and suffixes. By these devices a regressive structure can be eliminated merely by replacing it with a single compound word. For instance, in English the phrase "to build again" follows a progressive construction and so presents no problem. The word "rebuilding," however, is made up of three elements that present essentially the same concept in regressive order, and we condense these elements into one word [*see upper illustration on next page*]. The importance of word-building for conserving depth in a language is related, of course, to the way the rest of the language is organized. In the evolution of a language, word-building tends in time to be resisted, otherwise the vocabulary would grow too large to be mastered.

In addition to methods for limiting the depth of sentences to about seven, and for conserving depth, English also has an extensive and complicated mechanism for maintaining the power of expression of the language in the face of the severe depth restriction. This mechanism saves depth by providing alternative means of expression. Frequently the order of phrases or clauses can be interchanged without a change in meaning. Of course the roles of the phrases must be suitably marked, since word order is not available now for this function. Thus we have "The boy loves the girl" and "The girl is loved by the boy," where the position of subject and object have been interchanged. We have "He gave the girl the candy" as well as "He gave the candy to the girl." We have strong grammatical or stylistic feelings that make us prefer one or the other alternative under certain circumstances. These feelings can be characterized as urging us to place the "light" construction first and the "heavy" (potentially deep) construction second, where it starts with one less item in the temporary memory. Hence we find it awkward to say: "He gave the candy he got in New York while visiting his parents between Christmas and New Year's to her." It is much simpler to postpone the long clause and move *her* forward: "He gave her the candy he got in New York..."

The possibility of structure reversal provided by the passive construction often enables one to express complicated ideas that would be hopelessly deep if the active alone were available. Consider the following sentence, taken from a

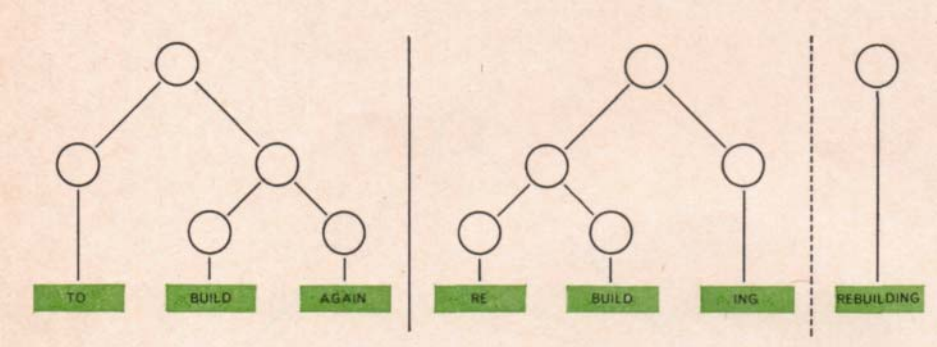


DEPTH IS CONSERVED by the conventional division of a sentence into subject and predicate (*top*) rather than into subject, verb and object. In the passive mood the subject-predicate division is preserved even though it means losing the relation between *girl* and *love* (*middle*). To do otherwise would require a depth of three instead of two (*bottom*).

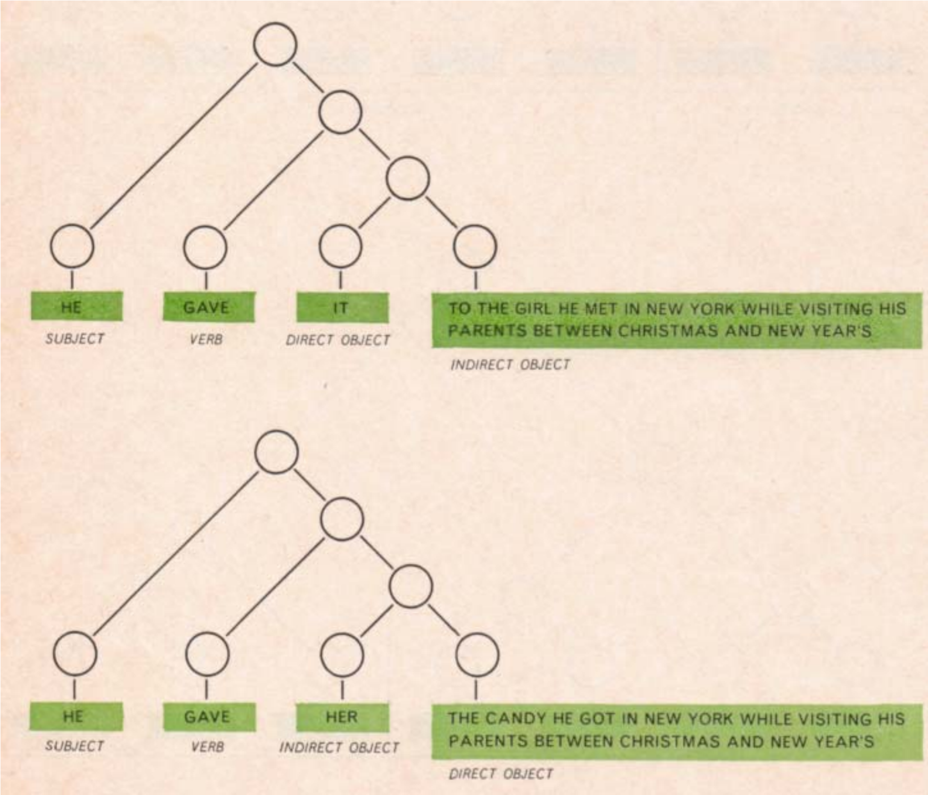
U.S. patent: “The said rocker lever is operated by means of a pair of opposed fingers which extend from a pitman that is oscillated by means of a crank stud which extends eccentrically from a shaft that is rotatably mounted in a bracket and has a worm gear thereon that is driven by a worm pinion which is mounted upon the drive shaft of the motor.”

The main type of structure reversal used here is the passive construction, although other types are also represented. This sentence is admittedly extreme, but without structure reversal one would have the following monstrosity: “A pair of opposed fingers that extend from a pitman which a crank stud that extends eccentrically from a shaft which is rotatably mounted in a bracket and which a worm gear that a worm pinion which is mounted upon the drive shaft that the motor has drives is on oscillates operate the said rocker arm.”

In addition to structure reversal we have another way of maintaining the expressive power of the language. Many of the complicated discontinuous constructions, which were puzzling to grammarians and which initially presented a programming problem, are now seen to serve the obvious function of postponing potentially deep constituents to a point where they start with an initial burden of one less remembered node. As an alternative to the ungrammatical “That that that they are both isosceles triangles is true is obvious isn’t clear” one has “It isn’t clear that it is obvious that it is true that they are both isosceles triangles.” Here the anomalous discontinuous construction “*It* isn’t clear that ...” shows its true function of postponing a potentially deep constituent to a point of lesser depth. Instead of the already cited ungrammatical “What what what he wanted cost in New York would buy in Germany was amazing" one now has the possibility of "It was amazing what could be bought in Germany for the cost in New York of what he wanted.” One is now in a position to explain why relative clauses follow their nouns, whereas single adjectives precede them. It is now clear that the function of postponement explains the utility of the discontinuous constructions in “too worn-out a car to drive” and “a more priceless possession than jewels.”



WORD-BUILDING, another device for conserving depth, does not take place (nor is it necessary) when the elements form a progressive structure (*left*). But when the parts are regressive (*right*), conditions are favorable for affixation, or combination into one word.


HE
SUBJECT
GAVE
VERB
IT
DIRECT OBJECT
TO THE GIRL HE MET IN NEW YORK WHILE VISITING HIS PARENTS BETWEEN CHRISTMAS AND NEW YEAR'S
INDIRECT OBJECT
HE
SUBJECT
GAVE
VERB
HER
INDIRECT OBJECT
THE CANDY HE GOT IN NEW YORK WHILE VISITING HIS PARENTS BETWEEN CHRISTMAS AND NEW YEAR'S
DIRECT OBJECT

FLEXIBLE WORD ORDER in English makes it possible to build sentences in such a way that a “heavy” construction is delayed, minimizing depth and maintaining the expressive power of the language. Here the order of the direct and the indirect objects is changed so that in each sentence the element containing an unwieldy subordinate clause comes last.

It remains to be seen how well the depth hypothesis applies to other languages. There are preliminary indications that depth phenomena consistent with the hypothesis may be found in Arabic, Turkish, Chinese and Japanese, as well as in Hidatsa and Mohawk (North American Indian languages), Shilha (a Berber language) and Toba-Batak (spoken in Sumatra).

In the meantime light has been cast on style in English. Perhaps it is not too much to hope that our machine-produced translations will be stylistically elegant as well as accurate and correct renditions of the original. But for accuracy and correctness purely syntactic programs will certainly not be enough. We are aware of great difficulties in the area of semantics—the precise definition of meaning—that must also be solved. But that is another story.

We are heartened by our effort to catalogue the manifold complexities of language; out of apparent chaos has come a glimpse of order. The architecture of language is truly amazing and beautiful. The balanced and complex interplay of various competing elements provides a superb instrument for human communication.