593 mμ, and of four cells to shifts around 622 mμ. In each case the open circles indicate the response to the standard wavelength and the crosses the responses to various other wavelengths.

For instance, in the shift back and forth between 570 and 593 mμ, the cells averaged 5.5 spikes to the 593-mμ wavelength and 13.8 spikes to the 570-mμ wavelength. These cells distinguish very well between 593 mμ and other wavelengths, but only quite poorly between 622 mμ and the other wavelengths, particularly ones of still longer wavelength. One might also note that the ability of the cells to discriminate between two wavelengths is just a continuous function of the wavelength difference. There is no evidence for a threshold in the sense of a region around the match point within which there is no discrimination.

The +B−Y and +Y−B cells in some cases are quite sensitive to the 550- through 600-mμ range, but in addition are very sensitive to wavelength shifts in the region of 470 to 500 mμ. The combined sensitivity of all of the opponent cells to wavelength shifts in different spectral regions agrees well with the hue-discrimination function of the macaque and human.

Previous experiments with intense chromatic adaptation (*1*) indicate that each LGN cell has inputs from several different types of receptors, each of which responds to changes in intensity with changes in amount of output. The non-opponent cells have two or more such systems feeding in the same direction—that is, all having excitatory or all inhibitory effects; whereas the opponent cells have an excitatory input from one system and an inhibitory input from another system.

The non-opponent cells are very sensitive to changes in intensity, since their responses reflect the changes in receptor output. Such a system is very insensitive to shifts in wavelength, however, since a shift from one part of the spectrum to another would merely lead to a shift from one excitatory input to another, or from one inhibitory input to another.

The opponent cell system is rather insensitive to changes in intensity because increasing the intensity of light simultaneously increases the amount of excitation from one system and the amount of inhibition from the other; the effects thus largely cancel each other out. This would occur, however, only in those spectral regions to which both of the underlying cone systems are sensitive.

For instance, since only the red system is very sensitive to the long wavelengths, the +R−G and +G−R cells become intensity-dependent rather than wavelength-dependent in this part of the spectrum. The opponent cells are very sensitive to wavelength shifts in parts of the spectrum which affect both underlying systems. In the case of the +G−R cell illustrated in Figs. 1 and 2, for instance, a shift toward the shorter wavelengths simultaneously increased the excitatory input from the G system and decreased the inhibitory input from the R system, thus producing a large increment in firing rate. A shift toward the longer wavelengths has just the opposite effect on such a cell.

RUSSELL L. DE VALOIS
GERALD H. JACOBS
ISRAEL ABRAMOV
*Psychology Department,*
*Indiana University, Bloomington*

**References and Notes**

1. R. L. De Valois, G. H. Jacobs, A. E. Jones, *Optik* **20**, 87 (1963).
2. ———, *Science* **136**, 986 (1962).
3. This research has been supported by USPHS grant No. NB-02274.

5 October 1964

## Computer Analysis of the Nuclear Test Ban Treaty

Abstract. *Experiments were undertaken to determine the applicability of a computer program for automatic syntactic analysis to the systematic discovery of ambiguities in textual material. Specific application of this program was made to portions of the Nuclear Test Ban Treaty. Results, though promising, indicate that such applications are not now economically feasible for large volumes of text.*

Syntactic analyzers, originally developed for the automatic translation of languages (*1*), may one day be used as automatic "ambiguity detectors" in our law courts and legislative assemblies. In automatic language translation, the syntactic analyzer determines the structure of each input sentence in terms of its constituent phrases and clauses. It makes no semantic discriminations. Consequently, it uncovers ambiguities in our everyday communication that may escape the human analyst who knows what a document is "supposed to say."

Would not such a syntactic analyzer, systematically determining the several interpretations of a sentence, have substantial application in fields remote from automatic language translation? (2).

Much of the litigation filling our court calendars arises directly from procedural or substantive ambiguities in the law. In drafting legislation or in drawing up contracts, legal advisers often identify, and sometimes remove, language that may be later subject to dispute. Treaties, which may at times retain somewhat ambiguous provisions, should perhaps be drafted with the fullest possible knowledge of precisely what these ambiguities are. Would not a syntactic analysis of such documents sometimes prove revealing?

It seemed worth while to attempt to answer this last question, particularly since a mechanized syntactic analyzer is essentially free from bias with respect to subject matter. Thus, it may discover ambiguities that are easily overlooked, since the review of documents is often approached with a particular "set" of mind, or attitude.

The opportunity to test automatic syntactic analysis as a technique for the systematic detection of ambiguities in legal and other documents was recently enhanced by the availability of the dictionary, grammar, and operational program for the Multiple-Path Syntactic Analyzer (*3*). This analyzer, which operates on the IBM 7090/94 computer, is believed to be unique in its capability to provide multiple analyses of syntactically ambiguous sentences in an effective and efficient fashion.

Since it was readily available, the analyzer was used to process selected portions of the recent Nuclear Test Ban Treaty. In this paper we present the results of the analysis of six of the more significant sentences from that treaty.

The actual text of the treaty, and the text as run through the analyzer, are given in Fig. 1. The minor differences between the two texts were necessitated by several considerations: (i) the analyzer will not at present

accept sentences more than 100 words long; (ii) certain grammatical constructions cannot be dealt with by the present grammar, so that "not to carry out," for example, had to be converted to "not carry out"; and (iii) punctuation is not handled very adequately by the present grammar; for example, a semicolon and a comma are treated in the same way. It was also found that the dictionary required augmentation to process this text, and 70 additional words were added (*4*). (The dictionary before augmentation contained 16,875 homographs selected primarily for processing scientific texts.)

When the text was run through the computer, a printed output was produced in which the English text and its structural analysis appeared side by side. This structural analysis is made up of a succession of strings of characters, one string for each word of the sentence. These strings are referred to as "structural codes," and each character in such a code stands for a particular syntactic structure (*5*). Different interpretations of the sentence are represented by different sequences of structural codes and are presented as separate outputs by the syntactic analyzer.

Since there is no standard technique for putting sentence structures into diagrammatic form, the interpretations obtained from the analyzer are most conveniently expressed by means of paraphrases of the original text. The nine most meaningful analyses are presented and discussed below.

SENTENCE 1

*Analysis 1*: Each of the parties to this treaty undertakes to prohibit, to prevent and not to carry out any nuclear explosion at any place that is under its jurisdiction or control.

*Analysis 2*: Each of the parties to this treaty undertakes to prohibit, to prevent and not to carry out any nuclear explosions at any place that is under its jurisdiction and also undertakes to prohibit, to prevent and not to carry out any control.

*Discussion*: Here there are two meaningful analyses. Happily one of these is the intended interpretation of the sentence. The other, which asserts that "explosions or control" are prohibited, is admittedly a bit strained for an English-speaking person. Moreover, it can probably be fairly argued that this interpretation is hardly tenable in the context of the entire treaty. Since the syntactic analyzer in its present form does not take account of contextual considerations outside the sentence under analysis, there is no way at present that this particular interpretation (or others like it) could be inhibited by the analyzer itself.

SENTENCE 2 (edited)

*Analysis 1*: This applies in the atmosphere and beyond its limits, including outer space, as well as under water, including territorial waters or high seas.

*Discussion*: The analyzer produced only one meaningful analysis, and it is gratifying that it corresponds precisely with the intended interpretation of the sentence.

SENTENCE 3

*Analysis 1*: This applies in any other environment if such explosion causes radioactive debris to be present outside the territorial limits of the state under whose jurisdiction or control such explosion is conducted.

*Discussion*: Again, only one meaningful analysis was produced, and it corresponds to the intended interpretation.

SENTENCE 4

*Analysis 1*: It is understood in this connection that the provisions of this subparagraph are without prejudice to the conclusion of a treaty which would result in the permanent banning of all

ARTICLE I

ORIGINAL TEXT — 1. Each of the parties to this treaty undertakes to prohibit, to prevent, and

AMENDED TEXT — Each of the parties to this treaty undertakes to prohibit, to prevent, and (1)

not to carry out any nuclear weapon test explosion, or any other nuclear explosion
not carry out any nuclear weapon test explosion or any other nuclear explosion

at any place under its jurisdiction or control:
at any place under its jurisdiction or control.

A. In the atmosphere; beyond its limits, including outer space; or
This applies in the atmosphere, and beyond its limits, including outer space; or (2)

under water, including territorial waters or high seas; or
under water, including territorial waters or high seas.

B. In any other environment if such explosion causes radioactive
This applies in any other environment if such explosion causes radioactive

debris to be present outside the territorial limits of the state under whose
debris to be present outside the territorial limits of the state under whose

jurisdiction or control such explosion is conducted. It is understood in this
jurisdiction or control such explosion is conducted. (3) It is understood in this

connection that the provisions of this subparagraph are without prejudice to
connection that the provisions of this subparagraph are without prejudice to

the conclusion of a treaty resulting in the permanent banning of all nuclear
the conclusion of a treaty resulting in the permanent banning of all nuclear

test explosions, including all such explosions underground, the conclusions
test explosions, including all such explosions underground. (4) As the parties

of which, as the parties have stated in the preamble to this treaty, they seek
have stated in the preamble to this treaty, they seek to achieve the conclusion

to achieve.
of such a treaty.

ARTICLE II

2. Any amendment to this treaty must be approved by a majority of the votes
Any amendment to this treaty must be approved by a majority of the votes

of all the parties to this treaty, including the votes of all the original parties.
of all the parties to this treaty, including the votes of all the original parties. (8)

ARTICLE IV

Each party shall in exercising its national sovereignty have the right to
Each party shall in exercising its national sovereignty have the right to (10)

withdraw from the treaty if it decides that extraordinary events, related to the
withdraw from the treaty if it decides that extraordinary events, related to the

subject matter of this treaty, have jeopardized the supreme interests of its
subject matter of this treaty, have jeopardized the supreme interests of its

country.
country.

Fig. 1. Original and amended texts of selected portions of the Treaty.

nuclear test explosions, including all such explosions underground.

*Analysis 2*: It is understood in this connection that the provisions of this subparagraph are resulting in the permanent banning of all nuclear test explosions, including all such explosions underground. It is also understood that the provisions of this subparagraph are without prejudice to the conclusion of a treaty.

*Discussion*: This provided perhaps the most interesting of the results obtained. One of the analyses corresponds precisely to the intended interpretation of the sentence. The second, however, is not at all strained and results in the astonishing interpretation that the treaty provisions result in banning all tests, *including those underground*! In this instance there seems to be little if any contextual guidance from the rest of the treaty text that will enable one decisively to reject this interpretation. In fact, referring to the original treaty text in Fig. 1, we see that continuation of this sentence tends, if anything, to reinforce this interpretation.

SENTENCE 8

*Analysis 1*: Any amendment to this treaty must be approved by a majority of the votes of all the parties to this treaty and must include the votes of all the original parties.

*Analysis 2*: Any amendment to this treaty must be approved by a majority of the votes of all the parties to this treaty and the treaty must include the votes of all the original parties.

*Discussion*: The two meaningful analyses obtained for this sentence are both unsatisfactory. The first states that "any amendment must be approved (and must be) including the votes of the original parties." What meaning is to be attached to this interpretation is far from clear. The second of the interpretations is, in some ways, worse. In this interpretation the participial phrase "including the votes of all the original parties" modifies "treaty." Since it is difficult to see how the treaty can "include votes," this interpretation, too, is far from clear. The difficulty seems to be that this sentence is so constructed that the phrase "including the votes of all the original parties" dangles with no syntactic clues as to what it modifies.

There seem to be two reasonable interpretations, neither of which was provided by the analyzer. In the first of these, the phrase "including the votes of all the original parties" modifies "majority" so that approval of an amendment requires a majority and that all the original parties vote "yes." The alternative is to consider the phrase "including the votes of all the original parties" to modify "votes," so that the approval of an amendment requires not only a majority of the votes of the parties but also that all the original parties vote—that is, not abstain. Presumably, the first is the intended interpretation of the sentence, but it does not seem possible to determine this from the sentence itself or from the remainder of the treaty text.

Table 1. History of computer usage. Except for updating the dictionary, when the IBM 1401 computer was used, the IBM 7094 computer was used for all runs.

| Sentence | Task | Total computer time (min) |
|---|---|---|
| | *Preparatory runs* | |
| | Test analysis | 6 |
| | Updating of dictionary | 69 |
| | Test analysis | 8 |
| | *First run* | |
| 1, 2, 3, 4 | Production of condensed grammar and analysis | 70 |
| | *Second run* | |
| 10 (modified) | Analysis | 3 |
| | *Third run* | |
| 2, 8 (modified) | Analysis | 2.2 |

SENTENCE 10

*Analysis 1*: Each party shall in exercising its national sovereignty have the right to withdraw from the treaty if it decides that extraordinary events related to the subject matter of this treaty have jeopardized the supreme interests of its country.

*Discussion*: This sentence provided only one meaningful analysis, and it corresponds to the intended interpretation.

These analyses were carried out in the course of three successive runs on the IBM 7094 computer (see Tables 1 and 2). Prior to the first run on the computer, the entire text of the treaty had been key-punched and the sentences arranged according to their interest and importance. The intent, of course, was to analyze the entire treaty. Since the amount of time available on the computer was limited, however, we hoped that the arrangement would permit the experiment to be stopped at any point with the maximum return for the computer time expended.

Table 2. History of computer usage: the time used for analyzing each sentence.

| Sentence | Total analyses | Meaningful analyses | Computer time (min) | |
|---|---|---|---|---|
| | | | Total | Per analysis |
| | | *Not edited* | | |
| 1 | 118 | 2 | 7.55 | 0.064 |
| 2 | 72 | 4 | 0.48 | .0067 |
| 3 | 18 | 1 | 9.82 | .55 |
| 4 | 124 | 2 | 42.37 | .34 |
| | | *Edited* | | |
| 10 | 1 | 1 | 0.20 | .20 |
| 2 | 2 | 1 | .06 | .030 |
| 8 | 2 | None | .26 | .13 |

After the text had been entered into the computer and the dictionary updated so that there were no word shortages, the analysis began and progressed well, although somewhat more slowly than expected, until sentence 4 was reached. The analysis of this sentence required a little over 42 minutes. Since the entire treaty contains 31 sentences, it seemed likely that the available computer time (1¼ hr) would be scarcely adequate for the entire treaty to be analyzed. The run was therefore terminated at the end of sentence 4.

Table 1 shows that the number of analyses resulting from the four sentences was unreasonably large. Sentence 4, for example, produced 124 analyses, of which only two were meaningful. An exhaustive review of all the analyses obtained from these first four sentences (332 of them) indicated that most of the undesired analyses resulted from the fact that in the dictionary many, if not most, words are found in several grammatical categories. This caused the analyzer to produce many analyses that, although grammatically sound, were highly inappropriate. For example, "water," "carry," and "place" are designated in the dictionary as both nouns and verbs. In the context of the treaty, the interpretations that employed these words as verbs were clearly inappropriate. Likewise "applies" is designated as both a transitive and an intransitive verb ("He applies glue to the picture." "He applies for a job."). As a result, half the analyses for sentences 2 and 3 employed "applies" as a *transitive* verb and produced such analyses as "This applies . . . water, including territorial waters or high seas" in which "in the atmosphere; beyond its limits, including outer space or under" is constructed as an adverbial phrase modifying "applies." This, of course, is a possible construction for the sentence, since "under" is found in the dictionary not only as a preposition (which is the intended (usage) but also as an adverb.

Clearly, then, many and perhaps most of the undesired analyses could be suppressed, with a consequent large decrease in computer running time, by deleting those homographs that are inappropriate for the text being run. This was done on a word-by-word basis in sentences 2, 8, and 10.

With the augmented text (*6*) thus modified, sentence 10 was run, and, as indicated in Table 1, only one analysis was produced. It was also meaningful, and corresponded to the intended interpretation of the sentence. The running time on the computer was satisfactorily short. Subsequently, it was decided to rerun sentence 2 and also to run sentence 8. This resulted in two analyses for each of the sentences. Again, the computer running time was satisfactorily short. It is particularly noteworthy that the editing of the augmented text reduced the running time of sentence 2 by a factor of 8.

R. A. LANGEVIN
M. F. OWENS
*Technical Operations, Incorporated, Burlington, Massachusetts*

**References and Notes**

1. "Current Research and Development in Scientific Documentation," *National Science Foundation Rept. NSF 62-20* (May 1962).
2. R. Stern, "Syntactic ambiguity in the Clayton Act," *Modern Uses of Logic in Law* Sect. 5(a) (Dec. 1960), p. 129; J. C. Miller, "Two examples of syntactic ambiguities in international agreements," *ibid.* (June 1962), p. 72; J. H. Ely, "The limits of logic," *ibid.* (Sept. 1963), p. 117; V. Fiordalisi, "Progress and problems in application of electronic data processing systems to legal research," *ibid.* (Dec. 1960), p. 174.
3. Developed at Harvard University by S. Kuno and A. Oettinger with National Science Foundation sponsorship. See "Mathematical Linguistics and Automatic Translation," *National Science Foundation Rept. NSF 8* (January 1963) and *NSF 9* (May 1963), 1 and 2.
4. We thank Mr. Susumu Kuno of the Harvard Computation Laboratory for assisting us with details of the dictionary update and certain of the program operating features.
5. "Mathematical Linguistics and Automatic Translation," *National Science Foundation Rept. NSF 9* (May 1963), vol. 1, p. 127.
6. That text actually used by the analyzer in which each word of a sentence appears with all its dictionary homographs.

2 October 1964

## Visual-Cliff Experiment with Mothered and Unmothered Lambs

In their report "Depth perception in sheep" (21 Aug., p. 835), Lemmon and Patterson conclude that "some unspecified elements in the mother-neonate relationship are closely related to the development of perceptual skills, particularly depth perception, as well as subsequent adjustive avoidance behavior."

Another interpretation should first be considered, however. Imprinting has been reported in sheep. The hours shortly after birth are critical in the establishment of the bond between mother and lamb, and with increasing age fear of strange objects appears. Thus in Lemmon and Patterson's experiment 1, mothered lambs become increasingly attached to their mothers and fear increases. It is almost certain that the lambs are aware of the observer 1 meter away in the only direction in which they can move; this "insures" that they will remain on the platform. In the unmothered, better called hand-raised, group, a bond with humans becomes established; during the test the presence of the human would elicit approach in spite of the visual cliff. The strangeness of the situation is not the same for both groups.

Since the results can be predicted on the basis of an imprinting hypothesis, this question needs further study.

ERICH KLINGHAMMER
*Department of Psychology, University of Chicago*

5 October 1964

Klinghammer's objection to the control of extraneous stimulation in the visual cliff would be well taken if it were possible for the animal in the apparatus to see the experimenter. Lambs from both groups were placed on the platform through a flap in the top of the box directly over the "solid" platform. The flap was then closed and the animals' behavior observed through an unobtrusive peephole in the other end. The conditions of the experimental situation were reasonably neutral as regards sound and obvious olfactory stimuli.

It is most likely that none of the animals was capable of fear; Scott [*Animal Behavior*, University of Chicago Press (1958)] has pointed out that the lamb's capacity to discriminate its own mother from other ewes takes some time to develop and is apparently dependent upon being butted away by animals other than its own mother. This phenomenon has also been reported by Hersher, Richmond, and Moore [*Behavior*, E. J. Brill, Leiden, Netherlands (1963); *Maternal Behavior in Mammals*, Wiley, New York (1963)]. Our unmothered animals were not encouraged to follow a human and were kept in warm pens after feeding and cleaning—with other lambs of comparable age. Mothered lambs were kept in the same building in separate stalls limited to ewe-lamb pairs. There was no obvious difference in the response of ungoggled lambs to human attendants, whether or not they remained with their mothers.

If, as Klinghammer suggests, the mothered lambs were motivated by fear when placed in the experimental situation they, even more readily than unmothered lambs, should have moved away from the "solid surface" under the flap, since this would put them even farther away from their last view of the experimenter. They did exactly the opposite.

W. B. LEMMON
*Psychological Clinic, University of Oklahoma, Norman*
G. H. PATTERSON
*Psychological Unit, Oklahoma Department of Public Welfare, Oklahoma City*

22 October 1964