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How Information Is Carried in Scientific Sub-Languages

Advances in linguistics may help improve communication between scientists speaking different sub-languages.

I. D. J. Bross, P. A. Shapiro, and B. B. Anderson

Our main purpose in this article is to consider how the linguistic structure of a given language reflects the language's function or functions and its related semantic, or information-carrying, properties.

The languages used by members of the scientific community in their jobs as practitioners or researchers can be especially useful for examining the relationships between structure and function since these highly specialized languages (or jargons) have evolved from the mother tongue in such ways as to better meet the specific functional needs of their users. During this evolution, as in biological evolution, the process of adaptation to a specific linguistic function leads to an emphasis upon and elaboration of certain features of the original linguistic structure and a corresponding de-emphasis or elimination of other features of the mother tongue. The specialized language becomes more effective for performing certain linguistic tasks while its ability to perform other functions is reduced or completely lost.

By considering the linguistic structure of scientific jargons from the theoretical standpoint developed by Harris (*1*), it has become possible to get a much clearer picture of the relationship between syntactic structure and semantic function than has previously been possible. The picture obtained from studies of natural languages is much more realistic and useful than the pictures obtained from semantic studies based upon artificial languages. At the same time, the scientific analysis of natural languages avoids the obscurity and circularity that has plagued the intuitive philosophical approaches to questions of meaning. We feel that the best currently available procedure for investigating the nature of language is to examine closely particular languages actually being used for a specific purpose. In this article we present some of the results of one such study.

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An Introduction to Linguistic Analysis

A language is basically a complex mechanism for encoding a message consisting of a set of information units into a form that can be both transmitted and received. It is the medium through which a particular set of users communicate about a particular universe of discourse. Within this mechanism, two important forces are at work.

First, the particular communication needs of the users of the language will determine a distinct semantic function that this mechanism must somehow satisfy. For example, some specialized languages function primarily to persuade or convince, such as the jargons of courtroom lawyers, advertisers, or editorialists. Other jargons function primarily to elicit emotional response, such as the language of poetry. The language discussed below is used solely for transmission of information.

Second, the nature of the universe of discourse will determine a set of semantic properties for the language that will profoundly affect how specific utterances in the language are interpreted. For example, sentences that mean one thing in one universe of discourse may mean something very different in another, and sentences that are ambiguous in a particular language may not be ambiguous in a restricted subset of that language.

Our hypothesis is that the syntactic structure of a language, the set of encoding rules used in generating messages, is greatly affected by both of these forces, and that the nature of the syntactic structure in turn affects the users of the language in various subtle ways, in a somewhat cyclic fashion.

In theory, the basic units of information in language are the "kernel sentences"—primitive nondecomposable sentences that can be modified and combined in various ways by well-defined rules of transformation to produce a very large number of different messages. The information in a sentence is contained both in its kernel sentences and in the sequence of transformational operators that have been applied to the kernel sentences.

To give an example for which the analysis has been slightly simplified, the sentence:

"The fascia was closed with interrupted silk stitches."

derives from the kernel sentences:

(k_1) X closed fascia.
(k_2) stitches were silk.
(k_3) stitches were interrupted.

Then the following transformations are applied:

(ϕ_s) a sentence operator which adds the information "was with stitches" to (k_1);

(ϕ_c) a connective which incorporates (k_2) and (k_3) into the sentence, producing (after some minor modifications): "interrupted silk stitches";

($\phi_{passive}$) a transformation which changes "X closed the fascia with interrupted silk stitches" into the final form of the sentence.

One possible representation of the analysis is to envision each sentence as the "product" of a set of transformational operators which have been applied to a set of kernel sentences. In our example the formula

$$S = \phi_{passive}\{\phi_c[\phi_c(\phi_s(k_1))(k_2)](k_3)\}$$

represents the sentence above.

Another possible representation is to construct a lattice (*1*; pp. 109–113) showing the application of the operators on the kernel sentences (see Fig. 1). Certain transformations (such as $\phi_{passive}$) serve only to produce paraphrases of existing information while others (such as ϕ_s and ϕ_c in this example) introduce new information.

This type of analysis, modified slightly to facilitate computerized operations, was used as the theoretic basis for an automated coder of report narrative (Acorn) which is under development at Roswell Park Memorial Institute in Buffalo, New York.

Our goal in the Acorn project, which has been fully described (*2*, *3*), was to develop a model for an automated storage and retrieval system in which all users of the system would deal with it directly through natural language communication. This is in direct contrast with nearly all automated information systems in existence today, which require that both input and queries be formulated according to rigid artificial formats.

From the point of view of an automated retrieval system such as Acorn it is desirable to store all of the information in a standard notation, such as $F(X) = Y$, irrespective of whether the information originated in a kernel sentence or was introduced by a transformational operator. Consider the sample sentence:

"The fascia was closed with interrupted silk stitches."

This would be decomposed by Acorn into the following "kernels" of information:

(1) OPERATION(FASCIA) = CLOSED
(2) MEANS(CLOSED) = STITCHES
(3) DESCRIPTION(STITCHES) = INTERRUPTED
(4) DESCRIPTION(STITCHES) = SILK

The functions (F) OPERATION, MEANS, and DESCRIPTION are 3 of 15 functions currently being used to represent the semantic content of the texts.

It should be noted that (2) above is not a kernel sentence according to Harris's analysis—it is information introduced by a sentence operator. With Acorn, in order to simplify automated storage and retrieval procedures, this distinction is ignored and all information is stored in its standard $F(X) = Y$ format. Thus, in the following discussion, the term "kernel" refers to Acorn's $F(X) = Y$ kernels and not strictly to Harris's kernel sentences.

The data presented below in discussing the linguistic structure of the jargon used by surgeons were derived with the help of Acorn by procedures that are described elsewhere (*3*). Basically, Acorn was used for a computerized syntactic analysis of a body of surgical reports. In addition, and as a cross-check, we made many manual analyses of the reports. The computerized analysis is particularly useful in two ways. First, it is a convenient way to count the occurrence and co-occurrence of linguistic items and hence to determine the frequency of usage. Second, it provides a guarantee that the background knowledge, personal opinions, or other unique characteristics of a human analyst are not influencing the analysis. Thus we are not involved in a circular process where the meaning of the sentence to the analyst determines the meaningful findings of the analysis.

Structure and Function in Surgical Jargon

One advantage of adopting the kernel as the basic unit of information in natural language is that this approach yields some simple straightforward answers to significant questions about information transmission. The wide variety of specialized jargons which are subsets of English differ greatly in function and therefore display varying degrees of stress on and elaboration of different structural features present in the mother language. What we would like is a useful frame of reference for the study of differences in the structural mechanisms used in different jargons.

In a sub-language whose primary semantic function is to report factual information, such as the jargon of surgeons, the information is carried mainly by the kernels. However, the relationships which exist between kernels are also important. For example, the kernels

(2) MEANS(CLOSED) = STITCHES
(4) DESCRIPTION(STITCHES) = SILK

are related by the fact that the word "stitches" occurs in both kernels, as the Y-value in kernel 2 and the X-value in kernel 4.

There is another superficially similar relationship between kernels, which can occur when the same word appears in both. For example, the kernels

(1) OPERATION(FASCIA) = CLOSED
(2) MEANS(CLOSED) = STITCHES

are related by the fact that the word "closed" is both the *Y*-value in kernel 1 and the *X*-value in kernel 2. On a deeper level, however, the word "closed" in kernel 2 is a surrogate for the entire kernel 1. In other words, kernel 2 is actually representing a relationship which could be shown more explicitly as:

MEANS [OPERATION(FASCIA)
= CLOSED] = STITCHES

While the emphasis in the surgical jargon is on the kernels themselves, in the jargons of mathematicians and logicians, where the primary function is not to carry factual information but to convince one of the validity of a formal argument, the emphasis is on the relationships between kernels. The contrasts between sub-languages will be discussed later.

To illustrate how the structure of a jargon is directly related to its semantic function, let us consider first the jargon used among surgeons. In this communication situation, it is essential that the pertinent information about what was done and what was seen in the course of an operation be transmitted clearly, concisely, and unambiguously. Because this information may be used in the subsequent management of a patient or may be critically reviewed by colleagues, the effectivenes of this jargon for the transmission of factual information from one professional to another may be literally a matter of life or death to the patient and may affect the career of the surgeon. Hence this is a jargon that has become highly specialized for the efficient transmission of a particular kind of information and which has almost no other function. For example, there is rarely any intention on the part of the surgeon to use this jargon to amuse, persuade, or influence the emotions of the readers of the surgical report.

The linguistic structure of this jargon has evolved in such a way as to serve the single-minded purpose of its users. Hence by observing the special features of this particular jargon we can see what aspects of linguistic structure are important for the no-nonsense transmission of important factual information. Moreover, by contrasting the structural features of this jargon with the features of jargons which have evolved to persuade or to arouse emotions or for other purposes we can determine the semantic roles of the different syntactic structures in a relatively objective and systematic fashion. This

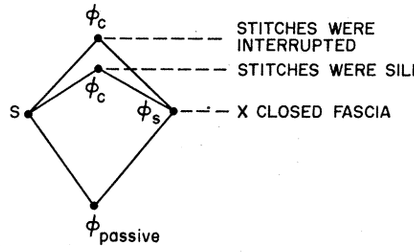

Fig. 1. The lattice structure of a sentence.

provides an approach to semantics which is scientific in exactly the same sense that an investigation in the physical or biological sciences is scientific.

In terms of Harris's overview of language, a key feature of the surgical jargon is the heavy emphasis on certain types of transformations and the virtual disappearance of other types of transformations. Perhaps the most notable example of this is the use of the passive transformation. The past tense is almost always used and the agent (or actor) is usually deleted. In a typical report, for example, we find in close proximity:

". . . the skin was prepared and draped . . . incision was made . . . axillary fat was dissected and bleeding controlled . . . the lymph node was dissected out . . . the wound was closed . . . dressing was applied . . . the patient was transferred . . ."

Several other related transformations are also used extensively in this jargon. These include the nominalization of transitive verbs (for example, ". . . it too was implanted to its full extent *with the excision* of a small margin of transverse neck skin"), the participial adjective form of these verbs (for example, "the skin flaps fitted quite nicely over the *amputated* stump"), and special lexical suffixes for surgical actions (for example, "-ectomy" as in appendectomy, "-otomy" as in colotomy, and "-oscopy" as in esophagoscopy). The effect of all of these transformations is to suppress the role of the surgeon as a human actor in this narrative (he is the actor in the overwhelming majority of sentences) and to emphasize the manipulations that he is carrying out and the effects of these actions.

While this restriction to a narrow subset of the wide set of transformations used in ordinary language increases efficiency in the communication of information about the particular events that occur during surgery, it also greatly reduces the range of statements that can be made in this jargon. Here then we have an instance of the cyclic effect described above where the language structure evolves to meet the functional needs of its users, but as this evolution progresses the speaker often becomes more and more a "prisoner of his jargon."

For instance, the surgeon has at his disposal a technical vocabulary that will allow him to describe with great detail and accuracy the appearance of anatomical structures. This may give him the impression that he has greater freedom in his jargon than in English to describe what happens during surgery. But even though the vocabulary is more extensive than everyday English in a few areas, the vocabulary is very limited in other respects. The fairly large sample of surgical reports analyzed so far has a vocabulary of only about 2700 words, and there are probably not more than twice this many active words in the jargon. Thus the freedom of a technical jargon is something of an illusion.

Another important gain in efficiency of information transmission that stems from the restrictions on the set of transformations and subsequent compression of the information-carrying kernel sentences is the avoidance of variations in tense. The events reported have always occurred in the immediate past and therefore a structure such as "with the excision" (as cited above) can be used as a simple and concise way to imply that one event immediately preceded another. In other jargons, even those used for reporting, the past tense may refer either to the far distant or to the immediate past, and time relationships require a more elaborate treatment if they are to be specified clearly and unambiguously.

The syntactic structure has thus evolved in such a way as to take advantage of the very special nature of the surgical environment and of the events that are being reported. Since all events take place in a relatively short time span (up to about 8 hours) and since one person initiates and controls virtually all of the activity, the syntax that evolves is both simple and direct.

To a nonsurgeon the jargon may seem tedious, unimaginative, and rigidly stereotyped—totally lacking in those linguistic features which add human interest or elegance to a narrative. The austere syntactic structure leaves little room for the niceties of other jargons but it does facilitate the transmission of particular factual information with brevity and clarity. The language has evolved to meet the needs of surgeons,

who tend to spend as little time as possible in dictating or working over the surgical report and who want to tell or hear the pertinent part of the story and nothing else.

Semantic Admissibility and Ambiguity

We were led to an awareness of the special features of the surgical jargon by a comparison of our own experience in developing fully automated procedures for the extraction of information from surgical narrative with the experience of investigators of other types of texts. We had chosen to work with surgical reports because they were convenient and of interest in cancer research. Most other investigators who have attempted to use syntactic analysis for information extraction and retrieval had used jargons which were quite different in character. Sager and her coworkers, for instance, have analyzed publications from journals of theoretical physics (*4*).

We noticed that many of the most troublesome problems which other investigators were encountering were not turning up in the surgical reports. In retrospect, it is clear that we were very lucky in the jargon we had chosen to work with. The extraction of information from a jargon which is highly specialized for the transmission of a particular kind of factual information is relatively simple. In jargons where the emphasis is on construction of a coherent scientific argument the extraction of content is no longer this simple.

One notable difference between the surgical jargon and other specialized languages was the situation with respect to ambiguities—syntactic and otherwise. There were syntactic ambiguities in the surgical reports but they were not nearly as troublesome as the ambiguities in other narratives. For example, one of the most common sentences in the surgical reports was the closing remark:

"The patient left the operating room in good condition."

From a syntactic viewpoint this might be read as a short form of: "The patient finished mopping the floor and left the operating room in good condition."

Whenever this syntactic ambiguity was pointed out to the surgeons they were both surprised and amused, because no surgeon would read the report in this ambiguous way. Indeed there is really no semantic ambiguity here because the universe of discourse is severely restricted in this jargon. A physical description of the operating room is not something which would appear in a surgical report. To put it another way, there are rigid conditions that determine the admissibility or acceptability of a sentence in a surgical report—conditions peculiar to this reporting jargon—and the syntactic ambiguity is resolved by these restrictions. There is therefore no ambiguity in the actual transmission of information.

Genuine ambiguities in the surgical jargon would be extremely dangerous since serious harm to the patient might well result. Therefore the language has evolved in such a way as to reduce the occurrence of ambiguities to the vanishing point—a very favorable situation for anyone attempting computerized extraction of information.

This evolution manifests itself in many different ways. For example, there are very few terms used synonymously in these reports. Individual doctors may sometimes use different terms for the same thing, such as two names for the same pathological condition, but each physician tends to be very consistent in his own usage and so there is no question as to whether he is in fact talking about the same entity at two different places in the report.

At another level, overriding semantic restrictions eliminate possible ambiguity in the kernels themselves. It turns out that one of the most significant semantic properties of this jargon is the existence of highly restrictive conditions of admissibility for its kernels. In unrestricted English a phrase such as "the shooting of the hunters" is ambiguous because we do not know whether "the hunters" is the subject or object of the verb "shoot" in the underlying kernel. However when a surgeon uses a phrase such as the "the bleeding of the vessels," the only admissible origin for the nominalization "bleeding" would be "the vessels bled" and not "someone [that is, the surgeon] bled the vessels." This is in contrast to ordinary unrestricted English in which a phrase such as "the bleeding of the vein" could mean either that the vein bled or that someone bled the vein.

These highly restrictive conditions of admissibility, like the other semantic properties discussed above, have a profound effect on the syntactic structure of the language by reinforcing certain usage patterns. In this particular case, the conditions of admissibility reinforce the use of the nominalization transformation by guaranteeing that the set of resultant ambiguities will be either minimal or nonexistent.

Moreover, the implications for an automated storage and retrieval system are just as profound. Just as an abundance of simple passive constructions simplifies the task of the linguistic analysis programs in generating the proper kernels, so too does the guarantee that the underlying subjects of nominalized verbs will almost always be unique.

Perhaps the greatest simplification of the syntax occurs with respect to the set of permissible sentence types. In ordinary unrestricted English, sentences may be declarative, interrogative, imperative, conditional, or subjunctive, for example, but in surgical jargon declaratives predominate because the semantic function is solely to convey information. The surgeon seldom questions, commands, hypothesizes, supposes, or the like while dictating, and so the corresponding syntactic structures rarely occur.

Broader Implications

The theory of mathematical structure of natural languages which has been developed by Harris provides a useful frame of reference for the comparative study of different jargons and, in particular, of the mechanisms through which information is carried. The distinction that we propose exists between the type of information carried in the kernels themselves and the type of information carried in the relationships between kernels provides an operational definition for the ordinary distinction that is made between "stating a simple fact" and "making a logical argument." While any intelligible narrative must use both mechanisms for carrying information, significant differences in emphasis occur.

In the discussion above we noted that in the fact-oriented jargon of surgeons the information is carried primarily in the kernels, which record either simple events and descriptions or specific aspects of complex events. Thus the observation of a tumor in the duodenum would lead ultimately to the kernel

"WHERE (TUMOR) = IN DUODENUM."

Also at this end of the scale are other scientific jargons with a high density of concrete items of information, particularly those jargons used in reporting laboratory findings in the biological and physical sciences.

Toward the other end of the scale, however, are the languages of mathematics and symbolic logic, where the emphasis shifts from the kernels themselves to the relationships between kernels. In these jargons the factual information contained in the kernels is minimal since the universe of discourse is so restricted, and the languages have evolved in such a way as to become almost purely relational, as opposed to factual. A skeletal form of the kernel is retained but the representation is now purely abstract and symbolic, and not tied to specific lexical items. For instance, the logical statement:

$$(p \supset q) \equiv \overline{(p \cdot \bar{q})}$$

which says that "if p then q" is logically equivalent to "not both p and not q" contains no "information" in the normal sense of the word until actual propositions (or the kernel sentences which represent them) are substituted for p and q in the skeletal framework. However, the statement does carry a logical argument via the expressed relationships between the skeletal kernels p and q, and when kernels carrying factual information are inserted the result is what we commonly call a factual argument. Thus in ordinary language we might argue that "if it's raining then the streets are wet" is logically equivalent to "it can't be true both that it's raining and that the streets aren't wet."

It is interesting that although the jargons of symbolic logic and of surgical reports are at opposite poles with respect to their information-carrying capacity, there is strong environmental pressure for conciseness and precision in both communication niches. This leads to interesting convergences in which similar end results are achieved although basic structural forms differ, analogous to biological evolutionary convergence (for example, the fins of fishes and those of mammals which live in an aquatic environment). One example of this convergence is the simplification which results from the elimination of the temporal reference markers. In the jargon of surgeons this results from the tense being uniformly past; in the jargons of logicians, by complete suppression of the tense marker in the abstract symbolism. In verbal illustrations of logical propositions (for example, "All men are mortal") the present tense is used uniformly without reference to time (for example "are" equals "were," "are," and "will be").

Another convergence occurs with respect to referencing. In the surgical jargon ambiguity of reference is minimized by the fact that the third-person personal pronouns (he, him, she, her, his, hers) always refer to the patient. Since the surgeon is always the actor, he is rarely mentioned and never in the third person. In the jargons of logicians ambiguity is avoided through a system of definitions that replace collections of symbols by single symbols (usually letters of an alphabet). Also, in one sense at least, both jargons suppress the actor. In surgical jargon, the actor is almost always the "invisible" surgeon. In the jargons of logicians, the assertion of a statement can be represented but there is no indication of the person who made this assertion.

From these convergences we can conclude that there are certain semantic features of a language which improve its clarity and conciseness. Whether the semantic function is transmission of information or construction of a formal argument, structural evolution will reflect certain semantic properties. However, the structural machinery which evolves may be entirely different. Hence the semantic functions do not determine syntactic structure in any unique, deterministic way but rather are the moving force in a stochastic evolutionary process which eventually develops some syntactic structure that will perform the function.

By noting which are the convergences and which are the divergences between the jargons of surgeons and those of logicians, we can utilize the divergences to determine the linguistic features that distinguish information-transmitting from argument-constructing languages. For example, the almost complete suppression of kernel sentences in the logicians' jargons as opposed to their dominant role in the surgeons' jargon shows very clearly that the kernel sentences are the primary information-carrying component of the language.

In principle, it should be possible eventually to determine by a formalized, possibly even computerized, linguistic analysis of a given language just what semantic functions this language can and cannot perform. This better understanding of the role of language in communication processes is of scientific interest in its own right but the application to public affairs is of much greater importance. For example, microbiology is also of interest in its own right but the major significance of the subject is in its contribution to control of human disease (or the diseases of useful animals and plants). Similarly, one of the major contributions of modern linguistics is its potential value in dealing with the malfunctioning of communication systems. Indeed the linguist, like the microbiologist, has a social responsibility to develop his subject in directions which will produce practical results even though he can often avoid this responsibility if he works in a purely academic environment.

The findings reported here have a number of important implications for human affairs. For one thing they indicate the stringent limitations of professional jargons. It is clearly nothing more than a vulgar superstition to suppose, as most professionals do, that their particular jargon is infinitely superior to ordinary language or to other professional jargons. The failure of experts to recognize the limitations of their languages—and hence of what they can usefully say—has led to major public problems and has hampered the solution of these problems. The worst therapeutic disaster in medical history, the epidemic of deformed babies produced by thalidomide, was in part due to experts who were "prisoners of jargon" and how this came about is explained in an article by that name (*5*). Advances in linguistics have created the possibility of "communication engineering" in a much broader sense—the possibility of the scientific diagnosis and cure of the communication breakdowns that are the plague of our contemporary technological societies.

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