[From: *Lingua* 21 (1968)]

# THE PLACE OF HEURISTICS IN THE FULCRUM APPROACH TO MACHINE TRANSLATION[1])

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ABSTRACT

This paper deals with the basic principles of the Fulcrum approach as applied to Russian-English machine translation, with particular emphasis upon the use of heuristics for the resolution of complex syntactic problems. The theoretical foundations of the Fulcrum approach are first discussed, then the general features of the approach are outlined, and finally questions of syntactic ambiguity and the use of heuristics in its resolution are treated and exemplified.

## 1. THEORETICAL FOUNDATIONS

The theoretical conception on which the Fulcrum approach is based is the definitional model of language. In this conception, the system of a language is considered to be, not a single hierarchy with a single set of levels ascending from phonology to semantics via syntax, but a multiple hierarchy structured in two dimensions, at least one of which in turn has three planes, with a separate set of levels proper to each of the planes.[2])

Language is viewed as a system of signs structured in two dimensions, those of the grammar and the lexicon. These two dimensions differ in terms of the purpose to which the signaling means of the language are put: the lexical dimension is defined as the system of reference to culturally recognized types of phenomena; the grammatical dimension is defined as the structure of discourse.[3])

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[1]) This paper is a revised version of Progress Report No. 14 under Contract NSF-C372, 'Computer-aided research in machine translation', with the National Science Foundation.

[2]) For a detailed discussion of an earlier formulation, see Garvin 1963a. For a more recent, but more concise discussion, see Garvin 1968.

[3]) For a detailed discussion of the two dimensions, see Mathiot 1967.

The grammatical dimension of language is characterized by three planes, each with its own set of distinctions: the plane of structuring, characterized in all languages by two *levels of structuring* – those of *phonemics* and *morphemics;* the plane of integration, characterized fit all languages by several *levels of integration* (the number of which varies from language to language); the plane of organization, characterized in all languages by two *organizing principles* - those of *selection* and *arrangement.*

All of these distinctions are defined by functional criteria:

(1) The two levels of structuring differ in terms of the extent to which the units of each level participate in the sign function (meaning) of language. The units of the phonemic level function primarily as differentiators of the sign function, the units of the morphemic level function as its carriers.

(2) The levels of integration differ in terms of the order of complexity of the units that constitute them: they range from the level of minimal units, which is the lowest, to the level of the maximal fused units, which is the highest. Fused units are considered to be not mere sequences of units of a lower order, but to function as entities of their own order, with certain overall qualities above and beyond the mere sum of their constituents.

A correlate of the concept of fused units is the conception that the internal structure and the external functioning of a given unit are separate and potentially independent characteristics: units with the same internal structure may have different external functioning; units with different internal structure may have the same external functioning.

Units with the same internal structure are called *identically constituted;* units with the same external functioning are *called functionally equivalent.*

(3) The two organizing principles on the plane of organization characterize different manners in which the signaling means of the language are employed: selection from an inventory versus arrangement in a sequence.

The three planes of the grammatical dimension of language are in a hierarchical relation to each other. The plane of structuring is defined by the most significant functional criterion and is therefore superordinate to the other two planes. Of the latter, the plane of integration is in turn superordinate to the plane of organization. Con-

sequently, within each level of the plane of structuring a set of levels of integration can be defined, and within each level of integration of either level of structuring, the operation of both organizing principles can be discerned.

This conception of the structure of natural language is only an approximation: like all natural objects, natural language exhibits many indeterminacies and is more complex than any conceptualization of it can be.

One conspicuous instance of the indeterminacies of natural languages is the perturbation of the covariance of form and meaning (which follows from the sign nature of language) by the well-known phenomena of homonymy and synonymy. Another instance is the lack of precision in the separateness of the levels of language, as shown by the presence of some aspects of meaning (rather than mere differentiation) in certain phenomena usually assigned to the phonemic level of structuring (for instance, intonation, emphatic stress).

The complexity of natural language is apparent from the observation that in its overt manifestations (text, speech behavior, etc.) the different aspects (dimensions, planes, levels) of its underlying structure are not displayed separately but are closely intertwined, in the sense that each individual manifestation of the system displays all of its aspects together in a complex signal.

It is because of these indeterminacies and complexities that the model chosen for the conceptual representation of natural language is not quantitative, but qualitative. The model postulates only the general attributes of the object of study, but not the specific values and detailed manifestations of these attributes. These are to be ascertained by empirical means. Thus, the statement of the structure of a particular language is not considered a theory of this language, but rather a description within the frame of reference provided by a theory.[4])

In a linguistic description based on the definitional model, the various features of the model determine the organization of the description as follows:

(1) The concept of the separateness of the two dimensions of language provides the justification for limiting the description to either

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[4]) The classical statement of the opposite view is found in Chomsky 1957: 49: 'A grammar of the language L is essentially a theory of L.'

of the two dimensions, and for keeping the grammar separate from the lexicon;

(2) The concept of the levels of phonemics and morphemics on the plane of structuring provides the reason for differentiating the description of the phonemic pattern from that of the morphemic pattern, and to deal with their interrelations as a distinct aspect of the description;

(3) The concept of the levels of integration provides the reason for organizing the description in terms of both minimal units and various orders of fused units, on both the phonemic and morphemic levels of structuring;

(4) The concept of the potential independence of internal structure and external functioning provides the reason for differentiating these two aspects of linguistic units throughout the description;

(5) The concept of the organizing principles of selection and arrangement on the plane of organization provides the reason for including in the description not only the inventories of units but also their distribution.

In the development of the Fulcrum approach, the primary concentration has not been on the further elaboration of the theoretical model of language, but on the design of a system appropriate to the task of translation, as well as the conduct of appropriate experimentation to test the adequacy of the system to the task. In the design of this system, the various features of the definitional model of language have served as guidelines but, by contrast with some other approaches to language data processing, the Fulcrum system is not intended to be a direct computer implementation of the underlying model. Rather, the function of the model is, from an operational point of view, to serve as a frame of reference for the design of the system, and from a theoretical point of view, to provide an explication and justification for the system.[5])

In this connection, it is important to note a basic difference between the application of the definitional model to linguistic description, and its application to the design of a machine translation system.

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[5]) For a different conception of the role of the model in a machine translation system, see Lamb 1965.

As was noted from the above, the organization of a linguistic description closely follows the hierarchic structure of the model. This is because, on the one hand, the model is considered a conceptual representation of the phenomenon of natural language in terms of its general properties, and on the other hand, a linguistic description presents the specific manifestation of these general properties in the case of a particular language.

In the design of the Fulcrum system, on the other hand, the properties of language as stipulated by the definitional model are taken into account in the order in which they are relevant to the process of translation. This order does not coincide with their organization within the model and the linguistic description.

Thus, the plane of organization, which ranks low in the hierarchy of planes of the grammatical dimension, is of primary significance in the theoretical interpretation of the translation process. The two organizing principles of selection and arrangement have been identified as the two basic components of the translation process since the early days of machine translation research (Garvin, 1956).

Of at least equal importance is the plane of integration. The syntactic recognition routines of the translation algorithm are formulated in terms of the requirement of identifying the boundaries and functions of syntactic fused units (Garvin, 1963b).

The plane of structuring applies to machine translation in the relatively obvious sense that the machine-readable input symbols (letters, spaces, etc.) belong to the graphemic level (which is functionally equivalent to the phonemic level of spoken language), while the units manipulated by the translation algorithm belong to the morphemic level (primarily words and syntactic fused units). The conversion from graphemic to morphemic units is accomplished by the dictionary lookup and by those subroutines of the translation algorithm which assign grammar codes (and with them morphemic status) to graphic elements not contained in the dictionary (such as symbols, missing words, etc.).

The two dimensions of language, which are kept separate in linguistic description, are taken into account together in the Fulcrum algorithm. The dictionary lookup is supplemented by special subroutines (such as the idiom and word combination routines) which allow the processing as single translation units of not only individual words, but also multiword lexical units. The syntactic recognition

routines then treat these lexical units in the same way as syntactic units of similar structure that have been identified on the basis of purely grammatical criteria.

## 2. General Characteristics of the Fulcrum Approach

The Fulcrum approach differs from other approaches for automatic sentence structure determination primarily in the following respects:

(1) The Fulcrum approach favors a bipartite, rather than a tripartite, organization of the parsing system.

(2) The Fulcrum approach is characterized by two basic operational principles: (a) the concept of the fulcrum; (b) the pass method.

(3) The Fulcrum approach aims at producing a single interpretation of each individual sentence, rather than at producing all conceivable interpretations.

Each of these characteristics will now be discussed further.

### 2.1. *Bipartite organization*

A bipartite parsing system consists of two basic components: a dictionary with grammar codes (and other codes), and an algorithm which contains both the processing subroutines and the information required for processing. A tripartite parsing system consists of three basic components: a dictionary with grammar codes (and other codes), a processing algorithm, and a separate store of information (such as a table of grammar rules and other rule tables) which is called by the algorithm. The basic difference between these two types of system thus is that in a bipartite system the information required by the algorithm is written right into it, while in a tripartite system processor and information are kept separate.

Two types of advantages of the tripartite approach are usually cited by its proponents:

(1) It separates the labor of the programmer who designs and maintains the processor from that of the linguist who designs and maintains the table of rules. The only thing they have to agree on is the format of the rules that the processor can accept. This minimizes the communication problem between linguist and programmer, since once these matters have been settled, the two portions of the program can be handled separately.

(2) The same processor can be used with more than one table of rules. This means first of all that rules can be modified or changed without having to change the processor, provided of course that the format is maintained. This gives the linguist great freedom of experimentation with different types of rules. It also permits the use of the same processor for the parsing of more than one language, by simply substituting one table of rules for another.

These advantages apply particularly well to small experimental systems oriented towards linguistic research: for larger-scale experimentation, oriented towards the processing of randomly chosen bodies of text with the ultimate aim of designing an operational translation system, the advantages of a tripartite system are less clearcut. This is why the Fulcrum approach favors a bipartite organization of the parsing system.[6])

The algorithm of a bipartite system is essentially not a 'parser' of the type used in tripartite systems. It is instead a linguistic pattern recognition algorithm which, instead of matching portions of sentences against rules stored in a table, directs searches at the different portions of the sentence in order to identify its grammatical and lexical pattern. Thus, the essential characteristic of the algorithm is the sequencing of the searches, and in each search subroutine, only as much grammatical and lexical information is used as is appropriate to the particular search. The rules of the grammar and lexicon are in fact applied by the algorithm in a definite order, and a given rule is not even called unless the previous searches have led to a point where its application becomes necessary. This means that the highly complex system of rules that makes up the real grammar and lexicon of a language is distributed over a correspondingly complex algorithm which applies the rules in terms of the ordering that the structure of the language requires.

The description of Russian which furnishes the information included in the Fulcrum algorithm is based on the definitional model of language. It was developed using conventional Russian grammars and dictionaries as a starting point, verifying the reliability of the information, and adapting it to the requirements of the Fulcrum approach. In this process, it was found that many of the conven-

[6]) For a more detailed discussion of the reasons for this preference, see Garvin 1966.

tionally accepted statements about Russian grammar are not only inaccurate, but also that they are insufficient for purposes of automatic syntactic recognition. This is particularly true with respect to government, complementation, and mandatory co-occurrence relations.

### 2.2. *Fulcra and passes*

A bipartite system stands or falls by the manner in which the problem of the sequencing of the searches within the algorithm has been solved. This is the key problem in developing the detailed structure of the algorithm.

The Fulcrum approach attempts to solve this problem by using two fundamental principles: the concept of the fulcrum and the pass method.

The concept of the fulcrum implies the use of key elements within the sentence (fulcra) as starting points for the searches performed by the algorithm. This means that the algorithm, in searching through a sentence, does not simply progress from word to word, but in fact 'skips' from fulcrum to fulcrum. It performs a little search sequence each time it has reached a fulcrum, and goes on to the next fulcrum when this particular search is completed.

The pass method means that not one, but several passes are made at every sentence, each pass designed to identify a particular set of grammatical conditions pertinent to the recognition process. Consequently, each pass has its own set of fulcra and its own search sequences. The pass method reflects the orderly progression in which the determination of the structure of the sentence is made: first, the sentence components are identified individually, then the relations between components are established, and finally the structure of the sentence as a whole is established. To each of these intermediate parsing objectives there corresponds, roughly, a pass or series of passes in the algorithm. The correspondence is not exact, because there are many ambiguities and irregularities interfering with the recognition process, and the design of the Fulcrum algorithm reflects these added complexities.

### 2.3. *Single interpretation of each sentence*

Many automatic parsing systems are theory-oriented: their aim is to apply, verify, or otherwise deal with, a formal model of lan-

guage, such as, for instance, a particular variety of phrase-structure grammars. One of the significant theoretical results of the use of such a parsing system is the determination of all the conceivable parsings that a given sentence is assigned by a particular grammar.[7])

The Fulcrum approach, on the other hand, is translation-oriented. Its aim is primarily to produce as correct a translation as possible. Clearly, for this purpose, the identification of all conceivable parsings of a given sentence is of no great interest. Rather, it is desirable for the algorithm to produce, at all times, if not the correct parsing, at least the most likely parsing of each sentence, to serve as the basis for its translation from Russian into English. In the earlier versions of the Fulcrum approach, this unique parsing was chosen deterministically on the basis of the contextual information available to it: for each set of conditions as identified by previous and current searches, the single possible - or most probable - interpretation was assigned to each syntactic and lexical configuration.

Thus, Russian clauses in which a nominal structure, ambiguously either nominative or accusative, both precedes and follows a predicate that agrees with either nominal structure, were interpreted by the algorithm on the basis of the highest probability in syntactic terms: the structure to the left of the predicate was interpreted as subject, that to the right of the predicate as object. The alternative interpretation (object-predicate-subject), although theoretically conceivable, was ignored. In the overwhelming majority of instances of course, this turns out to be the correct interpretation, as shown by the Russian one-clause sentence: Это предложение сохраняет нормальный порядок, which has only one reasonable interpretation: 'This sentence preserves normal order.'

There are a few structural configurations in which this probabilistic interpretation is not necessarily (or not at all) the correct one. First of all, there are some Russian clauses which, when used out of context, have only the one reasonable interpretation of consisting of subject-predicate-object. But, because of their particular lexical structure, they require the alternative interpretation in certain contexts. So, for instance, the Russian one-clause sentence

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[7]) Cf. Kuno 1965: 453: 'A predictive analyzer produces for a given sentence all possible syntactic interpretations compatible with the current version of the predictive grammar.'

Автобусы заменили тролеибусы would ordinarily be interpreted as: 'Motor buses have replaced trolleybuses.' But not so in the special context in which this sentence is preceded by У нас уже нет автобусов 'We no longer have motor buses.'[8]) This context requires the alternative interpretation of object-predicate-subject: 'Trolleybuses have replaced motor buses.' (A stylistically better English translation would preserve order and replace the active predicate by a passive: 'Motor buses have been replaced by trolleybuses.') There are, finally, a few Russian clauses which in any context have only the alternative interpretation (object-predicate-subject). The classical example of these constructions is Большой интерес представляет вопрос... which, because of its particular lexical structure, can only be interpreted as object-predicate-subject: 'Of great interest is the question…'

The principle followed here is that, as the searching capability of the algorithm increases, the likelihood of erroneous choices decreases correspondingly. Thus, by increasing the lexical recognition capability of the algorithm, constructions of the last-mentioned type, in which lexical conditions override the effect of the syntactic configuration, can be identified and translated correctly. By increasing the range of contexts that the algorithm can search, constructions of the first-mentioned type, in which contextual factors override the effect of the syntactic configuration, can be identified and translated correctly. Clearly, the former recognition problem is much easier to resolve than the latter, since it requires only that special lexical meanings be taken into account, while the latter requires a form of 'understanding' by the algorithm of the specific content of individual sentences.

Problems of the type just discussed are still within the capabilities of a deterministic recognition algorithm. There are, however, a number of identification problems of a different type which transcend the scope of a deterministic resolution capability and which require a heuristic approach to syntactic recognition. These will be discussed in the subsequent section.

[8]) I am indebted to A. Isačenko for this example.

## 3. THE NEED FOR HEURISTICS

The problems of the types treated in the preceding section do not require a revision of the basic design of the earlier versions of the Fulcrum algorithm. They do require access to more information of more kinds, but within the framework of the original pass method - perhaps with an increased number of passes, or an improved overall layout of passes.

There are, however, a number of recognition problems for which the original deterministic design is inherently inadequate. These are the cases in which the correct resolution of a problem arising in a given pass requires the use of information that only a later pass can provide. From the standpoint of syntactic and lexical configuration, these are the instances in which the immediate context suggests the probability of a certain identification which, however, in the light of the total context of the sentence turns out to be incorrect.

The classical example of this type of configuration is the genitive singular/nominative-accusative plural ambiguity of nominals, the resolution of which as a genitive is suggested by an immediately preceding nominal structure. This identification, though correct in the majority of examples in Russian technical text, may turn out to be erroneous if other conditions in the broader context prevail; for instance, if a plural subject is required for the predicate of the clause and only the ambiguous nominal is an available candidate. This configuration is shown by the nominal задачи 'of a task/tasks' in the clause В нашем плане задачи будут выполнеы... In our plan, the tasks will be fulfilled...' Note that the resolution based on the immediate context is still likely to be the correct one in the majority of instances; it is the 'usual' resolution which should be overridden only under 'special' conditions.

One treatment of the type of problem illustrated by the above example would be for the algorithm to record both possible interpretations of the ambiguous form early in the program, and make the selection later when the information from the broader context has also become available. This solution would, however, fail to take into account the characteristic feature of this type of configuration, which is that the two possible resolutions of the syntactic ambiguity are not equally probable: in the majority of occurrences, a correct identification can be based on the immediate context, and

the broader context has to be resorted to only under special conditions. This requires a method of resolution which will accept an identification based on the immediate context, will let it stand in the majority of cases, but will have the capability for revising this decision in all those cases in which the special conditions apply which call for an identification in terms of the broader context. Such a method of resolution is heuristic in nature; it is discussed in detail in the subsequent sections.

## 4. HEURISTIC PRINCIPLES

The Fulcrum approach has borrowed the concept of heuristics from its applications in artificial intelligence research.

As is well known, the concept of heuristics is related to problem-solving. This is how most students of artificial intelligence speak of it. According to M. Minsky (Feigenbaum and Feldman, 1963:407), 'The adjective 'heuristic', as used here and widely in the literature, means *related to improving problem-solving performance;* as a noun, it is also used in regard to any method or trick used to improve the efficiency of a problem-solving system.' G. Pask (1964: 168) speaks of '... a set of 'heuristics' ... or broad rules and suggestions for problem solution…'

One characteristic of heuristics is that it is 'provisional and plausible' (H. Gelernter in Feigenbaum and Feldman, 1963: 135). Another more important characteristic is that they are 'processes ... which generally contribute to a result but whose effects are not 'guaranteed'' (Newell and Simon, 1963: 390).

The major advantage of heuristic principles is considered to be that they 'contribute, on the average, to reduction of search in problem-solving activity.' (F. M. Tonge in Feigenbaum and Feldman, 1963: 172). Thus, '…a heuristic procedure substitutes the effort reduction of its shortcuts for the guaranteed optimal solution of an exhaustive method …' (ibid., 173).

Theorists of heuristics often speak of heuristic processes. The mathematician G. Polya, who is often cited as an authority on heuristics by students of artificial intelligence, defines modern heuristics as the study of 'the process of solving problems' (1957: 129). He links the use of heuristics to plausible reasoning, as applied in the 'heuristic syllogism', which he differentiates from the demon-

strative reasoning of logic (ibid. 186-190). Others emphasize the methodological aspects of heuristics. Thus, E. A. Guillemin (1931: 10) speaks of '... a method of solution ... which is used almost exclusively by physicists and engineers. This method is nothing more than judicious guessing. The elegant title by which this method is known is the *heuristic method.*'

All of the above-noted aspects of heuristics have to do with the general functional characteristics of heuristic processes or methods. Clearly, they all are in some way pertinent to syntactic resolution in general and the Fulcrum approach in particular. We are dealing with a form of problem-solving; the solutions may have to be provisional and plausible rather than definitive, and they are certainly not guaranteed; the Fulcrum approach, at least, has as one of its major aims the reduction of the number of required searches; certainly, all forms of syntactic resolution are based on plausible rather than demonstrative reasoning, and are in essence well-organized judicious guesses.

In view of all this, it might not be unreasonable to refer to all syntactic recognition procedures as recognition heuristics. The reason this has not been done is because in the Fulcrum approach a somewhat more specific and restricted definition of heuristics has been used than that implicit in the aspects listed so far.

Such a more specific definition is based on the design characteristics of a heuristic program, rather than on the general purpose of the heuristic approach. While these design characteristics are not explicitly stated in the literature, they can be extrapolated from an examination of the use of heuristics in artificial intelligence (cf. several of the articles in Feigenbaum and Feldman, 1963). In essence, a heuristic program consists of an alternation of trials and evaluations based on a clearly defined strategy. The strategy is that of a problem-solver, the trials are the 'judicious guesses' (see above) which characterize the heuristic method, and the evaluation of the trials is based on criteria of goal attainment derived from a definition of the problem.[9])

Usually a heuristic program and an algorithm are considered two alternative ways of approaching a problem. Thus, A. Newell, J. C.

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[9]) For a more detailed discussion of this view of heuristics, see Garvin 1964: 80-85,

Shaw, and H. A. Simon note (Feigenbaum and Feldman, 1963: 114) that there may be 'both algorithms and heuristics as alternatives for solving the same problem.' In the Fulcrum approach, on the other hand, heuristics is not used as an alternative to an algorithm. Rather, the two are combined in the same program: the Fulcrum algorithm contains certain heuristic portions designed for the resolution of only those identification problems that do not lend themselves to a straightforward algorithmic treatment. This means that the Fulcrum algorithm, in addition to the heuristic trial and evaluation components, must also contain provisions for identifying those sets of conditions under which heuristic resolution is required.

These design features of the heuristic portions of the Fulcrum algorithm will be discussed in the subsequent section.

## 5. DESIGN OF THE HEURISTIC PORTIONS OF THE FULCRUM ALGORITHM

As has been noted in the preceding section, the design of the heuristic aspects of the Fulcrum algorithm is not identical with that of an independent heuristic program. Rather, the need to adapt the heuristic design principles to the requirements of the Fulcrum approach has led to the development of a design quite specific to this particular purpose.

The most typical feature of this design has already been mentioned, namely, the overall characteristic that the heuristic is, as it were, embedded in an algorithm. Thus, the executive routine of the heuristic, which carries out the 'guessing' strategy by calling the trial and evaluation routines, in fact constitutes a bridge between the deterministic main portion of the algorithm and the heuristic portion. It operates on the basis of a capability of the deterministic main portion of the algorithm for recognizing when to call the heuristic portion. This capability is one for recognizing the circumstance, already noted previously, that for a given ambiguously interpretable form the conditions present in the immediate context do not guarantee a correct identification. Once this recognition has been effected, the Fulcrum algorithm makes the transition from the deterministic main portion to the heuristic portion and acts as the executive routine of the heuristic.

The remaining aspects of the heuristic portion of the Fulcrum algorithm, namely, those dealing with the conduct of the trials and

evaluations, likewise differ significantly in their design from an independent heuristic program.

An independent heuristic program, such as those used for game-playing or theorem-proving (see Feigenbaum and Feldman, 1963), carries out more than one trial every time it 'considers' a particular move or other operation. By contrast, the heuristic portion of the Fulcrum algorithm conducts only one trial each time it is called, or more specifically, it carries out a particular single syntactic identification in the form of a trial, subject to later revision. The question asked in an independent heuristic thus is, which of several trials (if any) is successful? The question asked by the heuristic portion of the Fulcrum algorithm is, is this particular trial successful?

In an independent heuristic, evaluation takes place immediately after each given set of trials has been completed. In the heuristic portion of the Fulcrum algorithm, the evaluation of a given trial identification does not take place until later in the program. This is because, as was repeatedly noted before, the trial identification is based on the broader context, and the Fulcrum algorithm deals with the immediate context significantly earlier in the program than with the broader context.

As in any heuristic, so in the heuristic portion of the Fulcrum algorithm, the essential subject-matter question concerns the factors on which the trials and evaluations are based.

In the heuristic syntax, the trials are based on probability: as has already been noted, a given trial identification is always made on the basis of the most likely solution suggested by the immediate context. It must be stressed that this likelihood is determined impressionistically on the basis of available knowledge of Russian grammar; it is not considered necessary to have recourse to a formal probability calculus. The evaluations are based primarily on the mandatoriness of certain syntactic relations within the broader context: if the broader context requires that a certain syntactic function (such as that of subject) be filled, and this condition can be met only by revising a previous trial identification, then this requirement constitutes the evaluation criterion on the basis of which the original trial is rejected and an alternative solution is substituted for it.

The heuristic portion of the Fulcrum algorithm operates in the following manner. Whenever the recognition routines identify a set

of conditions under which a trial identification is made, a record of this trial is written (a heuristic 'flag' is 'set'). When later in the program the broader context requires a mandatory syntactic component for which no suitable candidate is present, the algorithm 'looks for' a heuristic flag. If it finds a flag, the trial identification is * judged a failure on the basis of the newly encountered conditions of mandatoriness, and the alternative identification is chosen in its stead, in order to satisfy this condition of mandatoriness.

As can be inferred from the above, the use of heuristics in syntax presupposes the inclusion in the grammar code of the Fulcrum system of all those indications that are essential to the operation of the heuristic portion of the algorithm. In particular, this means including information about mandatoriness of syntactic relations where this is not implicit in the word class of the dictionary entry. Thus, for every attributive (adjective or adjectival pronoun), a head is mandatory and hence no special mandatoriness notation is required in the grammar code. In the case of predicatives, on the other hand, a subject or object may be either optional or mandatory, and hence a mandatoriness notation in the grammar code is necessary.

Specific examples of heuristic ambiguity resolution in the Fulcrum algorithm are discussed in the subsequent section.

## 6. APPLICATION OF HEURISTICS TO PARTICULAR SYNTACTIC RESOLUTION PROBLEMS

Two areas of syntactic resolution will be discussed to illustrate the application of the heuristic portion of the Fulcrum algorithm. These are the syntactic interpretation of genitive nominal blocks and the resolution of predicative-adverb homographs (word-class ambiguities of the type ясно). Genitive nominal blocks here include both those that are unambiguously genitives and those that are ambiguously genitives. The latter are nominal blocks which in addition to the genitive function have other case functions, requiring the resolution of the case ambiguity in addition to other aspects of syntactic identification.

### 6.1. *Genitive nominal blocks*

The cases of interest here are those for which the immediate con-

text suggests that the (unambiguously or ambiguously) genitive block functions as an adnominal genitive complement. This resolution may be overridden by conditions in the broader context which the heuristic capability of the program recognizes.

Thus, the ambiguous genitive полета '(of) flight' in the immediate context время полета 'time (of) flight' will be identified as the adnominal genitive complement. However, the broader context may require that this genitive form be interpreted as the genitive of reference of a negative predicate, as when the above example is expanded to read: В это время полета не было 'at this time there was no flight.' The heuristic capability of the program will then carry out the required revision of identification.

Other types of conditions in the broader context which may require heuristic revision are:

(1) Genitive nominal block is required as head of a (governing) modifier;
(2) Genitive nominal block is required as subject of a predicate;
(3) Genitive nominal block is needed as object of predicate;
(4) Genitive nominal block is required as genitive of subject or object of deverbative noun.

Note than in each of the above cases, a relation in the broader context (head of modifier, subject of clause, etc.) is considered mandatory. In order to comply with this condition of mandatoriness, the previous identification based on the immediate context is overridden, and an identification which satisfies the mandatory relation in the broader context is substituted.

The types of conditions listed above are illustrated by the following examples.

(1) Выполненные бригадой работы.. .

The immediate context here suggests the trial identification of the ambiguously genitive noun работы '(of) work(s)' as the adnominal genitive complement to бригадой '(by) the brigade', to read бригадой работы '(by) the work brigade.' The broader context, however, requires that a head be assigned to the nominative/accusative plural governing modifier (past passive participle) выполненне 'performed', and the ambiguously genitive noun рабоru (which can also function as nominative/accusative plural) is the only available candidate. Consequently, the trial identification as genitive ad-

nominal complement is rejected, and replaced by a definitive identification as head to the governing modifier. The sentence fragment is then interpreted correctly as reading 'work performed by the parade'.

(2) В эксперименте цели будут выполнены. . .

The immediate context here again suggests the trial identification of the ambiguously genitive noun цели '(of/to/by) goal(s)' as the adnominal genitive complement to эксперименте 'experiment'. The broader context, however, requires that a subject be assigned to the plural predicate будт выполнены 'will be fulfilled', and the ambiguously genitive noun цели (which can also function as nominative/accusative plural) is the only available candidate. Consequently, the trial identification as adnominal genitive complement is rejected and replaced by the definitive identification as subject. The sentence fragment is then interpreted correctly as reading 'In the experiment the goals will be fulfilled ...'

(3) данный метод результата не дает.

The immediate context suggests the trial identification of the unambiguously genitive noun результата '(of) result' as the adnominal genitive complement to данный метод '(the) given method'. The broader context, however, requires that an object in the genitive be assigned to the negative predicate не дает 'does not give', and the unambiguously genitive noun результата is the only available candidate. Consequently, the trial identification as adnominal genitive complement is rejected and replaced by a definitive identification as object. The sentence is then interpreted correctly as 'The given method gives no result.'

(4) .. определение с максимальной точностью формы диаграммы . .

Again, the immediate context suggests the trial identification of the ambiguously genitive noun формы '(of) form(s)' as the adnominal genitive complement to точностью '(by) accuracy'. However, the broader context requires that a genitive of object be assigned to the deverbative noun определение 'determination', and the ambiguously genitive noun формы is the only available candidate. Consequently, the the trial identification is rejected and replaced by a definitive identification as genitive of object. The sentence fragment is then inter-

preted correctly as reading The determination of the form of the diagram with maximum accuracy.'

### 6.2. *Predicative-adverb homographs*

The cases of interest here are those for which the immediate context suggests that the homograph functions as an adverb. This resolution may be overridden by mandatory conditions in the broader context which the heuristic capability of the program recognizes.

Thus, the homograph понятно 'is understandable/understandably' will be identified as an adverb in the immediate context понятно высказанное 'understandably voiced'. However, the broader context may require that this homograph be interpreted as a predicative, as when the above example is expanded to read: Нам понятно высказанное И.П.Павловым убеждение, что. .. 'We understand the conviction voiced by I. P. Pavlov, that ... (lit.: the conviction ... is understandable to us).' The heuristic capability of the program will then carry out the required revision of identification.

The mandatory condition in the broader context here is, of course, that a clause should have a predicate whenever any candidate at all is available. Since the neuter nominative nominal block высказанное И.П.Павловым убеждение qualifies as subject, and the nominal block нам qualifies as the appropriate dative object, the homograph reinterpreted as a neuter predicative will meet both the condition of agreeing with the subject and the condition of governing the object, thus providing the clause with the needed predicate.

## 7. IMPLEMENTATION OF HEURISTIC SYNTAX

The essential characteristics of heuristic syntax as applied in the Fulcrum approach can be summed up as follows:

(1) The heuristic portion of the Fulcrum algorithm is called whenever there is a possibility that a given identification made on the basis of the immediate context may have to be revised on the basis of information provided by the broader context.

(2) The conditions requiring the use of heuristics are recognized by the deterministic portion of the Fulcrum algorithm.

(3) The mechanism for calling the heuristic syntax consists in the writing of a record (setting a 'flag') in the sentence image which the

program produces, indicating that a given identification has been made on a trial basis and is subject to heuristic revision.
(4) The evaluation criteria for the revision of trial identifications consist in various conditions of mandatoriness of occurrence of certain syntactic components. These conditions are recorded in the grammar codes of the dictionary entries which the Fulcrum algorithm manipulates. Some of these conditions are contained in the grammar codes by implication: thus, the word class code notation 'modifier' implies the requirement of a head to which this modifier is to be assigned. Other conditions must be noted explicitly in the grammar code, for instance, the mandatoriness of subjects or objects for certain predicatives, or the mandatoriness of genitives of subject or object for certain deverbative nouns.
(5) The mechanism for applying a heuristic revision to a trial identification consists of the following:

(a) The program first notes the absence of a mandatory syntactic element by acting upon the requirements implicit in the grammar code, or by reading the specific mandatoriness notation.
(b) The program now tests for the presence of heuristic decision records ('flags') in the sentence image and checks whether the recorded element is a suitable candidate for the missing syntactic component.
(c) If these tests are positive, the trial identification is revised and a definitive identification is substituted for it.

As can be noted, the apparatus for the heuristic syntax consists primarily of a capability for recognizing the need for heuristics, suitable notations in the grammar code to allow the heuristic evaluation of trial identifications, and a mechanism for writing and reading heuristic records in the sentence image, on the basis of which the revision of trial identifications can take place.

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