XXI. MECHANICAL TRANSLATION*

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RESEARCH OBJECTIVES

The primary objective of our research program is to find out how languages can be meaningfully manipulated and translated by machine, and to evaluate the quality that can be achieved with different approaches, the usefulness of the results and their costs. A further objective is to achieve a basic understanding of human communication and language use, and to add to the general knowledge of noncomputational uses of digital computing machinery.

We have always stressed a basic, long-range approach to the problems of mechanical translation. We are placing emphasis on completeness, when completeness is possible, and on finding out how to do a complete job if one is not now possible. This emphasis has led us into the study of many of the fundamental questions of language and translation. We are not looking for short-cut methods that might yield partially adequate translations at an early date – an important goal that is being pursued by other groups. We are seeking definitive solutions that will be permanent advances in the field, rather than ad hoc or temporary solutions that may eventually have to be discarded because they are not compatible with improved systems.

A broad and basic program of research is being carried out. In linguistic theory, a computer model of linguistic behavior is being studied which has already provided insight into the reasons why human languages are complex. Linguistic descriptions are being prepared for English, German, French, and Arabic. An experimental Arabic to English translation program is under development. In the area of semantics, work is proceeding along several avenues in an attempt to program a machine to understand English. Language is also being studied from a logical point of view to clarify the semantic significance of certain difficult and crucial words. The nature of the translation relation is being given special emphasis. Computer programming languages are being studied. The group has developed and is improving COMIT, a convenient large-scale computer programming system which greatly reduces the effort required to write programs related to the research.

V. H. Yngve

A. GENERATIVE GRAMMARS WITHOUT TRANSFORMATION RULES

A phrase-structure grammar has been written which generates roughly the same set of sentences generated by the most comprehensive transformational grammar[1] of English with which we are acquainted.

Chomsky and others have argued that a grammar consisting of a set of phrase-structure generation rules, along with a very simple rule of interpretation, which assigns structural descriptions to sentences on the basis of the manner of generation,

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is inadequate for giving a full grammatical description of sentences in English. On the basis of these arguments, many grammarians have chosen to write grammars using transformational generation rules, rules of considerably more mathematical power than phrase-structure rules. However, as Chomsky would be the first to point out, the arguments that he has given do not show that no adequate grammar for English may be written which uses phrase-structure generation rules.

The argument against the use of phrase-structure grammars is threefold. First, such grammars will be quite long, complex, ad hoc, and therefore difficult to write. Second, grammatical description in terms of parsing alone is not complete.[2] Third, phrase-structure grammars cannot exploit or explain certain general features of particular languages.[3]

In order to circumvent these difficulties the following suggestion has been made by Chomsky[4]:

(1) To the phrase-structure rules of the generative grammar add rules that are essentially more powerful (transformational rules).

(2) Add interpretation rules to give added structural description where certain transformational rules have or have not been used.

We have found that it is not at all necessary to introduce transformational rules to circumvent these difficulties, and, in fact, there are certain advantages in not doing so. We restrict the generation rules to phrase-structure rewrite rules of the sort described by one of us.[5] We retain the parsing interpretation for these generation rules.[6] We augment this interpretation by using a notation for the abbreviation of the phrase-structure generation rules. This abbreviated notation makes use of subscripts of the kind that have been provided for the purpose in the COMIT computer programming language.[7] Grammatical relations beyond those disclosed through parsing analysis are explicated in terms of derivations in the abbreviated notation. Finally we introduce an "evaluation procedure" for choosing between equivalent sets of generation rules. Our evaluation procedure involves a criterion of simplicity which enables us to exploit (and thereby explain) grammatical regularities in a given language.

The phrase-structure grammar that has been written by one of us (Harman) has been written in the form of a computer program that can produce sentences chosen at random from the set generated by the grammar. Examination of the sentences that are produced aids in eliminating errors in the grammar. This grammar generates nearly the same set of sentences as does the transformational grammar on which it is based. The only differences involve a few points at which the transformational grammar appeared to be in error.

We are now in a position to compare the two grammars from the point of view of the threefold argument that has been given against phrase-structure grammars. We have compared the lengths of the two grammars and find them to be of approximately the same size: one reasonable method of comparison shows the transformational grammar to be shorter, another equally reasonable method shows the phrase-structure grammar to be shorter. As for complexity and ease of writing, it would appear that the phrase-structure grammar is easier to write because the rules, being unordered, are relatively more independent. Neither of the grammars can be said to be ad hoc.

The arguments that phrase-structure grammar would be incomplete and not able to exploit and explain certain general features of particular languages is not borne out in this case. Our phrase-structure grammar provides for and explains adequately all of the features of English provided for and explained adequately by the transformational grammar. It is able to do this by virtue of the additional interpretation provided by the subscript notation that also provides the compactness over an unabbreviated form of the rules.

In other words, arguments for the introduction of transformational generation rules, on the grounds that one type of grammar using phrase-structure generation rules lacks explanatory power, can be met.

Arguments that phrase-structure generation rules lack the mathematical power needed seem incoherent, at least at present. At any rate, the additional mathematical power of the transformation rules was not needed in the very sophisticated transformational grammar of English which we used for a comparison.

The result that a phrase-structure grammar appears to be adequate for English is also of great practical interest to those attempting to handle natural language by machine.

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References

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2. N. Chomsky, Syntactic Structures (Mouton and Company, The Hague, second printing 1962), Chapter 5.

3. Ibid., Chapter 8.

4. N. Chomsky, Syntactic Structures, op. cit.

5. V. H. Yngve, A model and an hypothesis for language structure, Proc. Am. Phil. Soc. 104, 444-466 (1960).

6. These rules differ somewhat from those discussed by Chomsky, op. cit., p. 41, footnote. The exact form of these rules is unimportant as far as our argument here is concerned.

7. V. H. Yngve, A programming language for mechanical translation, Mechanical Translation 5, 24-41 (1958).

B. AN ORDINARY LANGUAGE INPUT FOR A COMIT PROOF-PROCEDURE PROGRAM

Work is in progress on a COMIT program for the translation of arguments from ordinary language into logical notation. This is conceived as an input device to a COMIT program, based on the Davis-Putnam proof-procedure algorithm, which tests quantified and nonquantified logical formulae for validity by the reductio ad absurdum method of attempting to deduce a contradiction from the negation of a formula.[1-3]

The translation program works essentially as follows.

(a) It divides the words of the input argument into two basic categories – the punctuative words, or "P-words," words like 'if', 'then', 'either', 'or', 'therefore', etc., which usually divide sentential clauses from one another, and the nonpunctuative words, or "W-words," which are all the rest and constitute the content of the sentential clauses. Accordingly, every word or punctuation mark in the input argument is subscripted, by means of a dictionary lookup, with either 'P' or 'W'. In the sentence

If it rains then it pours.

the P-words are 'if', 'then', and '.', and the W-words are 'it', 'rains', and 'pours'. A sentential clause is any finite sequence of W-words occurring between two P-words; in the example, 'it rains' and 'it pours' are the two sentential clauses.

(b) It performs some simplifications and expansions on the input sentences. All verbal forms are reduced to the infinitive, so that 'If it rains then it pours', 'If it will rain then it will pour', 'If it is raining then it is pouring', 'If it would rain then it would pour', etc. (all of which state basically the same implication) are all reduced to 'If it rain then it pour'. Sentences in which several subjects are attached to the same predicate, or in which several predicates are attached to the same subject, are expanded into their implicit sentential clauses. Thus, 'Jack and Jill went up the hill' is expanded into 'Jack went up the hill and Jill went up the hill'; and 'Jack both fell down and broke his crown' (the program requires the 'both' as the cue to activate the expansion subroutine) is expanded into 'Jack fell down and Jack broke his crown'. Sentences using 'either... or... ' and 'neither... nor... ' constructions are likewise expanded whenever possible. A fallacy would result if this type of expansion were applied, e.g., to 'Jack and Jill are cousins'; thus the input arguments must be stated without using relational sentences of this sort. Later, we hope to improve the program to handle them.

(c) It substitutes the letters 'A', 'B', 'C', etc., for the sentential clauses in the argument, by using the same symbol for the same sentential clause whenever it occurs.

(d) It parenthesizes the argument, on the basis of a set of 20 rules that make explicit the groupings that are implicit in the use of the P-words. Thus, 'If A then B or if C then D' is parenthesized (by using the arrow for implication and the wedge for disjunction) as '$(((A) \rightarrow (B)) \vee ((C) \rightarrow (D)))$'. In COMIT notation this formula appears as '*(+ *(+ *(+ A + *) + IMPLIES + *(+ B + *) + *) + OR + *(+ *(+ C + *) + IMPLIES + *(+ D + *) + *) + *)'. A logical argument is usually stated as a set of premises in the form of sentences separated by periods, which is followed by a conclusion introduced by a word like 'therefore' or 'hence'. Our program symbolizes an argument as one long sentence in the form of an implication, the 'therefore' (or 'hence', etc.) being replaced by 'implies', and the periods being replaced by 'and'.

The characteristics of the restricted English employed follow from the limitations on what the program can do. The restrictions fall into three general categories:

(i) Restrictions following from the fact that the program's only criterion of identity of two propositions or "ideas" is the identity of the sentences expressing them. Two propositions stated in different words, even though they may be synonymous, are symbolized with different letters, unless one or more of the subroutines mentioned in (b) above result in the sentences being expressed in the same wording and word order.

(ii) Restrictions on the use of the P-words and the C-words (which are a subset of the P-words and include the binary connectives 'and', 'or', etc.). The P-words that are at the same time C-words may be used only if a boundary is intended between two sentential clauses, so that a sentence like 'He implies that it will not rain' is ruled out, since the 'impliès that' will fallaciously divide the sentence into two sentential clauses, 'He' and 'it will not rain', which are connected by an implication sign. Also, every intended division between two sentences must be made explicit, so that 'If it rains it pours' must have a 'then' inserted between 'rains' and 'it' before the program will correctly handle the sentence.

(iii) Restrictions on the vocabulary. The program employs no grammatical recognition routine to speak of; thus a fixed vocabulary must be selected in advance, with all of the nouns, verbs, and adjectives specified. A given word may not be used in more than one of these categories; e.g., if 'praise' is used in the set of arguments submitted, it must be used either as a noun or as a verb, but not both.

The program has been successfully tested on a variety of examples taken, with the required changes in wording, from Copi.[4] Some of the improvements contemplated for the program in the future include coupling the program with a more powerful grammar, and enabling it to perform the more subtle intraclause analyses required for quantificational and relational logic. The proof-procedure program, based on the Davis-Putnam algorithm, is finished and runs reasonably well. It will do propositional, quantificational, and relational logic. Other improvements in this program will have to await improvements in the theory of proof procedures. The ordinary language input program discussed in this report will, however, do only some of the analyses required for propositional logic.

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C. SENTENCE-MEANING AND WORD-MEANING

In Quarterly Progress Report No. 66 (pages 289-293), I pointed out that it is necessary for an understanding of the semantical behavior of those morphemes that function as structural-constants[1] to distinguish between sentence synonymy and word synonymy. The principle underlying this view is that it is the particular configuration of structural-constants belonging to a well-formed grammatical string which gives rise to the fundamental sentence-meaning, the meaning of each individual structural-constant, as a morpheme, remaining constant – hence the term 'structural-constant' – but the meaning of each configuration varying, the variation depending upon both the structural properties of the configuration and the particular indispensable structural-constants that occur in it.

This semantical theory has been constructed to apply only to the analysis of the meanings of structural-constants and their interlocking relationships and does not attempt to cover the analysis of the meanings of lexical items that function as denotative terms. It is the author's opinion that different methods are required for the semantical analysis of those morphemes that function denotatively and those that function structurally. This method of analyzing the meaning of structural-constants and their various configurations departs quite radically from the methods proposed thus far which have been formulated primarily to handle denotative terms. In this theory, the denotative morphemes are treated as variables, only the class over which they range having structural significance. Thus, although it makes a great deal of difference to the total meaning of a sentence whether Jane or John is named as the subject or object of an action and whether the particular activity or relationship named by the verbal is of a certain kind, appropriate substitution of one member of a set for another does not alter the basic sentence-type, nor do such substitutions alter the fundamental sentence-meaning.

For an illustration of this theory, let us look at the following sentence:

(1a) If John is to be president, he must get his organization ready now.

In sentence (1a) the fundamental sentence-meaning is: John's getting his organization ready now is a necessary condition of his being president. The event denoted by the clause 'John is to be president' has not occurred nor does the sentence as a whole claim that it ever will, since the getting ready of the organization is not the sufficient condition of being president. Some sentences that are synonymous with sentence (1a) which are important in that they express the same fundamental meaning with a complete change of structural-constant, are

(1b) Unless John gets his organization ready now, he can not be president.

(1c) Only if John gets his organization ready now, can he be president.

It should be noted that the fundamental sentence-meaning of the above synonymous sentences, when it can be expressed through a symbolic notation, will be logical in form, not grammatical. Grammatically, the form of sentence (1a) has the shape that 'If John is to be president' is the dependent clause, whereas 'he must get his organization ready now' is the independent clause. In sentence (1b), 'Unless John gets his organization ready now' becomes the dependent clause, and in sentence (1c) 'Only if' subordinates that which in sentence (1a) was the independent clause to the dependent clause. Thus, from the point of view of grammatical form, either elementary sentence can be subordinated to the other without a change in fundamental sentence-meaning. Logically, however, the event denoted by the sentence 'he is to be president' is dependent for its existence upon the previous occurrence of the event denoted by the elementary sentence 'he gets his organization ready now'. The symbolic notation, formulating the fundamental sentence-meaning, must express this physical dependency. Thus far, no new notation expressing explicitly the relations of necessary and sufficient conditions has been introduced into the formal logical systems.[2] Expanding the logical notation of the formal systems will be a necessary step in establishing rules for coordinating sets of synonymous strings of one language system to sets of synonymous strings from another language system so that a sentence-by-sentence translation can be carried out.

Sentence (1a) can be expressed as a partially interpreted sentence-type, i.e., a sentence-type whose indispensable structural-constants that form the configuration expressing the fundamental sentence-meaning are explicitly indicated and whose denotative morphemes are indicated only by the class to which they belong.

(1d) If x is to be f, then x (or y) must g.

Sentences (1b) and (1c) can easily be put into abbreviated schematical forms. The combination of a partially interpreted sentence-type set up as equivalent to another represents a tautology whose major connective is an equivalence. Each tautology is a transformation law. It is to be noted that the transformation laws for every language are obtained by empirical observation; the sentences established as transforms of each other must be synonymous in actuality.

To show how vital to sentence-meaning the particular configuration of structural-constants is, let us alter sentence (1a) by affixing to it just one morpheme, the structural-constant, 'even', in prenex position.

(2a) Even if John is to be president, he must get his organization ready now.

The sentence-meaning of sentence (2a) is immediately seen to be quite different from sentence (1a) which expresses a relation of necessary condition. The fundamental meaning of sentence (2a) is that the accepted fact of John's being president in the future is unexpectedly not the sufficient condition of John's not having to get his organization ready now. When the structural-constant 'even' enters into the configuration of indispensable structural-constants belonging to sentence (1a), there is an immediate effect upon the 'meaning' of the individual morphemes: the event of John's being president is now known to take place in the future, 'is to be' thus becoming a simple future tense instead of being an indispensable structural configuration expressing necessary condition; the auxiliary 'must' represents no longer an indispensable structural feature. Sentence (2a) is synonymous with sentences of the following set:

(2b) Although John is to be president, he must get his organization ready now.

(2c) In spite of the fact that John is to be president, he still must get his organization ready now.

(2d) If John is to be president, he must get his organization ready now anyway.

Sentence (2d) shows very clearly that the listener must be aware of the total structural configuration of a sentence before he can determine the meaning of the sentence, since sentence (2d) is exactly like sentence (1a) in shape except for its very last morpheme 'anyway'. The morpheme, 'even', in prenex position, prepares us psychologically for a second clause denoting an unexpected event; 'anyway' psychologically springs the event denoted by the second clause as a surprise. The partially interpreted sentence-type to which sentence (2a) belongs is

(2e) Even if x f's, x (or y) must g.

The distinction between sentence-meaning and word-meaning is particularly important in clarifying the semantic nature of the free-variables 'any', 'ever', 'whatever', and other related morphemes. Only if the two concepts are carefully kept separate can one explain how it is that the meaning or the definition of the free-variable can remain constant but the sentence-meanings of the structural configurations in which the morpheme occurs can vary.[2]

Whereas it appeared at one time to me that free-variables were the only structural-constants that behave in this peculiar way of apparently shifting in meaning in different contexts, recent investigation has convinced me that this 'peculiar' behavior attends many of the structural-constants.[3]

This theory opens the way to a solution of linguistic problems that have plagued grammarians for a long time. I have recently proposed a solution[4] for determining the proper occurrence of free-variable morphemes in sentences whose import has been termed negative by grammarians, although their grammatical forms contain neither explicit nor implicit negative morphemes. One of the results was to show that this 'negative' import, ascribed by grammarians to morphemes such as 'few', 'little', 'only', 'too', and 'hardly' as opposed to their respective polar words 'many', 'much', 'all', 'enough', and 'almost' had been obtained by the replacement of the original non-negative sentence under discussion by a negative sentence synonymous to it. The negative sentence had been derived by an unformulated, intuitive recognition that sentences as wholes are related semantically as synonymous although the negative quality was erroneously assigned to a particular morpheme rather than to the sentence-meaning as a whole. However, by selecting only one negative grammatical string as representing the canonical grammatical form of the sentence under consideration, they failed to see that there are many synonymous sentences, some negative in form, some positive. Thus it was not possible for them to understand the real function of the structural-constant; they had considered as 'negative' a morpheme that is not itself negative because the selected structural-constant can occur in other configurations that do not give rise to a negative fundamental sentence-meaning. Furthermore, since, by the rules that transform one grammatical string into another grammatical string preserving the original sentence-meaning, one can always transform a string in which no negative morphemes appear into a synonymous string in which negative morphemes do appear, the explanation offered appears very arbitrary. One has only to look at sentence (1a) and the sentences synonymous to it to see this point. In sentence (1a) there is no explicit negation, but in sentence (2b) when 'unless' occurs in the first clause, an explicit negation 'not' must occur in the second clause, but if 'only if' occurs in the first clause, the negation must disappear if the fundamental sentence-meaning is to be preserved. It is this constant interplay of structural-constants that the early grammarians overlooked. They relied upon intuitive semantic paraphrasing only when they were forced into it by the need of explaining certain phenomena in the language under analysis. The author is writing a paper on the problem of the occurrence of free-variable morphemes within these so-called negative contexts.

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References

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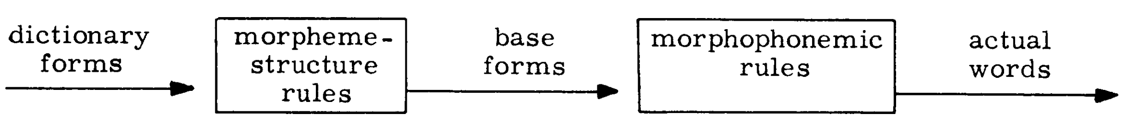
D. FINNISH NOUN MORPHOLOGY

This report gives a description of parts of a set of rules that I have written for the morphophonemics of Finnish nouns and adjectives.[1] The rules apply in a fixed order and are assumed to operate on the output of the syntactic part of a grammar of Finnish (this means that the rules may refer to the immediate constituent structure of, and the syntactic categories and syntactic boundary markers involved in, the forms on which they operate).[2] The complete set of rules takes care of the complete singular paradigm of all "regular" (I use this word in a rather broad sense) Finnish nouns.[3] It will be shown that the rules established for the "regular" nouns apply without change to several nouns and adjectives that are traditionally considered irregular. The complete set of rules has been tested by means of a computer program that executes the rules in sequence and prints out the results both in the form of a matrix of distinctive feature specifications and in a phonemic orthography.

The rules separate into two parts: a set of "morpheme-structure rules," which fill in feature specifications that are redundant by virtue of sequential constraints on the occurrence of the various segments, and a set of morphophonemic rules. The forms upon which the morphophonemic rules operate are called <u>base forms</u>. The dictionary part of the grammar of which these rules form a part will list forms in which only non-redundant feature specifications are made; these forms, which the morpheme-structure rules convert into base forms, are called <u>dictionary forms</u>. For example, in a 3-consonant sequence in Finnish, the last consonant must be a voiceless stop. The features relating to the manner of articulation of this consonant do not have to be listed in the dictionary, since only a stop can follow two consonants; one of the morpheme-structure rules will add the features of obstruent and noncontinuant to any consonant that is preceded by two consonants.

The rules thus operate according to the following scheme.



Consider the following paradigms:

	"eyelash"	"child"	"ski"	"door"	"name"	"snow"	"large"
Nominative	ripsi	lapsi	suksi	uksi	nimi	lumi	suuri
Genitive	ripsen	lapsen	suksen	uksen	nimen	lumen	suuren
Partitive	ripseä	lasta	suksea	usta	nimeä	lunta	suurta

These forms will be predicted corectly if one assumes that the words have base forms of ripse, laps, sukse, uks, nime, lum, and suur and supplies the grammar with rules whereby 1) e is added after certain consonants and clusters except in the partitive case; 2) the first of a sequence of three consonants formed at a morpheme boundary is eliminated (uks + ta → usta; I am assuming the traditional rule that the partitive ending is a/ä after a single vowel, and ta/tä elsewhere); 3) final e is raised to i in nouns and adjectives, and 4) nasals assimilate to the point of articulation of a following consonant.

Consider, for a moment, the rule that changes final e to i. This rule not only takes care of the alternation of i in the nominative with e in the oblique cases,[4] but also of certain other phenomena. Consider, for example, the forms with a possessive suffix: the rule given applies only when the e is final, so that e would remain e when no possessive suffix follows. This is in complete agreement with the facts:

ripsi, "eyelash";	ripseni, "my eyelash"
lapsi, "child";	lapseni, "my child"
suksi, "ski";	sukseni, "my ski"
lumi, "snow";	lumeni, "my snow"

Now consider situations in which an s in the nominative alternates with a t or d in the oblique cases.[5] It will be necessary to assume two separate morphophonemes t and c to represent those t's that do not and do alternate, respectively, with s; in many situations it is predictable whether or not the alternation will occur, but the existence of doublets, such as läksi/lähti (past tense of lähteä, "to leave"), means that there are environments in which this cannot be predicted.

In t/s alternations, the s occurs either before i (the i may be either an alternant of e in the nominative of nouns – see above – or the plural marker in nouns, or the past tense marker in verbs) or in final position in polysyllabic nouns. The first class of cases of t/s alternation thus requires a rule that states that c → s before i. Then paradigms such as

	"hand"	"one"
Nominative	käsi	yksi
Genitive	käden	yhden
Illative	käteen	yhteen

will be generated correctly if one assumes base forms of käc and yhc (a sequence of velar plus dental is subject to regressive assimilation of the feature of continuity: ht and ks occur, but hs and kt do not; this dissimilation rule will transform the underlying form yhsi into the correct form yksi).

What about the cases in which the s alternant of t is in final position and thus not followed by i? Example:

	"freedom"	"beauty"
Nominative	vapaus	kauneus
Genitive	vapauden	kauneuden
Illative	vapauteen	kauneuteen

To answer this question, let us return to the earlier examples of ripsi, etc. Note that these words are all disyllabic. Compare the examples above with the following paradigms:

	"gratitude"	"event"
Nominative	kiitos	tapaus
Genitive	kiitoksen	tapauksen
Partitive	kiitosta	tapausta
Illative	kiitokseen	tapaukseen

These paradigms differ from those of lapsi and uksi only in the nominative case, in which the final i is missing and the consonant cluster simplifies. The simplification of the final cluster is easily incorporated into the rules. The rule already required for simplifying clusters in the partitive now reads

$C \rightarrow \emptyset$ (i.e., is deleted) in the environment $\_\_\_ C + C$

(+ denotes morpheme boundary). All that is needed is to change the environment to read $\_\_\_ C \left\{ {+C \atop \#} \right\}$ (# means word boundary); this would then transform kiitoks and tapauks into the desired forms kiitos and tapaus. With respect to the fact that these words lack a final i, suppose that I just added a somewhat ad hoc rule that deletes final i if it occurs beyond the second syllable, so that kiitos would be obtained through an intermediate stage kiitoksi. That is, one rule would add a final i and then another rule would delete it, which admittedly sounds a trifle hocus-pocus-ish; however, it is no more complicated than the other solutions that present themselves, and, moreover, it turns out that it automatically takes care of vapaus and kauneus if base forms of vapauc and kauneuc are assumed: the final i is inserted, c → s before i, and then the final i is eliminated. This, incidentally, is exactly what happened historically: vapaus < vapausi; kiitos < kiitoksi. However, historical considerations aside, the solution given here seems likely to be the simplest synchronic description of the presence vs absence of final i and the t/s alternation, since it requres only the addition of one simple rule (i-deletion in polysyllabic nouns), in addition to rules that already have to be in the grammar to take care of other phenomena.

Consider, now, such paradigms as

	"tooth"	"spring"	"billy goat"
Nominative	hammas[6]	kevät	kauris
Genitive	hampaan	kevään	kauriin
Partitive	hammasta	kevättä	kaurista
Inessive	hampaassa	keväässä	kauriissa

The phenomenon to be accounted for is the disappearance of the final consonant and the appearance of the long vowel in the oblique cases. To explain this, let me digress for a moment and treat the topic of the occurrence of vowel sequences in Finnish words.

The vowel sequences that can occur within a syllable are the long vowels, the high-to-mid diphthongs (ie, yö, uo), and diphthongs whose second member is a high vowel. The long mid-vowels are of somewhat limited distribution: outside of a handful of recent loanwords, they only occur where they are created by some morphological process such as the vowel lengthening that occurs in the third person singular of verbs, the illative case of nouns, and the oblique cases of the class of nouns mentioned in the last paragraph. This means that aside from the loanwords, to which special rules will have to apply anyway, there will be no base forms containing long mid-vowels. This means that it would be possible to represent the high-to-mid diphthongs in base forms as if they were the corresponding long mid-vowels ee, öö, oo, and then obtain the high-to-mid diphthongs by a rule that raises the first mora of a long mid-vowel. This decision, based purely on the desire to simplify the statement of the occurrences of vowel sequences within a syllable (instead of saying "long high or low vowel, high-to-mid diphthong, or vowel plus high vowel," it now suffices to say "long vowel or vowel plus high vowel"), automatically removes an exception to the rules relating to noun plurals and the past tense of verbs. The rule in question relates to sequences of vowels that precede the plural or past-tense marker i. Most Finnish texts state that the second vowel of the sequence is lost except in the case of the high-to-mid diphthongs, in which the first vowel is lost. If these diphthongs are represented as long mid-vowels, this exception disappears, provided that the rule for the diphthongization of long mid-vowels follows the vowel-elimination rule (which will now state simply that the second vowel is lost). Example:

	"eats"	"ate"	"to the road"	"to the roads"
Base form	söö	söö + i	tee + lle'	tee + i + lle'
Vowel elimination	söö	sö + i	tee + lle'	te + i + lle'
Diphthongization	syö	sö + i	tie + lle'	te + i + lle'
Final result:	syö	söi	tielle'	teille'

Incidentally, these rules that I have established here for a synchronic description of Finnish morphology exactly mirror the historical development: Modern Finnish ie, yö, uo develop from Old Finnish ee, öö, oo. The vowel sequences within a syllable (in base forms) can thus be restricted to geminate vowels and vowel plus high vowel. This means that the grammar will contain a morpheme-structure rule corresponding to this restriction; the simplest candidate for this rule is a rule according to which progressive assimilation takes place when a vowel is followed by a non-high vowel within the same syllable.

Let us now return to nouns of the hammas type. I will attempt to account for these with as little machinery as is absolutely necessary beyond the rules already in the grammar. I already have a rule that adds an e in certain still vaguely specified environments. Suppose that it also applies to nouns of the hammas type. This will not affect the nominative case, since the final vowel would be eliminated later according to the rule already established. Consider the underlying forms for the genitive which would then result:

A. hampase + n   keväte + n   kaurise + n

If the s or t is removed, then a vowel sequence ae, äe, ie, etc., will arise. If the vowel-assimilation "morpheme-structure" rule is moved into the morphophonemic part of the grammar, then nothing more is needed. The forms A would be transformed into

B. hampae + n   keväe + n   kaurie + n

by the consonant-elimination rule and then into the desired forms

C. hampaa + n   kevää + n   kaurii + n

by the vowel-assimilation rule.[7] All that needs to be done now is to formulate the consonant-elimination rule, provided, of course, that one can be formulated, something that I still have not established.

Nouns of the hammas type are all disyllabic. They can, indeed (assuming the obvious base forms of hampas, kevät, kauris), be characterized as those nouns whose base form ends in a single obstruent (i.e., a single consonant other than a liquid or nasal). Note that nouns of the vapaus type, in which the final consonant is preserved, are trisyllabic (va pa us; kau ne us).[8] This fact immediately suggests a possible rule: An intervocalic obstruent is eliminated when preceded by exactly two syllables. However, a somewhat simpler, neater, and more intuitive form of the rule can be obtained by taking into account the alternating stress of Finnish. As far as I can determine, excluding certain recent loans and foreign names, base forms are at most three syllables long, so that a form obtained by the e-addition rule is at most four syllables long; the four syllables would have the stress pattern / ∪ ı ∪ (strong-minimal-low-minimal). The intervocalic obstruent is thus dropped if and only if it is preceded by a vowel with minimal stress.

The rules referred to here must apply in the following order:

(1) addition of e after a stem-final consonant,

(2) raising of a final e to i in nouns,

(3) deletion of final i from polysyllabic nouns,

(4) deletion of an intervocalic obstruent when preceded by a minimally stressed vowel,

(5) progressive assimilation of vowel segments within a syllable when the second is not high.

Note that these rules take care not only of the oblique forms of the hammas type of noun but also the forms with possessive suffixes. Hammas, kevät, and kauris have the following forms with a possessive suffix:

hampaani, "my tooth"
keväàni, "my spring"
kauriini, "my billy goat"

Starting from the forms

hampas + ni kevät + ni kauris + ni

rule (1) produces

hampase + ni keväte + ni kaurise + ni,

rules (2) and (3) do not apply (since the e added by rule (1) is not final), rule (4) yields

hampae + ni keväe + ni kaurie + ni,

and rule (5) yields the desired forms

hampaa + ni kevää + ni kaurii + ni.

On the other hand, if there is no possessive suffix in the nominative case, then the vowel added by rule (1) is deleted by rule (3), which means that the s or t is no longer intervocalic, so that rule (4) will not apply and the desired forms hammas, kevät, and kauris will not be obtained.

Further confirmation of the validity of these rules is given by the fact that the rules without any modification predict correctly not only the complete singular paradigms of all "regular" nouns and adjectives, which is what they were established to describe, but also the paradigms of several words that are usually regarded as "irregular." Three such examples are the nouns sydän and tuhat and the ordinal number words. Consider the following paradigms:

	"heart	"thousand"	"third"
Nominative	sydän	tuhat	kolmas
Genitive	sydämmen[9]	tuhannen[10]	kolmannen
Partitive	sydäntä	tuhatta	kolmatta
Illative	sydämmeen	tuhanteen	kolmanteen

The appropriate base forms are sydämm, tuhant, and kolmanc. The nominative case forms are generated as follows (for the other cases the derivations are obvious):

	sydämm	tuhant	kolmanc
e-addition	sydämme	tuhante	kolmance
vowel raising	sydämmi	tuhanti	kolmanci
c → s	sydämmi	tuhanti	kolmansi
i → Ø	sydämm	tuhant	kolmans
cluster simplification	sydäm	tuhat	kolmas
final → dental	sydän	tuhat	kolmas

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References

1. A paper that contains the complete set of rules, of which this is an abbreviated version, will be available soon in duplicated form from the Mechanical Translation Group, Research Laboratory of Electronics, M.I.T. Some of the rules are given here in a slightly simplified (and thus incorrect) form in the interests of simplicity; the differences are slight and affect only certain minor phenomena that are not treated here.

2. The descriptive model that I use is described in detail by Halle, The Sound Pattern of Russian (Mouton and Company, The Hague, 1959).

3. All statements that I make here for nouns also hold for adjectives; adjective morphology differs in no way from noun morphology in Finnish.

4. I use the term "oblique cases" to refer to all cases except the nominative and partitive.

5. The d is the result of consonant mutation, a process by which voiceless stops at the beginning of short closed syllables are modified. The larger version of this report contains a full treatment of consonant mutation rules.

6. The mp/mm alternation is a result of consonant mutation.

7. In order for the vowel-assimilation rule to be able to apply, not only the consonant but also the syllable boundary preceding it will have to be removed. Note that it is possible for the second and third syllables to be separated by a syllable boundary but no consonant: kor ke a; ta pa us. Vowel assimilation does not occur in such cases. Syllable boundary is, of course, nondistinctive: it is inserted according to rules that correctly predict its occurrence.

8. The au diphthong can occur in only the first syllable. In au sequences beyond the first syllable, both vowels are syllabic, i.e., they are separated by a syllable boundary, as in vapaus.

9. The oblique case forms of sydän are written with a single m in standard orthography; however, a double m is actually pronounced.

10. nn is the alternant of nt under consonant mutation.