THE PROGRESS AND TECHNIQUES OF MECHANICAL TRANSLATION*

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Introduction

If we can properly regard language as one of man's inventions, then it must have been one of the earliest that he made. No subsequent invention can be considered as having greater fundamental importance. Language is man's tool for the storage and dissemination of concepts. Language is essential for the preliminary organization of any complex group activity.

With the technological progress that language has made possible, concepts can be transmitted over greater distances than before and to larger numbers of people. Written language allows the storage of information for subsequent generations, but the written word can be read only by the literate proportion of the world's population. Radio broadcasts, on the other hand, can be heard in every part of the world and do not demand literacy on the part of the listener.

However, the spread of knowledge and understanding among the peoples of the world is now restricted, not so much by the physical nature of the communication channels used as by the nature of language itself. The work of translation and interpretation is probably the greatest obstacle.

Because of the number of languages in everyday use [c.3,000] and the manual labour involved, it is currently impractical to translate all the scientific[1] and technical[2] papers published each year into all the languages man uses.

As an example, the Commonwealth Agricultural Bureau receives annually more than 70,000 scientific papers. This frustrating situation has led some of those people concerned with information - in the widest sense - to look for a way to take the work of translation out of the hands of men and women and put it into the chromium-plated claws of the machine.

Hitherto, much of the writing on the progress of mechanical translation has been at the level of the scientific report. The technical nature of these reports has tended to restrict their readership to those having a direct interest in the subjects discussed. This essay, whilst not aimed at the layman, is an attempt to provide a readable abstraction of these papers for those whose time and/or training permit of no deeper study. Perhaps the experts will forgive me if I have made what

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[1] A recently-published list of scientific periodicals includes 59,404 entries, some of which admittedly have now ceased publication. However, it is probably safe to estimate that more scientific and technical periodicals have newly appeared since 1960 than those which disappeared in the preceding sixty years. See World List of Scientific Periodicals.

[2] A British publisher's catalogue listed 8,800 technical books as being in print in November, 1964. See Technical Books in Print.

seems to them some gross over-simplifications. The complexity of the material is not only due to the complexity of language in a general sense. The work of planning the beginnings of a computer system requires re-examination of many ideas which have been previously regarded as self-evident truths. As an example, it was once thought that automatic translation equipment designed for working from just one language to one other language would be more efficient than a multi-lingual machine. This idea was queried by the Russian linguist N. D. Andreyev and now is generally believed invalid.

Early History

Machine translation research at the University of Washington, Seattle, began in November, 1949. (The term "machine translation" has gradually given way to "mechanical translation" and the abbreviation "MT" is commonly used in the literature.) Research began with close cooperation between linguists and computer engineers to produce a pilot-model translating machine. This machine was planned to test a number of input recognition procedures devised by Dr Erwin Reifler. Later work led to a draft programme for use with a computer, envisaged as having so large a storage capacity that each entry in the memory would store not only lexical equivalents for input words, but also control-symbols for operating the machine and editing-symbols for modification of the output text. In May 1956, the study of large-capacity rapid-access memory technique for translation of Russian into English was the subject of a contract with the International Telemeter Corporation of Los Angeles. Like the earlier research, this was a joint effort of the linguists headed by Dr Reifler, and the engineers headed by Professor W. R. Hill. The linguist responsible for the special study of Russian language required for this task was Dr L. R. Micklesen. In the report[3] on this project came the first reference to the proposed use of a rotating optical disk as a memory device.

The first Mechanical Translation Conference was held at the Massachusetts Institute of Technology in June 1952. This was apparently the first time that the individuals working on the problems of MT had met to discuss their differing approaches. Some of these men were not linguists, but electronic computer engineers, and it was a principal conclusion of the conference that for certain types of input information, MT had become a real engineering possibility.

In March 1954, the Department of Modern Languages at Massachusetts Institute of Technology published[4] the first journal devoted entirely to the subject of mechanical translation. The journal appeared three times each year and provided a well-coordinated display of the problems and progress of researchers in mechanical translation from many parts of the world. The first doctoral thesis on MT, entitled "A Study for the Design of an Automatic Dictionary" was presented by A. G. Oettinger at Harvard in April 1954. The first book in the field was *Machine Translation of Languages*, edited by W. N. Locke and A. D. Booth, published[5] in 1955. This is a collection of fourteen essays by some of the pioneer workers.

In Russia, as elsewhere in the early years, reliance was placed on sophisticated word-for-word translation procedures, with grammatical rules applied chiefly as an aid in producing better constructions in the output language. However, in the reports[6] of the Fourth International

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[3] University of Washington News Service 1956: 31

[4] See *Mechanical Translation*

[5] See *Machine Translation of Languages*

[6] Rozentsveig 1958: 97

Congress of Slavicists, September 1958, it became clear that the group working at the Steklov Mathematical Institute of the Academy of Sciences had developed their procedure so that a thorough formal syntactic analysis of the input text preceded any attempt at translation. Moreover, the group working at Leningrad University under N. D. Andreyev was attempting to evolve a procedure whereby methods of analysis and synthesis were completely independent, the sole link being a logical system of symbols, serving as an interlingua or pivot-language.

In May 1959 research by the Linguistics Research Center, University of Texas, was begun under the directorship of Dr W. P. Lehmann. This work[7] was directed towards the development of two inter-related computer systems: one for automatic translation and the other for supporting research in linguistics.

The Current Decade

During August 1960, a report[8] was published by M. I. T., presenting a simple, mechanized model for sentence production. From this work, its author V. H. Yngve, predicted rules of syntax which are thought to be applicable to all human languages.

Related work is going on at various universities around the world, notably California, Bonn, Milan and Kyoto, Japan. The "N.A.T.O. Advanced Study Institute on Automatic Translation" was held in Venice in July 1962. Reports indicate that university centres in France are concentrating more upon automatic documentation than translation by machine.

Since November 1962, Arts graduates at the Faculté des Lettres et Sciences Humaines at Nancy have been able to take an option for the Certificate in Progamming Technology. This comprises a short course, including practical work with a machine, followed by an examination.

Most of the material published in France deals with the developments of linguistic theory which are necessitated by the acceptance of machine translation as a practical reality.[9, 10, 11.] A few authors refer to specific problems and offer partial solutions (e.g. Ronsse[12]), but I have yet to discover any reports concerning the application of these theoretical studies in the field; that is to say the use of existing computing machines for automatic translation trials, or the development of special computing machinery for the embodiment of the routines and subroutines variously suggested.

A symposium on the current status of research at the Linguistics Research Center (University of Texas) reviewed techniques and progress towards the goal of fully-automatic translation, as at June 1963. The major problems brought out by the symposium were:

the vast quantity of preparatory work required before any trials could be attempted;

the complexity of the concepts used by the linguists and programmers; and

the difficulty of establishing a thoroughly satisfactory mathematical analysis of linguistic structures.

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[7] See Quarterly Progress Reports

[8] Yngve 1960: 445

[9] Marthaler 1964: 12 [10] A.T.A.L.A. 1963: 78 [11] Coyaud 1963: 51

[12] Ronsse 1963: 10

Structure

A structure is a clearly-defined whole built from one or usually more parts. In written language the quanta are morphemes, and the smallest possible structure which can be built to stand without support from other similar structures is a sentence.

At first sight, it would seem reasonable to aim at translating a sentence at a time. A word-by-word translation leads to unresolved ambiguities and a loss of information arising from omissions and redundancies. Phrase-by-phrase translation is much better and for many purposes is good enough, but re-consideration of long or complex sentences which have been translated in this manner shows the need for re-casting some sentences in order to achieve the type of structure normally acceptable in the output language. A further practical point is that a machine can be easily programmed to recognize the beginning and ending of a sentence. Recognition of the boundaries of parts of a sentence is admittedly one function of a machine designed for automatic translation, but the designer of such a machine would not be satisfied with an outpouring of well-formed phrases having no sentence-type boundaries.

On further consideration then, it seems that a better plan would be to analyse the input language a phrase at a time, and perhaps in smaller units, while synthesizing the output language a sentence at a time.

Computer Meta-Languages

Before a comparison of sentence structures in more than one language can be made an automatic process which can be handled by a machine, a meta-language has to be devised to serve as a means of communication between the very complex human language systems and the very simple bivalent language used within the computer. The use of the term "meta-language" is not intended to refer to the sequences of elementary symbols having one of only two possible values which all digital computers use internally. The use of binary symbols to illustrate the stage-by-stage working of the computer circuits is really the province of the mathematician or the electronics engineer, and in any case, the language within the computer is much the same whether it is being used as a translation machine or for road-traffic control. Instead, the term meta-language is used to cover every intermediate level of symbolism employed to convey the intelligence of a sentence. As an illustration, let us look at the sentence "THE MAN IN THE BOAT SWORE LOUDLY" as the computer would.

A lexical analysis would give:- definite article, noun singular masculine, preposition, definite article, noun singular neuter, verb past tense, adverb, punctuation full stop. The machine will read, interpret and encode this analysis as a set of symbols in strict order.

The system outlined in the diagram (fig.1) incorporates a matching-device which I have labelled "comparator". The incoming phrase is held for examination in a temporary store. Successive words are fed one at a time to one of the comparator input terminals. Into the other comparator input terminal is fed the content of the complete lexical store, one word at a time, until a match is obtained. Immediately a match is obtained, a recognition signal is fed from the comparator to the lexical store to halt the flow of lexical items. The arrival of the recognition signal also sets off another circuit which provides a read-out of the information recorded in the lexical entry alongside the matching word. In the example provided for illustration purposes, the incoming phrase contains the word "BOAT". When the matching word "BOAT" is disgorged by the lexical store, the comparator halts the flow and demands the associated information. After a short pause, during which the information "N" is recorded elsewhere in the machine, the output of the temporary store is reset so that the next word of the stored phrase is fed to the comparator circuit and the search cycle recommences.

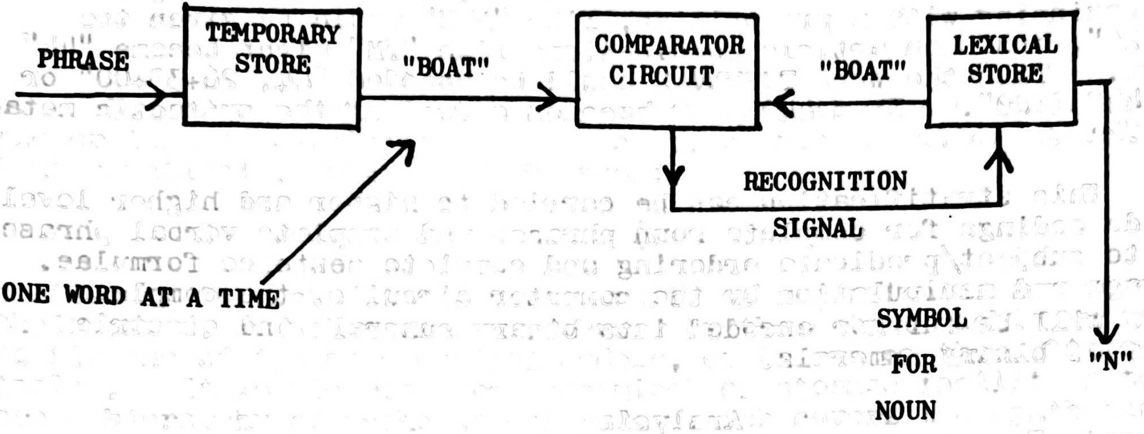

Figure 1 - Lexical Analysis Schematic

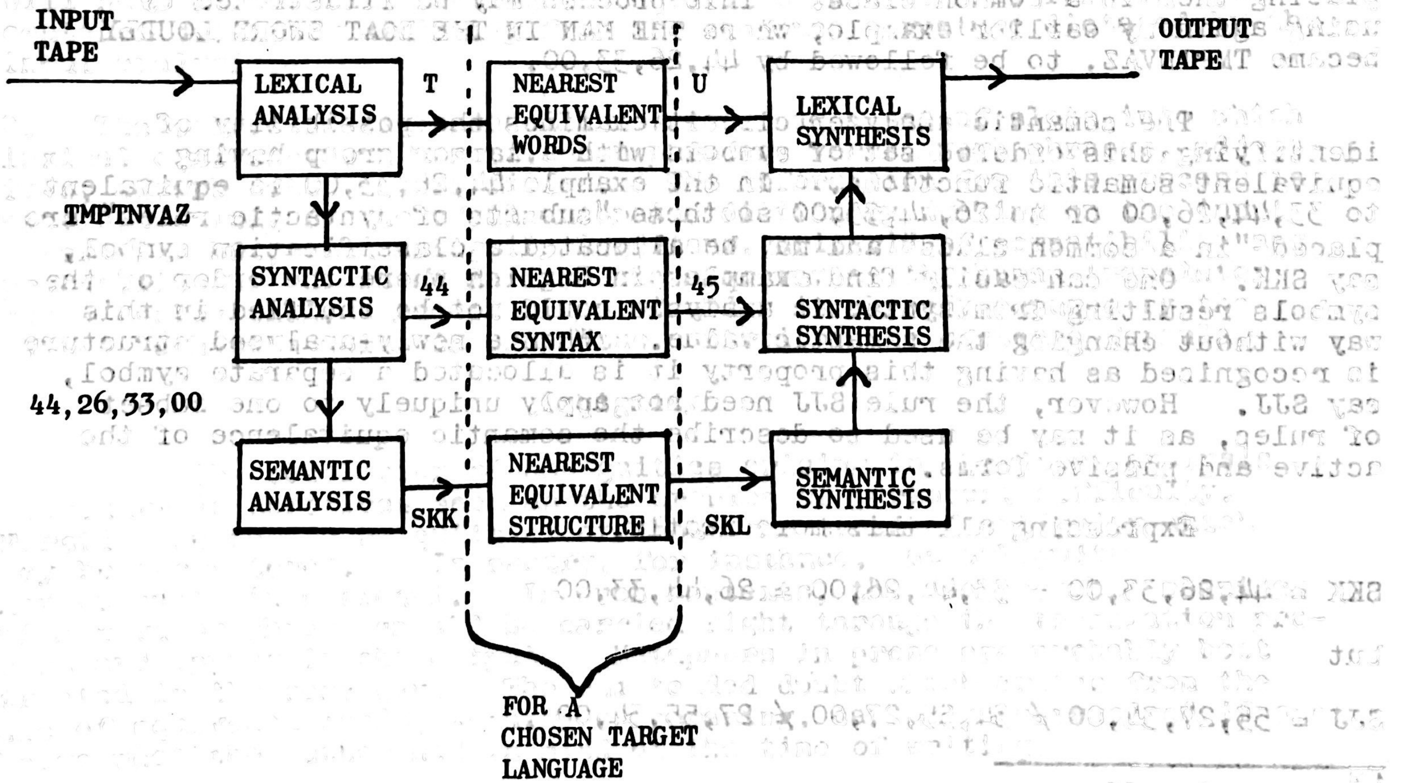

Figure 2 - Translation Schematic

Now, this code might give all definite articles the symbol T. Every singular masculine noun might be given the symbol M, and so on. Thus the sentence could be encoded "T+M+P+T+N+V+A+Z", or, more simply, "TMPTNVAZ". Then TMPTNVAZ becomes a word of the lexical meta-language.

We can take this example a stage further. At the syntactic level, one can say that "PTN" is acting adjectivally in that it qualifies "TM", and of course, "V" is modified by "A". This analysis will be read and enclosed as a further set of symbols in strict order. This code would be quite distinct from the previous one; perhaps all adjectival phrases beginning with a preposition, like "PTN" would be given the symbol "26", and noun article combinations like "TM" might become "44" and so on. Thus the word TMPTNVAZ could be encoded "44, 26+33+00" or simply "44263300". Then 44263300 becomes a word of the syntactic meta-language.

This stratification can be carried to higher and higher levels to provide codings for complete noun phrases and complete verbal phrases, through to subject/predicate ordering and complete sentence formulae. For storage and manipulation by the computer circuits, the complete sentences will be further encoded into binary numerals and electric analogues of binary numerals.

Analysis

The above discourse on computer meta-languages has underlined the stratification of this approach to input analysis. Stratification is on the basis of functional equivalence, so that lexical analysis involves the recognition and encoding of items having equivalent function at the lexical level, while syntactic analysis is seen as the recognition and encoding of items having equivalent function at the syntactic stratum.

Semantic analysis has been defined by Dr Tosh[13] as the process of identifying semantically equivalent subsets of syntactic rules and placing them in a common class. This process may be illustrated by using again my earlier example, where THE MAN IN THE BOAT SWORE LOUDLY became TMPTNVAZ, to be followed by 44,26,33,00.

The semantic analyzer circuit examines the possibility of identifying this ordered set of symbols with a larger group having equivalent semantic functions. In the example 44,26,33,00 is equivalent to 33,44,26,00 or to 26,44,33,00 so these "subsets of syntactic rules" are placed "in a common class" and may be allocated a classification symbol, say SKK. One can easily find examples in English where the order of the symbols resulting from syntactic analysis could not be shuffled in this way without changing the semantic value. When a newly-analysed structure is recognised as having this property it is allocated a separate symbol, say SJJ. However, the rule SJJ need not apply uniquely to one subset of rules, as it may be used to describe the semantic equivalence of the active and passive forms.

Expressing all this more neatly,

SKK = 44,26,33,00 = 33,44,26,00 = 26,44,33,00

but

SJJ = 55,27,34,00 ≠ 34,55,27,00 ≠ 27,55,34,00

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[13] Tosh 1963: 66.

however

SJJ = 55,27,34,00 = 27,66,34,55,00.

Clearly, at this level, one can compare structures built from one language with structures built from another.

As the input analyzers deliver a stratified analysis to the sentence synthesizing circuits, (fig. 2), then the only additional information needed by the computer to allow translation to proceed, is a list of the target languages in which the output is to be expressed.

Synthesis

In order to synthesize a sentence at a time, there has to exist a table or list of permissible sentence structures, or alternatively a quasi-mathematical statement of the type:

$$S = (x\ y\ z) \neq (x\ z\ y) \neq (y\ x\ z)$$

which attempts to restrict the constituents of a particular sentence-type and their order. Each sentence produced by the output machinery then has to fit one of the mathematical models, or be one of those listed in the tables. It is clearly more economical of storage facilities to prepare a hierarchy of mathematical rules which covers the synthesis of many possible forms, than to tabulate every known variant. Testing and subsequent modification of the mathematical rules for synthesis should be based upon sampling of the output texts and constructive criticism by a native speaker of the output language.

The procedure for language synthesis will then be:

1. The input analysis will have dictated a particular sentence in the output language; but a computer meta-language, having symbols which describe all possible sentence structures in the chosen output language, will have allowed a selection which results in a formula for the new sentence differing minimally from the sentence structure dictated by the input analysis.

2. The embryonic sentence will now exist as a set of slots into which lexical equivalents of nouns, noun phrases, verbs, verb phrases, adjectives, adverbs etc. may be fitted. The information for this process is provided mainly by the usual automatic dictionary working on the input material; but, when ambiguity threatens, criteria of compatibility and probability are employed in much the same way as the human translator would employ them. Acceptable word order is already ensured by the output mechanism which is under the control of the sentence formula.

Ambiguity

The resolution of ambiguities arising in the input analysis procedure is sometimes seen as the problem of paramount difficulty. Firstly one has to be quite clear about the types of ambiguity which may be encountered. In poetry, for instance, an ambiguity may be quite intentional. In such contexts, the two possible meanings of a word or phrase should be carried right through the translation process and appear in the output. Metaphors in prose are probably best treated in the same way. The unintended doubt which arises from the use of equivocal words, wording or phrasing, can only be resolved if one knows what the author had in mind at the time of writing.

The human translator tackles the problem by finding unambiguous synonyms for alternative possibilities and then weighing the relative probabilities of juxtaposition. The probability of two events co-occurring can be expressed as the product of their individual probabilities of occurrence. Statistical analysis of suitable texts allows calculation of the individual probabilities of occurrence of the chosen synonyms. The computer can be programmed to use conditional probability or probability in the general sense depending upon whether the operator considers the text to be a specialized treatise or more general reading. In this way, the output will contain the most likely translation in that context.

It is necessary to emphasise the difference between ambiguities which arise through the use of equivocal words and which may be resolved by assessing the probabilities of juxtaposition as outlined above, and those ambiguities which arise through the use of equivocal words and which may not be resolved by this technique in its simplest form. As an example, "WE ARE RETURNING REFUGEES" can have one of two alternative syntactical analyses, depending upon whether the verbal part is intended to be transitive or intransitive. This dilemma may be viewed as an unintended lexical ambiguity resulting from the use of "returning" to convey either "sending back" or "coming back", but the solution proposed above would at first sight seem unhelpful as the juxtaposing words are equally compatible in either sense. The problem is indeed insoluble unless one is given more information about the ambient context. In the light shed by surrounding sentences, the decision would not be painfully difficult.

This trend of thought precipitates a tentative hypothesis of stratified ambiguity, such that insoluble ambiguities at lexical level could be resolved at syntactic level, while ambiguities insoluble at syntactical level could be resolved at semantic level. Thus, to return to this example, let us suppose that the structure SKM is the semantic analysis of "WE ARE SENDING BACK REFUGEES." Then SKM can be said to have a statistical probability P_M. The surrounding structures, say SBB and SMJ, also have probabilities, P_B and P_J respectively. Then the probability of these structures co-occurring with SKM will be proportional to the products $P_M P_B$ and $P_M P_J$ respectively. If the analysis of "WE ARE COMING BACK REFUGEES" was SQQ and this had a probability P_Q, then the products would be $P_Q P_B$ and $P_Q P_J$. The computer would be programmed to accept the pairs with the highest net probability and in making this choice, would have selected by implication either SKM or SQQ. Again, the output text will contain the most likely translation.

The above-described synthesis procedure defines a sentence of the output language which is lexically equivalent, grammatically acceptable and semantically probable. Current researches will one day show whether this sort of translation is generally satisfactory.

Conclusion

Since a written language is an empirical code, it has natural redundancy and the rules of encoding and decoding may be phrased in a number of equivalent ways. The system of decoding, chosen at the outset by the man responsible for the design philosophy of the machine, will determine the efficiency of the input analysis techniques; and the system of encoding will control the efficacy of the output language synthesis.

The resolution of ambiguities by a strictly formal method based on probability theory must improve the overall accuracy of the translation process.

As Dr Lehmann has said:[14] "If we have learned anything from

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[14] Lehmann 1963: 5

research in machine translation, it is that our knowledge of language must be vastly deepened. Even from a theoretical point of view, work in machine translation is of tremendous importance for linguistics and other social sciences. It provides us with our first opportunity of testing models of language, of verifying linguistic theories in ways comparable with those available to physical and biological scientists."

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En SNF, |a|:|ɑ|, réalisé [æ]:[ᴀ], p.ex.[tæʃe] :[tᴀʃe].
Pour tous les témoins, dans le contexte C+|u|+|A|, on ne trouve que|a|, réalisé[a]~[ᴀ], p.ex. |luA| = [lwa]~[lwʌ] loi; mais quand cette syllabe est fermée par une consonne: CuAc, la réalisation de |A| change pour les témoins E et I, devenant [ɛ:]~[ɛ^{I}]~[a], dans p.ex. |buAt| boîte, |muAn| moine.

|u|: A l'IS devant V, et dans les contextes CuAC,CuA, on a toujours [w], p.ex. |ui| = [wi] oui, |buAt| = [bwat] boîte, |luA| = [lwa] loi.

Ailleurs, on ne trouve que [u], p.ex. |lue| = [lue] louer.

|y|: A l'IS devant V, et dans les contextes Cyi, CCyi, CyiC, on ne trouve que [ɥ], p.ex., [kɥijɛʀ] cuiller, [fʀɥi] fruit, [kõdɥit] conduite.

Ailleurs, il n'y a que [y], p.ex. |bye|=[bye] buée, |lyœʀ|=[lyœʀ] lueur.

|O|: En SFO, toujours |o|, p.ex. [bo] beau, [so] sot, [kaʃo] cachot.

En SFF, on a l'opposition |o|:|ɔ|, p.ex. |sot|:|sɔt| saute : sotte, |bot|:|bɔt| boat:botte.

En SNF, quatre témoins sur cinq utilisent l'opposition |o|:|ɔ|, mais rarement et dans des paires suspectes comme |bote|:|bɔte| beauté: botté, où, à cause du conte du Chat botté, la prononciation [bɔte] peut très bien ne pas représenter la pratique courante. La réalisation du |O| en SNF serait donc plutôt [ɔ]~[o]~[ŏ], p. ex. [ŏtostɔp]~[otostɔp]~[ŏtostɔp] autostop, [dɔne] donner.

|O| suivi de |-z| ou |-ʒ| se réalise [o]; suivi de |ʀ| de la même syllabe, [ɔ] sauf chez le témoin A qui dit en SFF [ɔ^{ɔ}], et en SNF [ɔ̆], p.ex. [pɔ̆ʀte] porter, [mɔ^{ɔ}ʀ] mort.

|œ|: En SFF:[œ]~[ø]~[ə]~[ɛ] , p.ex., [ʒœn]~[ʒøn]~[ʒɛn] jeune, jeûne.
En SNF: [ø], p.ex. [deʒøne] déjeuner.
Devant |ʀ| de la même syllabe: [œ]~[ə]~[ø] , p.ex. [otœʀ]~[otəʀ]~[otøʀ] auteur.
Ailleurs: [ø], p.ex. [øʀø] heureux.

N'a pas été observée la désonorisation des voyelles |i|,|y|,|u|, signalée par Gendron 1959.

Corrélation nasale

ẽ œ̃ õ

ã

|ẽ| = [ẽ]; |œ̃| = [œ̃]; |õ| = [ẽ].

|ã| se réalise principalement [ã], parfois [ɑ], p.ex. [ʃɑ̃te] *chanter*, |ãfãs|=[ãfãs] *enfance*, |ãfõs|=[ãfõs] *enfonce*.

Il y a tendance à toujours dénasaliser les voyelles lorsqu'à la liaison on prononce la consonne nasale: [bɔnarijẽ] *bon à rien*, [mwajɛnaʒ] *moyen âge*.

PHONEMES CONSONANTIQUES

L'inventaire consonantique se compose de la corrélation proportionnelle:

p	f	t	s	ʃ	k
b	v	d	z	ʒ	g
m		n		ɲ	ŋ

et des phonèmes hors système |l|, |ʀ|, |∅| et |h|.

|t|: devant les voyelles |y|, |i|, |e|, |t|=[ts], p.ex. [ymɪdzɪtse] *humidité*, [tsjɛd] *tiède*.

|d|: devant les voyelles |y|, |i|, chez les Montréalais (surtout le témoin I), |d| = [dz], p.ex. [dzy] *du*, [kõdzɥɪt] *conduite*.

|ɲ|: à l'intervocalique, se distingue bien de |nj|, p.ex. [laɲɛl] *l'agnelle*, [lanjɛl] *la nielle*.
à la finale, se confond avec |n| et |ŋ|: |siɲ|=[sɪŋ]~[sɪn] *signe*.

|ŋ|: ne se trouve guère qu'à la finale, surtout dans des mots empruntés à l'anglais.

|ʀ|: se réalise généralement [ʀ], mais parfois [ɹ], p.ex. [kilpaɹ̣t] *qu'il parte*, [kɹ̥obɑɹ] *crowbar*.

|∅|: se réalise en soixante-dix pour cent des contextes et des cas étudiés comme en français parisien. En neuf pour cent des cas, |∅| n'existe pas du tout, alors qu'il existe en français parisien, p.ex.[lezɔʀd [lezɔʀdœvʀ]. En huit pour cent des cas, |∅| du francais est remplacé par |h|, et en de faibles pourcentages |∅| se réalise par un hiatus, ou [ʔ] ou [zh] ou [zʔ], p.ex. |lE∅Eʀitie| peut se réaliser [lɛɛʀitsje], [lɛhɛʀitsje], [lɛzhɛʀitsje], [lɛzʔɛʀitsje], [lɛzɛʀitsje]. Il est à noter qu'il n'y a aucune homogénéité: un même témoin peut réaliser |∅| par un ou plusieurs des procédés indiqués. Celui qui dira [lɛzʔɛʀitsje], dira [lɛzhɪstwaʀ] et [ãʔo], [lɛkao] et [lɛzɔm]. La palatalisation de |k|, |g| n'a pas été observée, ni les réalisations [x] et [h] de |ʒ| signalées par Charbonneau 1957: 14.

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