[*Mechanical Translation*, vol.4, nos.1 and 2, November 1957; pp. 2-4]

# *A Model for Mechanical Translation*

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A mathematical model for a translating machine is proposed in which the translation of each word is conditioned by the preceding text. The machine contains a number of dictionaries where each dictionary represents one of the states of a multistate machine.

**IN MECHANICAL TRANSLATION** the foreign language (input text) words are operated on by a computer, which is programmed to effect certain formal rules to produce a series of target language (output text) words. Mechanical translation may therefore be regarded as a transformation of a series of data $S_1$ to a series $S_2$.

Suppose the series $S_1$ is composed of elements of the finite set $(a_1, a_2 \ldots\ldots a_n)$ and $S_2$ is composed of elements of $(b_1 \ldots\ldots b_m)$. These elements $a_1, a_2 \ldots\ldots a_n, b_1 \ldots\ldots b_m$ correspond to the words of the input text and output text respectively. Let $S_1(n)$ denote the n-th datum of the series $S_1$. Then the simplest type of transformation by which the output series $S_2$ is printed is expressed by the rules,

"rule r: If $S_1(n) = a_{\mu_r}$ print $b_{\nu_r}$, add 1 to n and go to rule 1.

If $S_1(n) \neq a_{\mu_r}$ go to rule r + 1,"

where r = 1 .... n and where the set $(a_{\mu_r})$ is identical with $(a_1, a_2 \ldots\ldots a_n)$. The transformation corresponds to a word-for-word translation and also to a simple coding expressed by the table

| $S_1$ element. | $S_2$ element. |
|---|---|
| $a_{\mu_1}$ | $b_{\nu_1}$ |
| $a_{\mu_2}$ | $b_{\nu_2}$ |
| ⋮ | ⋮ |
| $a_{\mu_n}$ | $b_{\nu_n}$ |

which may be regarded as a dictionary. If the input data S and the output data are punched tape on an automatic computer with unidirectional reading and printing devices, then the above transformation is effected by a single-state machine.

A word-for-word translation in which the equivalents selected for an input word depend upon the context of the preceding text is represented by a compound coding, effected by a multistate machine. This type of transformation, called "conditional" is effected by the rules:

"rule r: If $S_1(n) = a_{\mu_r}$ and if $S_1(n)$ is preceded in the $S_1$ series by elements $a_{\mu_{r,q}}, a_{\mu_{r,q-1}} \ldots\ldots a_{\mu_{r,1}}$ in that order (not necessarily juxtaposed) then print $b_{\nu_r}$, add 1 to n and go to rule 1.

If $S_1(n) \neq a_{\mu_r}$ or if $S_1(n) = a_{\mu_r}$

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and either

(i) $S_1(n)$ is not preceded by elements

$a_{\mu_{r,q}}$, $a_{\mu_{r,q-1}}$ ...... $a_{\mu_{r,1}}$, or

(ii) if $S_1(n)$ is preceded by these elements, and they are not in the required order in $S_1$, then go to rule $r + 1$,"

where r = 1, 2................ We suppose that the sequence of rules provides a course of action for each possibility. ( The exact conditions on the number of rules will not be investigated here, but it should be noted that the rules are in a certain order.) If we let the sign ' »' denote 'precede in the message' then rule r can be abbreviated to

"rule r:

$$a_{\mu_{r,q}} \gg a_{\mu_{r,q-1}} \gg \ldots \gg a_{\mu_{r,1}} \gg a_{\mu_r} \longrightarrow b_{\nu_r}"$$

Thus the ordered list of rules is:

$$a_{\mu_{1,q}} \gg a_{\mu_{1,q-1}} \gg \ldots\ldots a_{\mu_{1,1}} \gg a_{\mu_1} \longrightarrow b_{\nu_1}$$

$$a_{\mu_{2,s}} \gg a_{\mu_{2,s-1}} \gg \ldots\ldots a_{\mu_{2,1}} \gg a_{\mu_2} \longrightarrow b_{\nu_2}$$

$$\vdots$$

$$a_{\mu_{p,t}} \gg a_{\mu_{p,t-1}} \gg \ldots\ldots a_{\mu_{p,1}} \gg a_{\mu_p} \longrightarrow b_{\nu_p}$$

$$a_{\mu_{p+1}} \longrightarrow b_{\nu_{p+1}}$$

$$a_{\mu_{p+2}} \longrightarrow b_{\nu_{p+2}}$$

$$\vdots$$

$$a_{\mu_{p+n}} \longrightarrow b_{\nu_{p+n}}$$

The last n rules cover those instances where a datum of $S_1$ is not preceded by its relevant context. These rules cannot be reduced to the simple dictionary with a finite number of entries as in the previous simple transformation. Instead a connected series of dictionaries may be constructed by the following method, which is best illustrated by supposing one conditional rule only. Suppose the sequence of rules is

$$a_p \gg a_{p-1} \gg \ldots \gg a_2 \gg a_1 \longrightarrow b_q$$

$$a_1 \longrightarrow b_{\mu_1}$$

$$a_2 \longrightarrow b_{\mu_2}$$

$$\vdots$$

$$a_n \longrightarrow b_{\mu_n}$$

The sequence of dictionaries will contain some entries which will refer the operator to another dictionary. If we let, say

$$\text{"}a_s \longrightarrow b_{\mu_s}\ (t)\text{"}$$

denote an entry in dictionary u which prints $b_{\mu_s}$ when $a_s$ occurs in $S_1$ and then changes the dictionary from u to t, and let

$$\text{"}a_s \longrightarrow b_{\mu_s}\text{"}$$

denote an entry which does not affect a change of dictionary, then the list of rules above may be replaced by the dictionaries

| Dictionary (1) | Dictionary (2) | Dictionary (3) |
|---|---|---|
| $a_1 \longrightarrow b_{\mu_1}$ | $a_1 \longrightarrow b_{\mu_1}$ | $a_1 \longrightarrow b_{\mu_1}$ |
| $a_2 \longrightarrow b_{\mu_2}$ | $a_2 \longrightarrow b_{\mu_2}$ | $a_2 \longrightarrow b_{\mu_2}$ |
| $\vdots$ | $\vdots$ | $\vdots$ |
| $a_p \longrightarrow b_{\mu_p}$ (2) | $a_{p-1} \longrightarrow b_{\mu_{p-1}}$ (3) | $a_{p-2} \longrightarrow b_{\mu_{p-2}}$ (4) |
| $a_{p+1} \longrightarrow b_{\mu_{p+1}}$ | $\vdots$ | $a_{p-1} \longrightarrow b_{\mu_{p-1}}$ (1) |
| $\vdots$ | $\vdots$ | $a_p \longrightarrow b_{\mu_p}$ (1) |
| $\vdots$ | $\vdots$ | $a_{p+1} \longrightarrow b_{\mu_{p+1}}$ |
| $\vdots$ | $\vdots$ | $\vdots$ |
| $a_n \longrightarrow b_n$ | $a_n \longrightarrow b_n$ | $a_n \longrightarrow b_n$ |

**Finally**

Dictionary
(P)

$a_1 \longrightarrow b_q$ (1)

$a_2 \longrightarrow b_{\mu_2}$ (1)

$a_3 \longrightarrow b_{\mu_3}$ (1)

$\vdots$

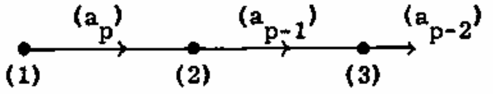
$a_p \longrightarrow b_{\mu_p}$ (1)

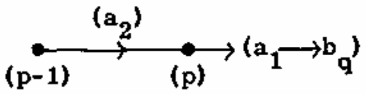
$a_{p+1} \longrightarrow b_{\mu_{p+1}}$

$\vdots$

$a_n \longrightarrow b_n$

With obvious convention the connection of the dictionaries may be represented by




For two conditional rules

$a_p \gg a_{p-1} \gg \dots \gg a_1 \longrightarrow b_q$

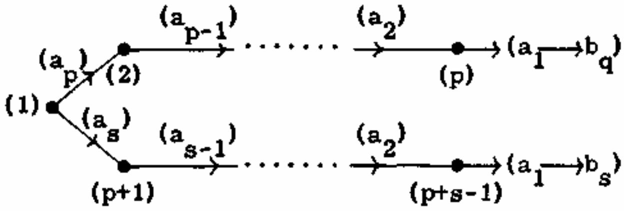
$a_s \gg a_{s-1} \gg \dots \gg a_1 \longrightarrow b_t$

$a_1 \longrightarrow b_{\mu_1}$

$\vdots$

$a_n \longrightarrow b_{\mu_n}$

The connection of dictionaries is represented by




If the conditional rules are effected by a computing machine, each dictionary represents a state of the machine. A transformation which depends upon context therefore can be represented as a compound coding or a multistate machine.