KYBERNETIKA ČÍSLO 4, ROČNÍK 1/1965

Steps toward Models of Language Learning*

H. SCHNELLE

In this paper some necessary features and components of language learning devices are discussed.

There are two main problems within the theory of *linguistic communication*. The first is how human beings use their mastery of a language in the actual processes of communication, the other is how they develop this mastery of a language and the ability to use it. The first will be called the problem of *linguistic performace*, the second the problem of "*faculté de langage*" (using the well-known term of de Saussure). We shall be mainly concerned with the latter.

The theory of linguistic communication must be clearly distinguished from theories within linguistics proper, which are intended to describe the *form of* general and particular *linguistic systems*; that is to say, of *linguistic universals* and of "*les langues*". Though clearly distinguished, the theories of linguistic form and of linguistic communication must be related to each other. It is often argued that the former is logically prior to the latter, and it is obvious that the latter is genetically prior to the former. It is, however still, to be specified how these dependencies are to be understood exactly.

The problem of "faculté de langage" is posed by the following questions: what is the initial structure of a device capable of learning a language and how is the process of the acquisition of a mastery in language communication to be understood. The difficulty of answering these questions depend on the criteria of adequacy which this device, considered as a model, is required to satisfy. We distinguish the following criteria: 1. behavioral adequacy, 2. conceptual adequacy, 3. psycho-physiological adequacy, 4. ontological adequacy. Correspondingly, we might distinguish behavioral, conceptual, psycho-physiological and ontological models. We believe that it is

* Communicated at the *Prague Colloquium on Algebraic Linguistics and Machine Translation*, September 18th—22nd, 1964.

impossible to give a model of the fourth type in a formal mathematical description but we shall not discuss this question here. A psycho-physiological model is one which is intended to correspond in all essential psycho-physiological details to the processes in the brain which are connected with linguistic performance. A behavioral model is one, which, judged only on the basis of externally observable behavior is comparable with the behavior of human beings. A conceptual model is one which in addition to the external behavior must explain the relation between behavioral items and items representing an understanding of them. We believe that at present the information available is *not sufficient* to set up any reasonably satisfactory model of language learning, not even a behavioral one. On the other hand we believe that it is possible to formalize the features which must be considered *necessary* for models of the language learning process. Moreover, these features might be integrated and incorporated into a device thereby rendering it capable of reaching a mastery of a language comparable to that of a child of two, three or even four years.

The model of linguistic learning we are aiming at will *not* take account of extralinguistic perception. In this sense, it is not adequate to the reality which it attempts to represent, since the learning of *extralinguistic* perception and the process of linguistic understanding develop in mutual interconnection. Moreover language learning seems even to be *dependent* on previously developed perception, e.g. in ostensive definitions which seem to play an important role in the early stages of learning. Because of the complexity involved when considering perception and language communication simultaneously, we would rather describe a model of language learning which is independent of perceptual learning. This can be done either by coding perceptual data and referring to these codes by linguistic expressions or by neglecting perception altogether. The latter solution is by far the simpler one, and we shall try to set up such a model, i.e. one without reference to extralinguistic entities.

As a further simplification we shall consider a system which accepts utterances in terms of morphemes (coded in letters or phonemes). Thereby the description of the learning process of phonetic, phonemic and morphemic entities is ruled out.

Now let us summarize the task we have set ourselves: A behavioral model of language learning is sought, incorporating all features available and considered to be necessary for such models, and being capable of reaching a status of mastery in an arbitrary language, if taught approximately in the same manner as a child. Moreover it would be desirable to implement this model as a program for an automaton because this is the easiest way to make it testable.

Language learning takes place when a learning system with appropriate faculties is placed in communication with one or several teaching systems experienced in language and pedagogically adapting themselves to the status of partial mastery of the developing system. Accordingly there are two interacting components in each system: in the teaching system the competent linguistic performance and pedagogics, and in the learning system the "faculté de langage" and the partially developed performance, the performance being completely vacuous – a tabula rasa – initially,

whereas the "faculté de langage" incorporates innate faculties (cf. Fig. 1). We shall henceforth concern ourselves only with the learning system and its components and neglect the structure of the teaching system altogether.

Let us begin by a discussion of a conceptual model of linguistic performance. This may be described formally by an effective mapping procedure from codes representing utterances into codes representing the understanding or understandings of utterances and vice versa.

We shall introduce some notations for the description of the systems. There is a basic alphabet V (of phonemes, letters or morphemes), and an extended alphabet V_e

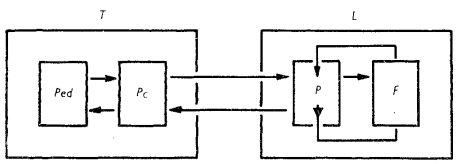

Fig. 1.

containing the elements of V plus an element indicating pauses between utterances. The set of all possible combinations of occurences equiform to elements of V shall be denoted by W_v. An element of W_v shall be denoted by u and called *utterance*. The performance model in a certain stage i shall be denoted by P^i and the set of *understandings* which P^i assigns to some utterance u shall be denoted by P^iu and the set of understandings associated with a set U ($U \subset W_v$) is denoted by P^iU. In particular the understandings contain information on the *degree of acceptability* of an utterance. On the scale of degrees there is a highest and a lowest value and there are utterances to which these extreme values are assigned. There are utterances and other communicational acts which convey information on the degrees of acceptability of specified utterances. Let us denote the degree of acceptability assigned to some utterance u by D^iu. Let us call the set of utterances to which the highest degree is assigned the set of fully acceptable language expressions U_L. This set is not to be confounded with the *set of utterances U_N normally communicated* by experienced speakers.*

Both sets are contained in the set of utterances U_u completely understood by an experienced speaker. On the other hand there is the set of utterances completely understood at some stage i. Let us denote this set by U_u^i. It is not assumed that U_u^i is a subset of U_L since usually auxiliary language forms are used to facilitate the development of understanding; they are eliminated at a later stage of development.

Utterances not understood completely are nevertheless partially interpreted. This center indicates the complexity of a sentence. If the system is still in its initial phase,

* U_N overlaps with U_L, since there are utterances normally ocurring but not highly acceptable and others acceptable but practically not occuring (e.g. very complicated utterances).

fact is essential for the further development of the system since certain partial interpretations contain sufficient information, as to how the performance model P is to be changed in order to also provide a complete understanding to the utterance currently under consideration and only partially interpreted.

In order to extract this information from the partial interpretation of an utterance, the device modeling the "faculté de langage" must contain an *interpretation analyzer* A_I, which decides whether the performance model should be modified and where

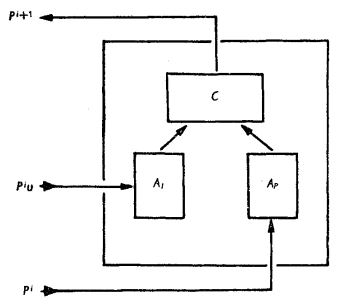

Fig. 2.

and how and transmits this information to a *constructor device C*, which executes the modification (cf. Fig. 2).

Let us say that an utterance is accepted by A_I (or rather by $A_I P^i$) and that it is *almost understood* if it causes A_I to give modification information. It is obvious that, if we want to keep the device A_I sufficiently simple, it may accept only interpretations of an utterance which are not too incomplete. We see that in this case the class of utterances W_V is partitioned into three subclasses with respect to complete understanding by P^i and acceptability by $A_I P^i$, namely the class of utterances *completely understood* U_u^i the class of utterances only partially interpreted but *almost understood* and the class of utterances *not understood* at all and too complicated to determine how they might be understood by an appropriate modification of P^i.

It is clear that such a system as ours will not learn at all if utterances are presented to it which are not even almost understood. If the system is still in its initial stage, practically all utterances used in communication between experienced persons are outside of the region of almost understood utterances. Only simple morphemes and expressions have a chance to cause the system to learn, just as in later stages only very simple composite utterances fall within the region of expressions which are almost understood. These regions determine learning stages, that of e.g. the one-word- utterance, the two-word-utterance and the simply composed utterance.

Let us represent these regions as concentric circles, where the distance from the

center indicates the complexity of a sentence. If the system is still in its initial phase, there are no utterances completely understood, but there is a certain set U_m^o of almost understood utterances, near the center of the representation (cf. Fig. 3).

The normal communication between experienced speakers (i.e. the set U_N) contains almost exclusively utterances of higher complexity which are not covered by the set U_m^0. A teacher may nevertheless communicate simple utterances to the learning system, and by placing such utterances within the region U_m^0 of the learning system this latter builts up a region of completely understood utterances U_n^1 containing the

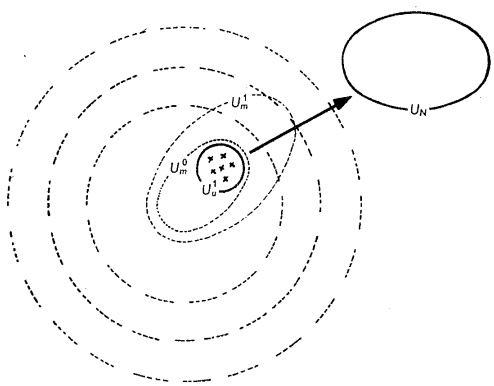

Fig. 3.

received ones. This region is surrounded by a region of almost understood utterances U_m^1 being larger than the initial U_m^0. The region of utterances understood by the learning system grows towards the region U_N of experienced speakers if the process just described is iterated.

The growing of the internal structure of the system is to be described as follows: The constructor element within the "faculté de langage" changes some stage P^i into another one P^{i+1} by inserting or deleting elementary components either in the event of utterances out of the set of those almost understood; or, if some previous utterance of the learning system has been judged unacceptable by the teaching system, i.e., if the system has previously made some faulty generalization.

However important, the analysis of an incomplete interpretation executed by A_I is not always sufficient for the indication of how and where the model *Pi* shall be modified. An analysis of the structure of the model *Pi* itself must provide additional information. This analysis may be performed by a *performance structure analyzer* A_p (cf. Fig. 2). Later, we shall give some examples why this is necessary.

It is not possible at present to give the detailed structure for this system. Its functioning, however, may be illustrated by various examples.

Let us first discuss some cases of almost understood utterances. As we have already indicated above, all simple, basic words, in particular those connected with ostensive definitions and simple perceptions are almost understood. There are also more complicated cases. Let us assume that in some stage of the development where the system is tending towards understanding structures more complicated than simple sentences, the simple sentences "Peter is my friend" and "Peter comes home" are completely understood utterances. Suppose now that the sentence occurs: "Peter, who is my friend, comes home". This is a sentence to be considered almost understood at that state, since with one single rule specifying that "is my friend" is to be amalgamated into "Peter" by the occurence of "who" the sentence may be transformed into a completely understood one. Since the introduction of the rule occurs higher up in the hierarchy of categories it incorporates directly a generalization into all structures of the same type interconnectable by the relative pronoun "who".

It is clear that the model of "faculté de langage" must by all means incorporate the well-known procedures of segmentation, classification, association etc. So if, e.g., the model understands a and receives an utterance such that it contains a and a remainder which is a possible morpheme this latter is incorporated into the set of morpheme structures. The utterance received is thereby obviously *segmented* into two parts. Moreover if there is an utterance ab and the system receives ac a class $\{b, c\}$ will be formed with respect to the property of occurrence to the right of a This roughly exemplifies *classification*. Since these procedures have been discussed extensively in the literature [e.g. [1], [2], [3] etc.] it is not necessary to go into further details.

The principles indicated sofar are only of the type of reproductive organization. More interesting are the principles leading directly to generalization, i.e. to the understanding of utterances which have not been already perceived by the system. Among these principles, considered of being the most important ones are a) analogic inference and b) periodicity generalization.

Let us first discuss *analogic inference*. The great importance of analogic inference in everyday life has been discussed by I.M. Copi [4]. He writes:

"Most of our own everyday inferences are by analogy. Thus I infer that a new pair of shoes will wear well on the ground that I got good wear from other shoes previously purchased from the same store. If a new book by a certain author is called to my attention, I infer that I will enjoy reading it on the basis of heaving read and enjoyed other books by that author. Analogy is at the basis of most of our ordinary reasonings from past experience to what the future will hold. Not an explicitly formulated argument, of course, but something very much like analogical inference is presumably involved in the conduct of the burnt child who shuns fire."

"None of these arguments is certain, or demonstratively valid ... But then, no argument by analogy is intended to be mathematically certain ... Probability is all that is claimed for them."

The analysis given by I. M. Copi is very important in our present context, since it

finally leads to a formalization of analogic inference. This can be represented schematically as follows:

a, b, c	are	P, Q, R
d	is	P, Q
d	is	P, Q, R

(where a, b, c, d denote entities and P, Q, R properties).

The well known linguistic examples for analogic inference are drawn from morphology: *learn* and *listen* occur in the context *-s* and *-ed* and *has ... -ed*. *Care* occurs together with *-s*. From this it is rightly concluded by analogic inference that it also occurs together with *-ed* and *has ... -ed*. But it is clear that this inference often leads to false conclusions: *ride* occurs together with *-s* and hence it is infered that *ride* also occurs together with *-ed* and *has ... -ed*. This false conclusion has to be eliminated by subsequent correction by the teacher.

Let us now turn to *periodicity generalizations*. Assume that our performance model learned that some element a might occur once or twice in a sequence. So it might contain the rules

$$A \rightarrow aB,\ F, \qquad (1)$$
$$B \rightarrow aC,\ F.$$

Now it receives an utterance with a sequence of three a's: $aaax$ (where x is an F). Instead of adding a further rule

$$C \rightarrow aD,\ F$$

to (1) it transforms the subsystem (1) into

$$A \rightarrow aA,\ F. \qquad (2)$$

The same obviously might occur with iterated embedding. From

$$A \rightarrow BCD,\ F, \qquad (3)$$
$$C \rightarrow BED,\ F,$$

and from an occurrence of three=fold embedding of the same type, one might derive

$$A \rightarrow BAD,\ F, \qquad (4)$$

instead of adding a rule $E \rightarrow BGD,\ F$, which would also have taken account of the third embedding.

It is obvious that these examples are little more than hints to possible procedures and indications of what has to be incorporated into a learning system. We are, however, not discouraged by our first analysis of the structure of learning models; and we think it is wortwhile to set up a learning model capable of reaching at least the ability of a child in the period of two word utterances. Decisive steps towards such

models require research into powerful enough methods for the structural analysis and comparison of linguistic descriptions (devices for A_I) and of linguistic processors such as grammars and performance models (analyzers A_p).

(Received November 9th, 1964.)

REFERENCES

[1] Garvin P. L.: Automatic Linguistic Analysis — A Heuristic Problem. Pp. 655—672 in Nat. Phys. Lab.: 1961 Int. Conf. on Machine Translation and Applied Language Analysis. Her Majesty's Stationary Office, London 1962.
[2] Feigenbaum E. A.: An Information Processing Theory of Verbal Learning. RAND Corp. Paper P-1817, 1959.
[3] Feigenbaum E. A., Simon H. A.: Generalization of an Elementary Perceiving and Memorizing Machine. Pp. 401—406 in C.M. Popplewell (Ed.). Information Processing 1962. North Holland Publ. Comp., Amsterdam 1963.
[4] Copi I. M.: Introduction to Logic. The Macmillan Comp., New York 1961.

VÝTAH

Vytváření modelů jazykového učení

H. SCHNELLE

V článku jsou probrány nutné zásady a složky, které musí obsahovat zařízení, modelující učení jazyka. Je třeba rozlišovat dva podsystémy: jednak částečně vyvinuté užívání jazyka, modelující proces porozumění a mluvení, jednak zařízení, realizující "faculté de langage". Toto zařízení dále obsahuje tři podsystémy: konstrukční část, analyzátor gramatické struktury a analyzátor strukturního popisu. V závislosti na síle analyzátoru strukturního popisu se získává informace z neúplného strukturního popisu, připsaného výpovědi, která není zcela srozumitelná. Tento údaj pak informuje konstrukční zařízení, jak má být model užívání upraven, aby mohl připsat úplný strukturní popis dané výpovědi. Tak se vysvětluje, proč proces učení může úspěšně pokročit jen tehdy, vkládají-li se do systému pouze takové výpovědi, které jsou již téměř srozumitelné.

H. Schnelle, Institut für Phonetik und Kommunikationsforschung der Universität Bonn, Bonn, Koblenzerstr. 98a, DBR.