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A NEW CONCEPT IN ARTIFICIAL INTELLIGENCE

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ABSTRACT

The primary subject of discussion in this report is the conceptual aspects of CHILD (Cognitive Hybrid Intelligent Learning Device). CHILD is a self-adaptive learning machine which was conceived, designed, and constructed at the Information Processing Lab, Rome Air Development Center.

An attempt is made to describe learning machines in a functional sense in order to isolate the unique properties of this concept. To do this, learning machines must be placed on some common ground. Therefore, adaptive learning devices will be viewed as networks of redundant adaptive elements which are capable of being organized by some "learning" logic. The common function performed by the learning machines under consideration here consists basically of a remapping of the sensory space in some manner which will enable decision elements to divide the remapped sensory inputs into various classes. The primary adaptive function of such machines is (or should be) the determination of the transformation(s) required in order to successfully solve the given problem. With this common basis for comparison, the unique properties of CHILD as a new concept in artificial intelligence should become apparent.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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A NEW CONCEPT IN ARTIFICIAL INTELLIGENCE

The object of this report is to describe the conceptual aspects of CHILD (Cognitive Hybrid Intelligent Learning Device) in such a manner as to permit the reader to perform a valid comparison with other learning machine concepts which intend to perform a similar function.

In order to discuss learning machines, they must be placed on some common ground. The function performed by the learning machines under consideration here consists basically of a remapping of the sensory space in some manner which will enable decision elements to divide the remapped sensory inputs into various classes. The primary adaptive portion of such machines is (or should be) the determination of the transformation(s) required in order to successfully solve the given problem. A further function of these machines is to then subdivide the new sensory space such that the decision elements can act on the remapped inputs in order to perform the classification function.

The input to CHILD consists of n analog values, which can be thought of as an n-dimensional analog vector. This input vector can be derived either directly from the sensors, or from some preprocessing technique utilized to extract characteristics (or features) from the sensory pattern. The fact that many such extraction techniques yield analog values constitutes the primary reason for the choice of analog inputs for CHILD. It is CHILD's primary purpose, then, to determine (1) which components of the input vector are important, (2) the range of acceptable values each component may assume, and (3) the degree of importance to be assigned to each component.

The basic element in CHILD has a transfer function that causes an output only if the input satisfies certain criteria, i.e., falls between two stored values. The output thus caused consists of a third stored value. The transfer function of a CHILD cell, then, is shown in Figure 1. The circuitry following each CHILD cell sees w_{ij} when the input stimulus falls between θ_{iju} and θ_{ijl}. Connecting n of these cells in parallel to form a row of cells, and arranging rows of cells in a parallel array results in a functional diagram as shown in Figure 2.

The analog outputs from the cells in each row are added together and compared with a fixed threshold on the right-hand side of the array. The outputs of the threshold devices are a binary indication that the input stimulus has satisfied the requirements of enough cells in a row to cause the threshold for that row to be exceeded. The adaptive procedure consists of adjusting the θ_{ij}'s and w_{ij}'s in the machine to cause the outputs of the threshold devices to correctly classify the input stimuli. The adaptation logic has been derived, and will be carefully described in the next section concerning the theoretical basis for CHILD, as compared to other machines.

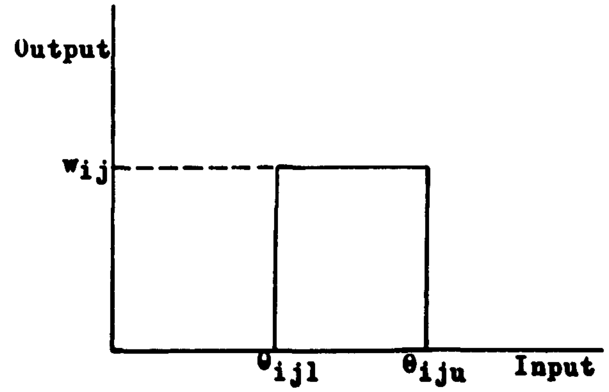


Figure 1. CHILD Cell Transfer Function.

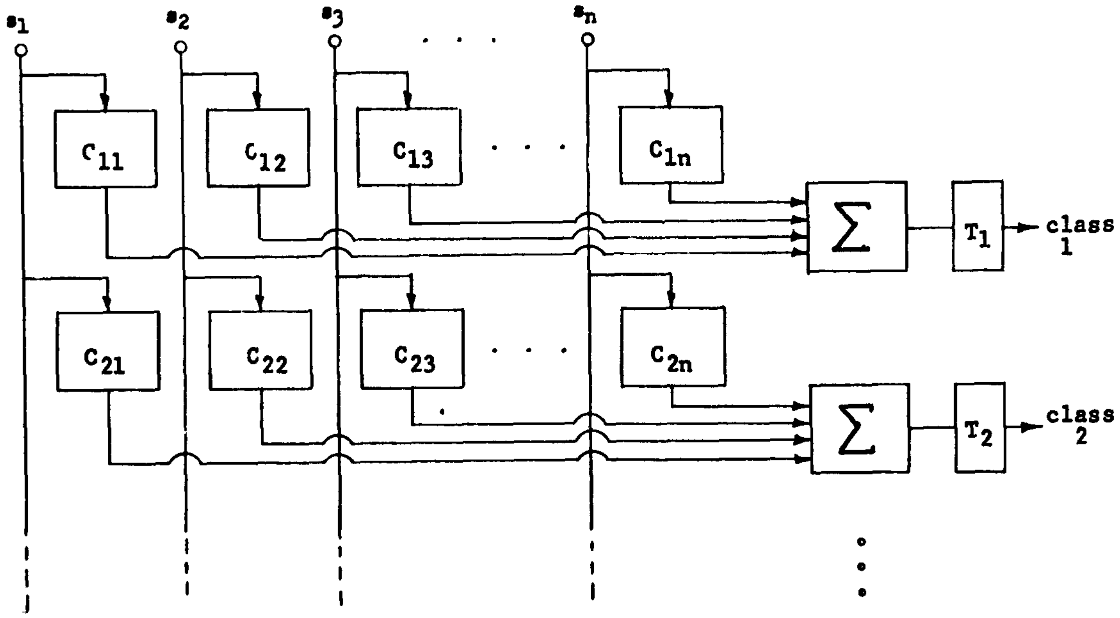


Figure 2. CHILD Functional Diagram.

As was mentioned previously, the common function of learning machines is that of remapping the sensory space into a new space where the decision elements perform the required classification. A general learning machine might then be represented functionally as shown in Figure 3. In order to compare and contrast CHILD with other learning devices we shall analyze a typical (non-CHILD) mapping element of the remapping layer (Figure 4) and explain how the remapping function is accomplished.

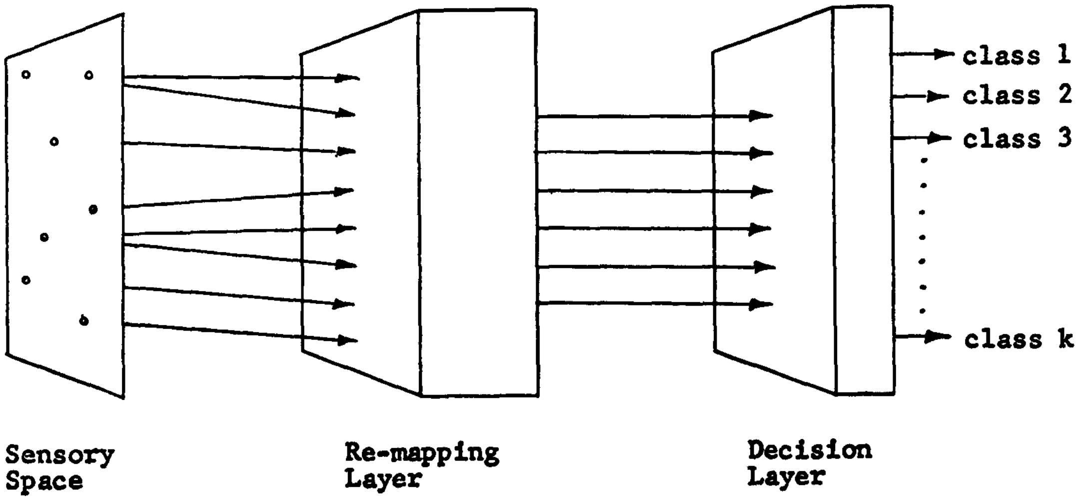
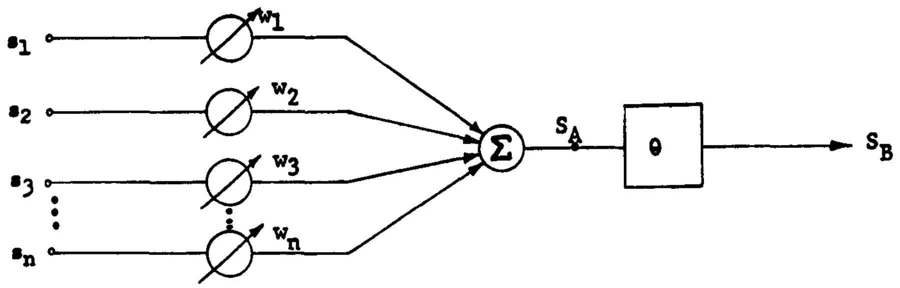


Figure 3. General Learning Machine



$\bar{S}$ = input vector = $s_1\bar{i}_{s1} + s_2\bar{i}_{s2} + s_3\bar{i}_{s3} + \dots + s_n\bar{i}_{sn}$

$\bar{W}$ = weighting vector = $w_1\bar{i}_{s1} + w_2\bar{i}_{s2} + w_3\bar{i}_{s3} + \dots + w_n\bar{i}_{sn}$

$S_A = \bar{S}\cdot\bar{W} = s_1w_1 + s_2w_2 + s_3w_3 + \dots + s_nw_n$

$$S_B = \begin{cases} 0 \text{ if } S_A < \theta \\ 1 \text{ if } S_A > \theta \end{cases}$$

Equation of Hyperplane: $s_1w_1 + s_2w_2 + s_3w_3 + \dots + s_nw_n = \theta$

Figure 4. Typical Remapping Element.

Typically an input vector defined in an n-dimensional sensory space is operated on in each remapping element by a weighting vector. The components of the weighting vector are defined by stored variable weights so that the orientation of the weighting vector in the sensory space can be altered by changing the values of the stored weights. The operation performed on the input vector is merely the scalar product of the input vector with the weighting vector. Thus the signal at point A is

$$S_A = \bar{S}\cdot\bar{W} = s_1w_1 + s_2w_2 + \dots + s_nw_n.$$

The signal S_A is then passed through a threshold set equal to θ. If S_A is equated to θ,

$$S_A = \theta = s_1w_1 + s_2w_2 + \dots + s_nw_n,$$

we obtain the equation of a hyperplane in the n-dimensional sensory space. The output of the threshold element (S_B) is equal to one if $S_A > \theta$ and equal to zero if $S_A < \theta$. Thus the remapping element places a hyperplane in the sensory space and maps every input on one side of the hyperplane into $S_B = 1$ and all inputs on the other side into $S_B = 0$.

Since there may be many remapping elements in parallel, making up the remapping layer, there are the same number of weighting vectors, each defining a hyperplane in the sensory space. Thus we see how the sensory space is partitioned and mapped into a new space. A similar weighting vector is defined (this vector may be fixed or adaptable) in the new space where a decision is made. The learning logic then controls the adaptable weights which in turn locate and orient the hyperplanes in the sensory space.

The input parameters sensed by the typical CHILD mapping element (Figure 5) are passed through two-sided adaptable thresholds designated by δ_{ij}. The output of each

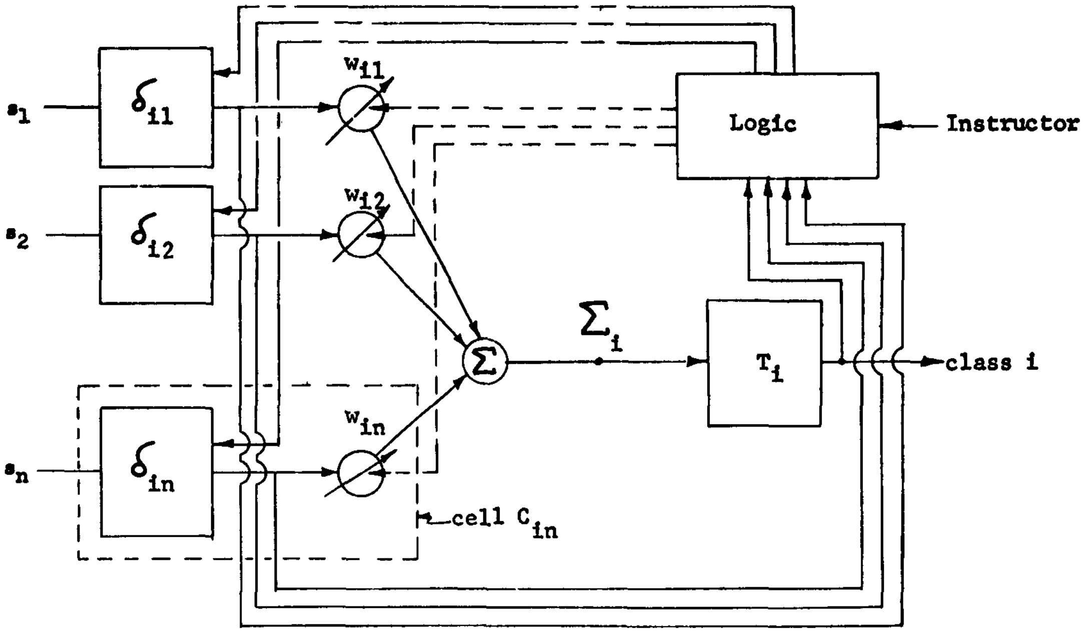


Figure 5. Typical CHILD Row i.

δ_{ij} is "0" if $\theta_{ijl} > s_j > \theta_{iju}$, and "1" if $\theta_{ijl} < s_j < \theta_{iju}$. This output is then weighted by w_{ij} and summed with similar signals of the row i. The output of the summer is $\Sigma_i = \sum_{\text{all } j} \delta_{ij} w_{ij}$ which is compared with a fixed threshold T_i. If the threshold is exceeded, the input is said to be in class i. The mapping element in CHILD, then, consists of all the cells in a row.

Now let us analyze the mapping function of CHILD. A δ_{ij} threshold defines two parallel hyperplanes in the sensory space which are perpendicular to the input axis s_j. If the end of the input vector ($\bar{S}$) lies within the region between the parallel planes, the s_j component of $\bar{S}$ initiates a vote of magnitude w_{ij} for the class i. Since each cell has a δ which is independent of every other cell's δ, the sensory space is partitioned in a controllable manner by sets of parallel hyperplanes. Thus, as seen in Figure 6, the cells of each row partition the sensory space into regions, and maps these regions onto a real line. Referring to Figure 6, region A is mapped onto the real line at point ($w_{i1} + w_{i2}$), region B into point w_{i2} and region C into point w_{i1}. The fixed threshold T_i then makes the decision as to whether $\bar{S}$ is in class i. The weights in the regions defined by the sets of parallel planes and the positions of the planes are controlled by the learning logic, a description of which follows.

CHILD has a binary output for each class of inputs. Therefore, in a learned state, an input stimulus will cause one and only one output to occur. CHILD's goal is to achieve this condition.

The teaching procedure is as follows: a stimulus of class i is presented to the machine and each cell of row i is given a command to place the stimulus between their

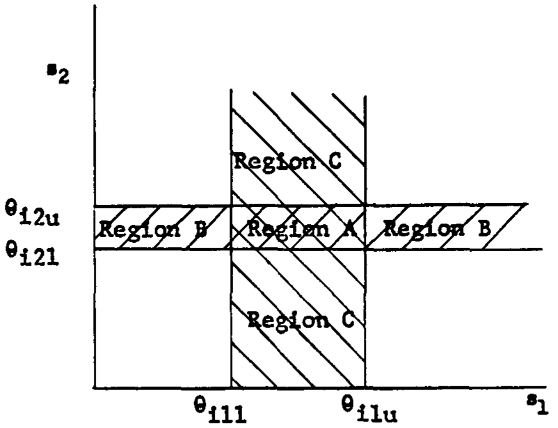


Figure 6. Mapping in Row i Performed by Cells C_{i1} and C_{i2} in Two-dimensional Sensory Space.

respective parallel hyperplanes. Each set of parallel hyperplanes is separated by some arbitrarily small distance e. When this condition is met, a region such as region A in Figure 6 is defined in the sensory space. (Region A is an acceptance region in the sensory space which is common to every cell in the row. We shall refer to such common regions as primary regions throughout the rest of the paper. Regions such as B or C shall be referred to as secondary regions, i.e., regions which are common to all cells but one in a row. In higher dimension sensory spaces a ternary space is defined as regions which are common to all but two cells in a row, etc.). Now in order to cause threshold T_i to be exceeded, all the weights of row i are increased until the threshold is crossed, indicating that the present stimulus is a member of class i. This abstraction procedure can then be followed for samples of stimuli belonging to classes not yet taught. At this point CHILD has no generalization capability since the acceptance regions for each class are minimum size primary regions scattered throughout the sensory space.

Generalization for a class is achieved by increasing the size of the acceptance regions. This may be accomplished in two ways: (1) by expanding the primary region, or (2) by increasing the weights in secondary (or ternary, etc.) regions so that stimuli in these regions cause their respective thresholds to be exceeded. Assume CHILD is now shown an additional stimulus in (previously taught) class k. It is probable that CHILD will not respond correctly since the machine has essentially only a rote memory. Therefore the instruct switch would now be set which would activate the following logic: If row k does not have an output (which would probably be the case), and cell C_{km} *does not* have an output (i.e., the stimulus does not fall between θ_{km1} and θ_{kmu}), then either θ_{km1} *or* θ_{kmu} is moved toward the stimulus s_m, depending on which is closer to s_m, until cell C_{km} has an output. A second logic rule is activated at the same time which states that if row k does not have an output and cell C_{kn} *does* have an output (equal to w_{kn}) then w_{kn} is increased.

These two operations are continued until row k has an output, indicating that the present stimulus is of class k. This logic will correct the error occurring when CHILD fails to classify a stimulus of class k into class k.

The other type of error which can possibly occur is when a stimulus of class k is classified as being a member of class j. In this case the logic will decrease all w_{jr}'s which are contributing to the erroneous response. This means that all w_{jr}'s of the cells that have an output in the row j will be decreased until row j no longer has an output. Through the use of this generalization logic (to correct both types of errors), the features common to two or more classes are therefore weighted lower than are the unique features of each class. Now CHILD has a generalization ability since the acceptance regions have been expanded in a controlled manner.

It might be advisable at this point to summarize the instruction logic which CHILD employs.

Let us define R_k = row k has an output
S_k = row k should have an output
C_{ki} = cell ki has an output.

If CHILD makes an error after the abstraction procedure, the following logic is implemented by setting the instruct switch:

$R_k \cdot \overline{S}_k \cdot C_{ki}$ - decrease w_{ki}
$\overline{R}_k \cdot S_k \cdot \overline{C}_{ki}$ - move θ_{kiu} *or* θ_{kil} toward the input depending upon which one is closer to s_i
$\overline{R}_k \cdot S_k \cdot C_{ki}$ - increase w_{ki}.

For all other possibilities there is no change in the adaptable parameters.

The efficiency of CHILD is obviously dependent to a great extent upon the nature of the analog sensory space. It can be seen from the previous discussion that CHILD is capable of organizing itself such that only the important characteristics for each class are relied upon to make the discriminations required. This is done in an independent fashion such that different characteristics can be found important for different classes. In addition CHILD makes the determination as to what specific range of values are acceptable for each characteristic. It is therefore not required that the analog inputs be absolute invariances (although this is obviously desirable!), and in many instances, simply scaling and/or normalization of numbers obtained from the real world are acceptable.

Pattern recognition problems of more complex nature require that more thought and ingenuity be devoted to the "front end" design, but it relieves the burden a great deal to keep in mind that CHILD will decide which values of which characteristics are important (as well as their degree of importance) to make the proper classification of the input stimuli.

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