An Aid to Pattern Recognition. Part 2

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The architecture of associative memory is explored. A system is presented that uses a simple sentence to describe its environment as discerned by several detectors. Simulations, using a digital computer, have demonstrated that the system learns by experience the form of the output sentence and which words to associate with particular inputs to each of the detectors. The system will then correctly describe a previously unencountered combination of known inputs. An extended architecture is also suggested to give the above system characteristics similar to the 'mind's eye'.

INTRODUCTION

In an environment of rapidly developing electronic system complexity and capability, a machine/operator interface that is able to describe combinations of complex phenomena, either within or detected by the machine, in simple standard sentences could be of considerable advantage.

In this second paper concerning pattern recognition using associative memory, an architecture will be described that can perform this task. The system learns by experience the form of the output sentence required to describe the combination of a number of phenomena, and discerns for itself which particular word in the sentence the operator wishes to associate with a particular phenomena.

SYSTEM DESCRIPTION

This paper is an extension of previously published work[1] and, therefore, the same terminology and diagrammatic conventions are used.

The associative memory system operates by storing related and concurrent pattern generated signals so that any reoccurrence of one signal will cause related pattern signals to be synchronously regenerated. In the present case, a possible simple example of which is shown schematically in Fig. 1, the signals generated by two 'environmental inputs', e.g. the shape and colour of an object, are stored concurrently with a third signal which represents a simple standard sentence describing those inputs, for instance, 'The square is red'. This sentence signal is also of the form that will write the sentence on the output display, e.g. a sequence of numbers that will display the sentence on an alphanumeric display.

The construction and operation of the sections are the same as described previously,[1] but with two significant modifications. First, the marking of unit terminals has been changed from the previous binary method to a multi-level regime, in which the amount a terminal is marked depends upon the number of times this terminal has experienced terminal marking conditions. This modification ensures that after an input of sufficient environmental/sentence combinations, for each subsequent environmental input, e.g. a square shape into Section 1A, a section pair is able to reconstruct that signal which represents the most frequently associated word, e.g. 'square', in Section 1B. Secondly, Sections 1B and 2B have been linked in such a way that this combination can potentially reconstruct either of the two word signals associated with the environmental inputs. Spontaneous signal reconstruction is inhibited by introducing a minimum value of unit potential function, $P_{U\,min}$. A pair of environmental inputs will now, if the system is prompted by the first word of the standard sentence, cause the construction of the signal representing the sentence describing those inputs, even if the combination of environmental inputs has not been previously encountered. The reconstructed signal writes the descriptive sentence on the output display. The structure of this sentence is inferred from the consistent inclusion of

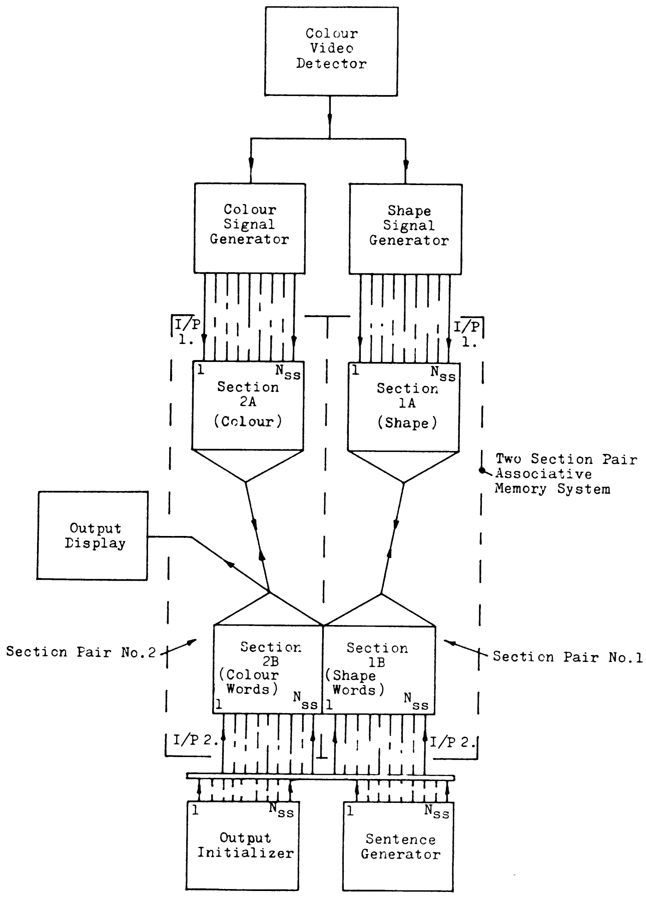

Figure 1. Schematic of example system.

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words such as 'The' and 'is' in the series of standardized descriptive sentences such as 'The square is red'.

The system concept allows additional environmental inputs, e.g. surface texture, about which alternative sentences such as 'The square is red and smooth' may be learnt.

SYSTEM HARDWARE AND OPERATION MODE

The system will operate with any reasonable combination of detectors or machine internal signals which have or can be given the correct form, and with any sentence having the correct structural content. However, for the purposes of description, an example system will be assumed to have as its environmental inputs the shape and colour of an object, and to use sentences of the general form 'The "object" is "colour"'. It is in this way that the randomly generated subsection number selection sequences which form the input to the associative memory simulation program AMY–3 will be described.

The descriptions of the input signal generators for the example system have been left intentionally in a conceptual form as their function is simply to facilitate an operational description of the associative memory part of the system.

The example system is shown schematically in Fig. 1. The environment is monitored by a 3 colour video detector. The video output is coded into signals suitable for input into Sections 1A and 2A by the colour and shape signal generators. These take the form of a number of detectors each sensitive to a different parameter of the video output, and in their most rudimentary form would probably be as follows. The colour signal generator detectors, a conceptual schematic of which is shown in Fig. 2, respond to the video input by outputting a pulse whenever the time integral of a given primary colour mix reaches a threshold value. A different fraction of the pulses from the voltage to frequency generators is allowed into each detector's pulse counter by the ratio gates. When the total of input pulses to a counter reaches a threshold value, the count discriminator outputs a pulse to Section 2A. The shape signal generator, a conceptual schematic of which is shown in Fig. 3, has detectors which view vertical strips of the area scanned by the video, and output a pulse whenever the sum of the primary colour intensities changes by greater than a threshold value. The output signal from the colour and shape detector banks is thus a pattern of pulses whose timed sequence along the parallel signal generator detector outputs are unique representations of the colour and shape components of the input video signal. Each detector output is connected into a different subsection within the colour or shape sections. A detector output pulse will cause a subsection to trigger. Each subsection is further divided into units. The simulated AMY–3 video input consists of a repeated sequence of 25 randomly selected digits for each of the possible environment colours and shapes, and represent the subsection triggering order.

The sentence generator creates a sequence of subsection input pulses, common to both Sections 1B and 2B. The order of these pulses represents the required sentence by giving the number sequence necessary to write the sentence on the alphanumeric output display. The form of the simulated AMY–3 input, consisting of four sequences of randomly selected subsection triggering orders, is shown in Fig. 4.

The associative memory part of the system consists of two linked section pairs. The section pair hardware differs from that described previously[1] in that the local and crossover connection terminals on the units within the sections can now be marked to a number of levels. During system operation, each time the conditions are such as to promote terminal marking, those terminals

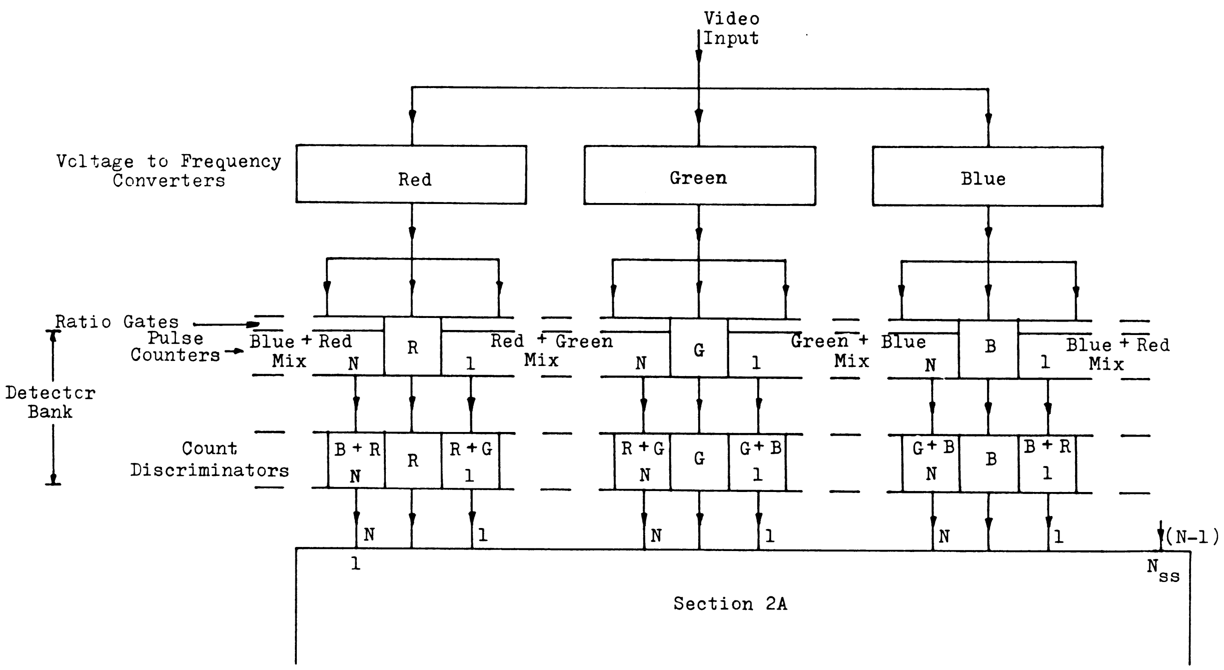

Figure 2. Conceptual design schematic of colour signal generator.

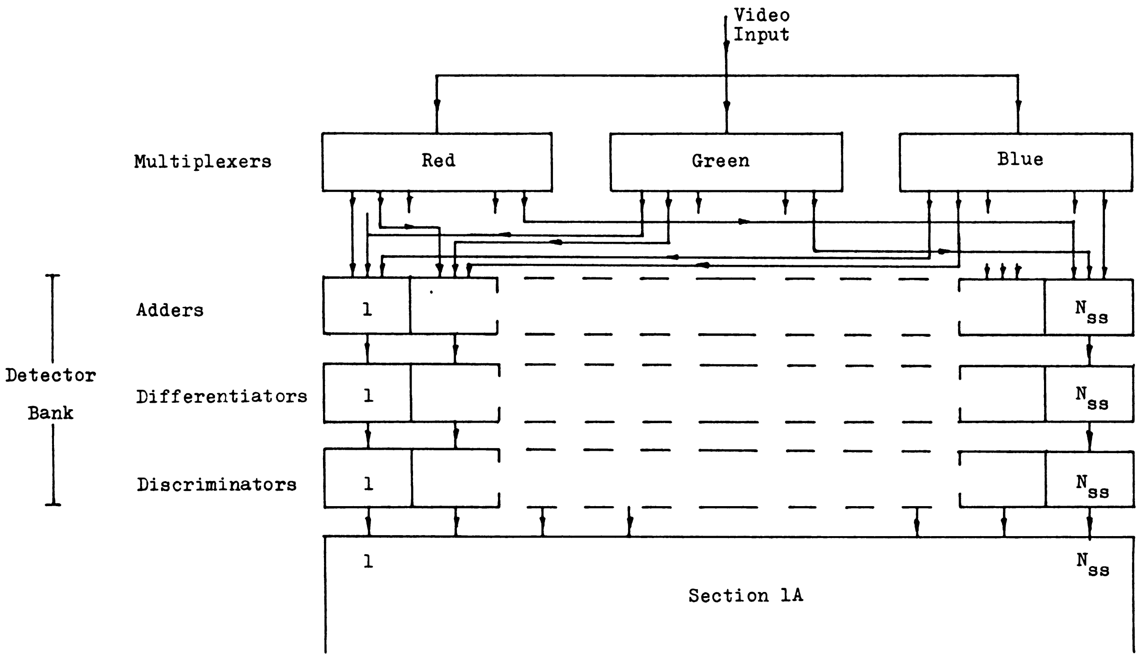

Figure 3. Conceptual design schematic of shape signal generator.

being marked have their marking level increased by a fixed amount (δM). During signal reconstruction, a marked pulse stimulates a unit by an amount dependent on the marking level of the terminal. The unit potential function is thus now redefined as the minimum total stimulus by coincident marked pulses that must be applied to a unit in order to cause it to trigger. Similarly, a pulse to a marked crossover terminal will only allow a possible unit trigger if the terminal marking level is above the minimum level, P_c.

The linked Sections, 1B and 2B, have equal numbers of subsections. Each subsection in Section 1B is paired with that subsection in Section 2B which is receiving pulses from the same sentence signal generator 'detector'. During signal reconstruction the occurrence of unit triggers still depends on coincidences within a section pair, whereas the triggering of a subsection now depends on the sum of unit triggers within its subsection pair. To obtain the control necessary to operate sentence signal regeneration, a minimum value of the unit potential function, $P_{U\,\text{min}}$ has been introduced. When this is set greater than zero it has the effect of suppressing spontaneous regeneration of the type described previously,[1] and will also increase the available signal storage space within these sections. Sentence signal regeneration must now be initiated by a prompt in the form of the common beginning of the descriptive sentences, i.e. 'The'.

The mode of operation of the system is most easily illustrated by the results from the simulation program AMY–3. Table 1 shows the parameters used, and Table 2 is a summary of an AMY–3 run sequence where, for clarity, the different sequences of random numbers have each been allocated a word. Cycles 1 to 6 represent the learning phase, and cycles 7 to 9 the phase where the system is being prompted to describe a previously unseen combination of shape and colour. The original output for cycle 8 is shown in Fig. 5. (The sentence sequence is the same as in Fig. 4.)

It will be observed from Table 2 that each shape or colour is associated twice with the word referring to it, but only once with other words. The multi-level marking of the unit terminals demands that when a sentence reconstruction is initiated, as in cycles 7 to 9, only those words that have been associated most often with the present colour and shape input can be reconstructed; the other possibilities being biased off by P_U rising above the maximum unit stimulation level attainable from other

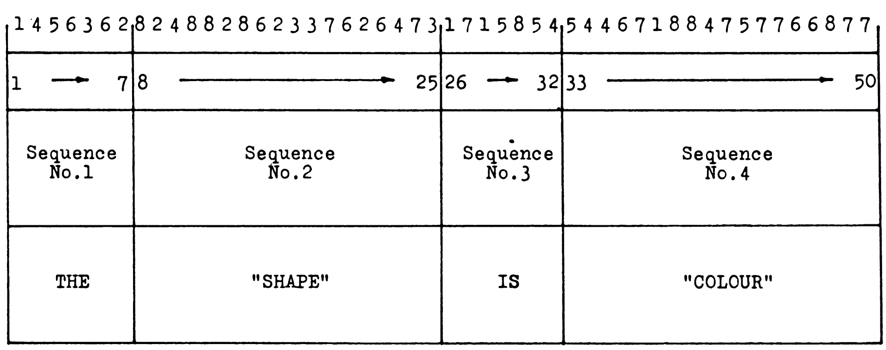

Figure 4. AMY–3 sentence sequence.

Table 1. Parameters used in AMY-3

		Sections 1A and 2A	Sections 1B and 2B
(1) Average rate of subsection trigger (time unit^{-1})	R	1	1
(2) No. of subsections per section	(N_{SS})	8	8
(3) No. of units per subsection	(N_U)	56	56
(4) No. of input connections per subsection	(N_I)	11	21
(5) Maximum local delay time (time units)	(D_L)	7	7
(6) Maximum crossover delay time (time units)	(D_C)	7	7
(7) Coincidence time interval (time units)	(τ)	1	1
(8) Maximum value of unit potential function	$(P_{U\max})$	12	12
(9) Minimum value of unit potential function	$(P_{U\min})$	0	8
(10) Rate of change of unit potential function	$\left(\frac{dP_U}{d\tau}\right)$	2	2
(11) Minimum value of subsection potential function	$(P_{SS\min})$	4	7
(12) Minimum value of subsection potential function for terminal marking	(P_{SSto})	10	20
(13) Minimum crossover terminal marking level for possible unit triggering	(P_c)	2	2
(14) Terminal marking increment	(δM)	1	1

less frequent associations. The way in which a correct word is inserted automatically into the standard sentence structure is illustrated by Fig. 6. Here, shapes and colours have been associated with sentences in the same way as for Fig. 5, but Sections 1B and 2B (Fig. 1) have been

Table 2. Summary of AMY-3 run sequence

Cycle no.	Sentence input	Shape input	Colour input	Output sentence
1	The square is red	Square	Red	As input
2	The square is green	Square	Green	As input
3	The triangle is blue	Triangle	Blue	As input
4	The triangle is red	Triangle	Red	As input
5	The circle is green	Circle	Green	As input
6	The circle is blue	Circle	Blue	As input
7	The	Square	Blue	The square is blue
8	The	Triangle	Green	The triangle is green
9	The	Circle	Red	The circle is red.

decoupled. In this separated state reconstruction is initialized by the 'The' sequence in Section 1B, and by the 'is' sequence in Section 2B. It will be observed that the 'is' sequence has been appended to the end of the shape sequence in Section 1B. When Sections 1B and 2B are coupled together, as in Fig. 5, the 'is' sequence reconstructed by section pair No. 1 has a similar initializing effect on section pair No. 2 as the 'is' sequence of Fig. 6.

The way in which the AMY-3 data is selected as random digits, makes the example system, where only two environment/word associations have been used during the learning phase, vulnerable to the statistical effect of identical digits occasionally occurring coincidentally in those signals being biased off during a reconstruction cycle. These can disguise the 'correct' digit if they occur a few time units after the end of the 'The' or 'is' sequences, causing an ambiguous or erroneous digit. However, run sequences entailing a greater number of environment/word associations in the learning phase are increasingly less susceptible to this irritation.

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CYCLE NO   8  :  SECT PAIR NO   1

I/P 1 (St 2)    5786247678137316133575371578624767813731613357537157862476781373161335753715786247678137316133575371
O/P 1           5786247678137316133575371578624767813731613357537157862476781373161335753715786247678137316133575371
Prob O/P seq    5786247678137316133575371578624767813731613357537157862476781373161335753715786247678137316133575371
Pss             BBBBBBBBBBBBBBBBBBBBBBBBBBCDEFGHIIIIIIIIIIIIIIIIIIIIIIIIIIIIIHHHGFFEEDDCFDCEEFGEEEDCBBBBBBBBBBBBBBBBBB
Pu              02468ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

I/P 2 (St 8)    0000000000000000000000001456362000000000000000000000000000000000000000000000000000000000010100010
O/P 2           0000000000000000000000001456362824882862337626473171585454467188475776687700000000000000000000000010
Prob O/P seq    0000000000000000000000001456362824882862337626473171585454467188475776687700000000000000000000000000
Pss             777777777777777777777777LLNSPTZ879778777777777797889C9DE99788889B78887878A87777777777777777777777777
Pu              888888888888888888888888ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCA888888888888888888888888


CYCLE NO   8  :  SECT PAIR NO   2

I/P 1 (St 5)    8415436386564182285388181841543638656418228538818184154363865641822853881818415436386564182285388181
O/P 1           8415436386564182285388181841543638656418228538818184154363865641822853881818415436386564182285388181
Prob O/P seq    8415436386564182285388181841543638656418228538818184154363865641822853881818415436386564182285388181
Pss             BBBBBBBBBBBBBBBBBBBBBBBBBCDEFGHIHGGFEEEDDCCDDCDDEEGGHGHHIIIIIIIIIIIIIIIIIIHGFEDCBBBBBBBBBBBBBBBBBB
Pu              02468ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

I/P 2 (St 8)    0000000000000000000000001456362000000000000000000000000000000000000000000000000000000000000100010
O/P 2           0000000000000000000000001456362824882862337626473171585454467188475776687700000000000000000000000010
Prob O/P seq    0000000000000000000000001456362824882862337626473171585454467188475776687700000000000000000000000010
Pss             777777777777777777777777LLNSPIZ879778777777777797889C9DE99788889B78887878A87777777777777777777777777
Pu              888888888888888888888888ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCA888888888888888888888888
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Figure 5. Example of AMY-3 output cycle.

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CYCLE NO   8  :  SECT PAIR NO   1

I/P 1 (St 2)    5786247678137316133575371578624767813731613357537157862476781373161335753715786247678137316133575371
O/P 1           5786247678137316133575371578624767813731613357537157862476781373161335753715786247678137316133575371
Prob O/P seq    5786247678137316133575371578624767813731613357537157862476781373161335753715786247678137316133575371
Pss             BBBBBBBBBBBBBBBBBBBBBBBBBBCDEFGHIIIIIIIIIIIIIIIIIIIIIIIIIIHGFEDCBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
Pu              02468ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

I/P 2 (St 8)    0000000000000000000000000145636200000000000000000000000000000000000000000000000000000000000100100010
O/P 2           0000000000000000000000000145636282488286233762647317158540000000000000000000000000000000000010101010
Prob O/P seq    0000000000000000000000000145636282488286233762647317158545446718847577668770000000000000001010101010
Pss             7777777777777777777777777BBDGDFI77777777777777777777777777777777777777777777777777777777777777777777
Pu              88888888888888888888888888ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCA88888888888888888888888888888888888888888


CYCLE NO   8  :  SECT PAIR NO   2

I/P 1 (St 5)    8415436386564182285388181841543638656418228538818184154363865641822853881818415436386564182285388181
O/P 1           8415436386564182285388181841543638656418228538818184154363865641822853881818415436386564182285388181
Prob O/P seq    8415436386564182285388181841543638656418228538818184154363865641822853881818415436386564182285388181
Pss             BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBCDEFGHIIIIIIIIIIIIIIIIIIIHGFEDCBBBBBBBBBBBBBBBBBB
Pu              02468ACCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

I/P 2 (St 9)    0000000000000000000000000000000000000000000000000017158540000000000000000000000000000000000101010100
O/P 2           0000000000000000000000000000000000000000000000000017158545446718847577668770000000000000000100100010
Prob O/P seq    0000000000000000000000000145636282488286233762647317158545446718847577668770000000000000000000101010
Pss             77777777777777777777777777777777777777777777777777BBDDDHI7777777777777777777777777777777777777777777
Pu              888888888888888888888888888888888888888888888888888ACCCCCCCCCCCCCCCCCCCCCCCCA88888888888888888888888
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Figure 6. AMY-3 output cycle with sections 1B and 2B decoupled.

TOWARDS A MACHINE 'MIND'S EYE'

The 'mind's eye' is defined as a mental view, or visual imagination. We are concerned here with the machine equivalent of the mental view that can be caused by a descriptive sentence. The retention of this view enables the machine to reconstruct relevant sentences.

The operation of an associative memory system is such that any input will cause the associated sequence(s) to be regenerated. It has been observed that if $P_{U\,\min}$ is set to zero in Sections 1A and 2A so as to allow spontaneous regeneration, then a sentence input to the system in Fig. 1 will cause these sections to spontaneously reconstruct a significant part of the associated colour and shape signals. It has also been observed that a one section pair system, which has had as both its inputs repeating sequences such as those used above for colour and shape, can be made to repeatedly reconstruct an associated pair of signals by inputting a short section from one of them.

From the above observations it follows that a system such as the one shown schematically in Fig. 7 could well exhibit the characteristics of a 'mind's eye'. Section pairs 1 and 2 are the equivalent of Fig. 1, and Section pairs 3 and 4 are those that will sustain any colour/shape sequences initiated by Sections 1A and 2A. The probable operation of such a system can be summarized as follows. The system is first trained by sequences such as cycles 1 to 6 in Table 2. Then in the absence of environmental inputs, a standard sentence input will cause Sections 1A and 2A to reconstruct a part of the associated shape and colour signals. These, through the links with Section pairs 3 and 4 will cause the whole of these sequences to be repeated continually. These repeating sequences, being 'seen' by the system in its 'mind's eye' are indistinguishable from that caused by a real input, and

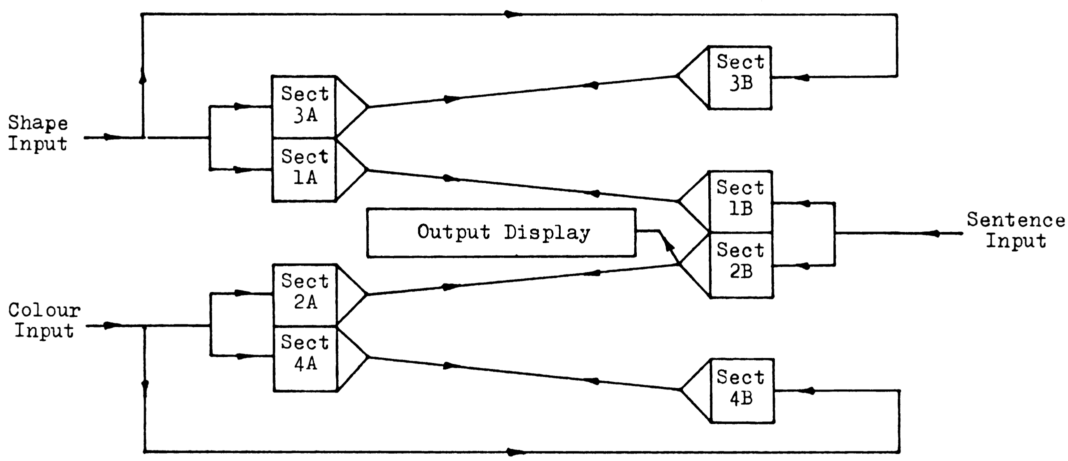

Figure 7. Schematic of proposed system to demonstrate 'mind's eye' characteristics.

can be thus subsequently used to reconstruct other relevant sentences. These repeating signals are initiated by just the environment descriptive part of the input sentence, i.e. the shape and colour words. Thus, if the system has again been trained as above, one could expect an input sentence such as 'Here is a blue square' to cause the prompt 'The' to initiate the sentence 'The square is blue'.

The present system employs values of D_L and D_C that are short compared with the length of the input sequences. A system can be envisaged in which some of these parameters have been effectively increased so as to span several input lengths simply by causing some units to trigger a number of times, when sufficiently stimulated, with a period of the order of D_L.

With respect to the system being considered above (Fig. 7), D_L and D_C in Sections 1B and 2B would be considerably lengthened, whereas those parameters in the other sections would be effectively limited to a time period equal to the length of one environmental input sequence. Sentence outputs would thus be additionally determined by the effect of previous sentence inputs over a time of several D_L. This could enable the initializing prompt for sentence signal reconstruction to be in the form of a question; the contents of which give additional control over the sentence being reconstructed. Thus, a system having environmental inputs monitoring shape, colour and surface texture could be expected to learn to respond to words such as 'see', 'feel', 'colour' and 'shape' in a series of questions and answers such as:

What do you see? A square that is blue and rough.
How does it feel? It feels rough.
What colour is it? It looks blue.
What shape is it? It is square.

After training, the environmental inputs could be replaced by a sentence such as 'Here is a rough, blue square'.

This mode of operation could be of interest in the field of machine intelligence.

REFERENCE

1. A. J. B. Travis, An aid to pattern recognition. *The Computer Journal* **25** (1), 37–44 (1982).

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