Apparatus for assisting an Operator in performing a Skill

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The present invention relates to apparatus for assisting an operator in performing a skill and is concerned particularly but not exclusively with apparatus for teaching an operator to perform a skill.

In this specification a skill is intended to mean acts an operator is required to perform in response to data supplied to him. Thus the operator may be supplied with data visually and be required to perform manual operations, such as pressing buttons or turning knobs, in response thereto. A telephone operator who has to insert a plug in a given jack whenever a certain flap falls down is performing a fairly simple skill. A plant control engineer who observes a screen of dials and manipulates control switches, valves, etc. in response to the indications of the dials performs a more complex and difficult skill.

The examples given above illustrate two different types of skills. The telephone operator responds to stimuli which occur at spaced intervals in time and each time a response is made it is either right or wrong: thus the right jack is or is not selected. Thus the degree of success of the telephone operator may be largely measured by observing what proportion of his responses are correct. In connection with this same type of skill, another important quantity which may be measured is the average time taken for the operator to respond to a stimulus, and this is a particularly important measure of success when the rate at which a skill is performed is limited not by the rate at which stimuli occur, but by the rate at which the operator can deal with stimuli.

The second of the two types of skill referred to is exemplified by the piano control engineer who is supplied continuously with data. The times at which any responses are to be made are determined by the judgment of the engineer. Some of his responses are capable of being judged "wrong", as it may be known, for instance, that they will definitely lead to an undesired result, for example to an explosion. However, many responses cannot be said to be "right" or "wrong", and the engineer's degree of success can only be judged by measuring the efficiency with which he operates the plant.

Having discussed these examples of skills, certain factors which make an operator inefficient in performing a skill, or which render a training routine inefficient, will be considered.

If the operator is receiving data at too slow a rate, he is likely to become bored and attend to other irrelevant data.

If the data given indicates too precisely what responses the operator is required to make, the skill becomes too easy to perform and the operator again tends to become bored.

If the data given is too complicated or is given at too great a rate, the operator is unable to deal with it. He is then liable to become discouraged and lose interest in performing or learning the skill.

Ideally, for an operator to perform a skill efficiently, the data presented to him should always be of sufficient complexity to maintain his interest and maintain a competitive situation, but not so complex as to discourage the operator. Similarly these conditions should obtain at each stage of a learning process if it is to be efficient. A tutor teaching one pupil seeks to maintain just these conditions.

Normally, however, systems which require data to be transmitted to an operator are in-
efficient, often because attention cannot be given to the individual. Inefficiency must then arise because individuals vary so much from one to another and vary so much from time to time.

In order to overcome such inefficiency the data needs to be "coded" in such a manner that it is optimally matched into the operator, that is, the data actually supplied to the operator has to be made such that it is adapted to the capabilities of the operator at all times. In the case of performance of a skill, as distinct from learning a skill, the data to be dealt with being externally determined without reference to the operator, what has to be "coded" is existing data. In the case of teaching a skill, the "coding" needs to be more far-reaching, and does not merely have to modify the way in which the data is presented, but also has to modify what data is presented.

In either case the aim must be to match the data into the operator continuously, even though his characteristics are always varying.

The invention is based on the realisation that any apparatus capable of effecting such a matching must comprise a device having characteristics like those of an operator, insofar as an operator is non-stationary and trainable. The operator is here called non-stationary because his characteristics cannot be represented as a set of transfer functions.

Accordingly reference will hereinafter be made to "trainable assemblages", to indicate assemblages which can be so "trained" or adapted by performance characteristics of the operator that, with reference to the skill in question, they come to have characteristics related to those of the operator.

According to the present invention there is provided apparatus for assisting an operator in performing a skill, comprising a marking device adapted to be supplied with input signals representative of the responses of an operator to data supplied to him, and to generate output signals representative of the operator's degree of success in responding to the data, in at least four channels, each corresponding to a different category, each category being determined by one or more characteristics of the skill, a trainable assemblage having its input coupled to the marking device in such a manner as to have its state determined by the output signals and to generate, in dependence upon such state, from time to time or continuously, control signals suitable to control one or more parameters of the data-supplying means in such a way as to tend to increase the said degree of success to an optimum value, and to maintain the degree of success at this optimum value.

The word "marking" has been chosen to characterise the device adapted to generate output signals representative of the operator's degree of success since the device acts in a manner analogous to an instructor who marks or assesses the performance of a pupil.

The expression "trainable assemblage" as used herein is defined as an assemblage including at least four storage means storing quantities determined by signals applied to the input of the assemblage over a period of time, and whose state at any instant can be represented by a vector whose components are the quantities held at that instant by the storing means respectively.

The assemblage must comprise at least four storing means in order to make it complicated enough to assume states which have characteristics related to those of the operator. Thus there will be some pattern in the state of the assemblage related to some pattern in the responses of the operator. It is in order to enable such a related pattern to exist in the assemblage that the operator signals representative of the degree of success must be provided in a plurality of channels each corresponding to a category determined by one or more characteristics of the skill.

Thus in skills wherein the data supplied to the operator consists of discrete indications selected from a finite number of such indications and the operator is required to make corresponding discrete responses selected from a finite number of responses, the categories may correspond to the responses, respectively.

The indications and responses from which indications and responses are selected will be called populations of indications and responses, respectively.

In skills such as those described in the preceding paragraph wherein each response may be marked in more than one marking category, the categories to which the storing means respond can be further subdivided, the total number of categories being the number of responses of the population of responses multiplied by the number of marking categories employed. For example, there will hereinafter be described an embodiment of the invention (referred to as a Type II coordinator) having a population of twelve discrete indications and a population of twelve corresponding responses. Each response, however, requires two switches to be pressed and the operator may make a correct or an incorrect response in two marking categories. Accordingly the marking device has twenty-four output channels, and the assemblage has twenty-four storing means, which as will be described are capacitors.

In skills, such as that of chemical plant control, parameters of the data-supplying means are not those of the situation, the divisions between categories have to be determined more arbitrarily. Very often
some categories can be determined by imposing marking categories in the apparatus. For instance in an embodiment to be described hereinafter under the name of a Type III coordinator, four marking categories are imposed in dependence upon the spatial relationships between two spots of light on a cathode ray tube screen (one spot representing a target aircraft and the other a pursuing aircraft).

Furthermore four "strategy categories" are imposed in this embodiment, in dependence on four strategies that the spot of light representing the escaping aircraft can adopt. This enables a total of four times four, namely sixteen, categories to be defined and the trainable assemblage in this embodiment comprises sixteen capacitors.

Having discussed the trainable assemblage and the types of categories with which its storing means may correspond, the nature of the input signals to the marking device and the nature of the marking device will be considered.

In apparatus for assisting an operator to perform a skill wherein the operator is required to make a succession of discrete responses the input signals may be pulses, which may, for example, be present only when a response is correct. Alternatively pulses may be present in one circuit when the operator makes a correct response and present in another circuit when the operator makes an incorrect response. The marking computer may then comprise an integrating device which computes a marking variable measuring the average number of correct responses in unit time. Furthermore, as described hereinafter, for example, in connection with the embodiment of the invention under the name of the Type I coordinator, this variable may be increased by correct responses and decreased by incorrect responses and may furthermore be "compensated", that is the amount by which it is increased by a correct response may be made dependent on how long before a limit time the response is made. Thus a variable representative of the operator's degree of success over a period of time is derived.

In cases where the operator determines a strategy, the input signals to the marking device may include a signal representing, for instance, in the case of a "pursuit" skill in which the operator tries to bring one pointer or spot of light onto coincidence with another pointer or spot of light, the deviation between the two pointers or spots of light. In this case the marked computer may provide a compensated marking variable by subtracting from this signal a signal representing the expected deviation, computed for instance from the state of the trainable assemblage. In the case of chemical plant control, a compensated marking variable may be computed by subtracting a signal representing an expected rate of production from a signal representing the actual rate of production.

The input signals to the marking device need not be of the nature exemplified above, but may, for example, be derived by measuring a physiological or a psychological variable of the operator, as will be hereinafter described.

Some examples of characteristics of the data supplied to the operator which may be varied will now be considered, pointing out how they may be varied in such a manner as to increase the operator's degree of success to an optimum value.

For skills wherein the data consists of discrete indications and where, accordingly, each indication may be regarded as a selection from a finite number of possible indications, various characteristics may be varied. Fundamentally the rate at which the indications are presented may be increased as the operator increases his degree of success, but this is not sufficient by itself to achieve the desired results. Such an increase in rate could be achieved without a trainable assemblage, but it has been found that this does not lead to satisfactory results. The apparatus becomes "oscillatory", getting alternately too fast and too slow for the operator. In apparatus concerned with such skills it is for this reason that the trainable assemblage is required. The trainable assemblage is able to vary some characteristic in a "patterned" manner, that is to different degrees in the different categories.

Thus superimposed upon the average increase in the rate of presentation of the indications there may be a "patterned" increase, the operator being required to respond more quickly to indications in a category in which the operator has achieved a relatively high degree of success, than to indications in categories in which the operator has achieved a relatively low degree of success.

It will be appreciated that such an increase in rate may be described, alternatively, in terms of the determination of the positions in terms of time limits before which responses to the indications may be made.

Another characteristic which may be varied is the clarity with which the indications are made. Thus the discrete nature of the indications may be blurred by displaying all the indications all the time, accentuating only the relevant indication. This may be described by saying that "ambiguity" is introduced in the indications. The ambiguity is of course "patterned". Also, when the indications occur in a repeated sequence in a training routine, the appearance of the indication, or the time at which it becomes apparent, which indication is the relevant one when ambiguity is being introduced, may be delayed, in a "patterned" manner, so that the operator
has to remember the sequence in order to achieve a high degree of success.

In skills wherein each discrete indication requires a number of discrete responses, the number of responses required per indication may be increased as the operator’s degree of success increases. For instance, each indication may consist of flashing up a sequence of symbols, each of which requires a corresponding key or switch to be pressed, and the length of the sequence of symbols may be progressively increased. This procedure would be appropriate in teaching a skill such as typing.

Although the procedures outlined above are adequate for making the data presented to the operator more and more difficult to deal with, they are not so well adapted to help the operator in stages in a learning process where he needs help. In the early stages of learning a skill an operator does not usually merely require the apparatus to be not too competitive, but he requires the apparatus to be actively co-operative if he is to learn the skill efficiently. Thus “corrective information” may be added to the data in a “patterned” manner, the corrective information indicating to the operator directly which response is required. In a skill wherein the responses are made by pressing switches or keys, the corrective information may be provided by lights adjacent to the switches or keys which light up when the switch or key to which they are adjacent is to be pressed. Corrective information may then be withdrawn by decreasing the intensity of these lights and causing them to light up progressively later and later, that is nearer to the limit.

In other embodiments of the invention the operator may be provided with “anticipatory information”, such embodiments being particularly useful for purposes of mental testing. The use of apparatus according to the invention for purposes of mental testing will be described hereinafter. Anticipatory information may be in the form of an indication to the operator that he is shortly to be provided with data to which he is to make a response. The anticipatory information may then be provided, for example, by means adapted to flash a warning light a short time before the data is caused to appear. Furthermore, the means may be adapted to decrease the interval between the flashing of the warning light and the appearance of the data as the operator’s degree of success increases.

When the data is supplied visually, anticipatory information may also be in the form of a short preview of the data to be formally supplied at a later time. The data is formally supplied at the instant of time from which the operator’s response time is measured. For instance, in an embodiment of the invention wherein the data is formally supplied by illuminating a line of symbols, each of which has to be recognised by the operator and responded to appropriately, the like of symbols may be briefly illuminated a short time before they are formally illuminated, and again the length of the interval between the brief illumination and the formal illumination may be decreased as the operator’s degree of success increases.

In apparatus teaching a skill wherein the operator determines a strategy, the apparatus in effect determines a strategy with which it plays against the operator. Since this strategy may be made more or less competitive or co-operative, the need for the separate provision of corrective information is decreased. Although so far the concept of selection from a population of possible contingencies has only been used in discussing the teaching of skills wherein discrete indications are selected from a finite number of indications, the concept may in fact be universally applied. When the apparatus determines a strategy, that strategy will frequently be one of an infinite number of possible strategies. The apparatus may thus be said to select from an infinite population of possible contingencies. Likewise the operator’s responses may always be regarded as a selection from a population, finite or infinite, of possible responses.

In this terminology the function of the apparatus may be described as follows. The apparatus provides, by touch, or by other sensory paths, with data or information from a “display”. In response to this information the operator performs selective operations on a population of responses and operates which also, in general, receives signals from the trainable assemblage and provides output signals to the assemblage. The trainable assemblage may also affect the said appropriate signals directly to effect a scaling procedure whereby the computation of a compensated marking variable is facilitated. The output signals alter the state of the trainable assemblage by varying the quantities held by its storing means. Control signals derived from the assemblage are used to effect selective operations on a population or set of possible contingencies and thereby the data “displayed” to the operator by the “display” is largely determined. However the actual representation of this data is coded, again under the control of the trainable assemblage, in order to present the data in a manner appropriate to the operator.

A scaling procedure, mentioned above, may for instance be effected, in apparatus wherein the operator makes responses by turning a knob, by providing a servo-mechanism which controls a gear-ratio in a drive between the knob and the device which the knob actuates, thereby varying the sensitivity of the actuation. The servo-mechanism is controlled by the apparatus and the sensitivity of the actuation.
may be increased as the operator’s degree of success increases.

It will be apparent from the foregoing that embodiments of the invention may take a very wide variety of forms. Accordingly three embodiments of the invention will be described in detail, and as indicated previously these will be called a Type I coordinator, a Type II coordinator, and a Type III coordinator.

The three Types are by no means representative of all the different forms the invention may take, but they do illustrate some important distinctions between different forms of apparatus according to the invention.

One important division of types is between those, including Type I and Type II coordinators, in which the coordinator is adapted to teach a predetermied routine and adapts the rate and manner of presentation of the routine, without varying the basic routine itself, and those, including Type III coordinators in which the coordinator is adapted to teach a basic routine within which, however, it adopts a strategy, that is it “plays against” the operator”, adapting its strategy to suit the skill of the operator. The division of types is determined by the nature of the coordinator.

Another important division is between those types, including Type I coordinators, in which the responses which the operator is required to make are of the same nature as the instructions given to the operator, and those types, including Type II and Type III coordinators, in which the responses are of a different nature from that of the instructions.

Thus the properties of the three types of coordinator will now be summarised and briefly exemplified by reference to the embodiments to be described later.

Type I coordinators:

(a) Operate in a fixed training routine, varying the rate and manner of presentation of the routine.

(b) Responses are of the same nature as the instructions given.

Thus in the embodiment to be described instructions are given by a plurality of lamps which light up in a fixed sequence, the operator being required to press one corresponding switch for each lamp when it lights up. Both the sequence in which the lamps light up and the correspondence between the lamps and the switches is made of a random nature, so that to perform the skill the operator has to learn the correspondence and the sequence.

Type II coordinators:

(a) Operate in a fixed training routine, varying the rate and manner of presentation of the routine.

(b) Responses are of a different nature from that of the instructions given.

In the embodiment to be described instructions are given by a plurality of lamps which light up in a fixed sequence, the operator being required to press two switches of two groups of switches respectively for each lamp when it lights up.

Type III coordinators:

(a) Operate in a basic routine within which they adopt a strategy.

(b) Responses are of a different nature from that of instructions given.

In the embodiment to be described instructions are given by the position of two spots of light on a cathode ray tube, the operator being required to adjust control knobs to bring one spot of light (representing a pursuing aircraft) into coincidence with the other (representing a target aircraft). The coordinator adopts an “escape strategy” which makes the target aircraft sufficiently elusive to maintain the operator’s interest, but not so elusive that the operator feels he has no chance of ever catching the aircraft.

This embodiment of a Type III coordinator has also been chosen because it is concerned with continuous variables, the operator achieving success as he gets the pursuing aircraft nearer the escaping aircraft, whilst the other embodiments are concerned with discrete variables, the operator achieving success as he makes more and more correct responses more and more quickly.

In modifications of both the Type I and the Type II coordinator (of which modifications no detailed embodiments are described), the said fixed training routine is made one of a plurality of routines, the coordinator being adapted to present different routines in succession, that routine in which the operator is least successful being presented most frequently.

It will be appreciated that whilst, for simplicity of description, embodiments of Type I and Type II coordinators have been described which teach arbitrary skills of no practical use, other embodiments may teach an operator to use a typewriter, a desk computing machine or a punched card keyboard for example.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a diagrammatic representation of the exterior of the Type I coordinator, hereinafore referred to;

Fig. 2 is a block circuit diagram of the Type I coordinator;

Fig. 3 is a diagram of two voltage waveforms illustrating the operation of the Type I coordinator;

Fig. 4 is a circuit diagram of a uniselector bank $U_1$, a terminal block $TB_1$, and a display $DS_1$ shown in block form in Fig. 2;

Fig. 5 is a circuit diagram of three uniselector banks $U_2$, $U_3$, and $U_4$, a permutator $PB_1$, and a set of control relays $CR_1$ shown in block form in Fig. 2;

Fig. 6 is a circuit diagram of a selector $SE$, and a store $ST_1$ shown in block form in Fig. 2;
Fig. 7 is a circuit diagram of a terminal block $T_B$ and a response board $R_B$, shown in block form in Fig. 2;
Fig. 8 is a circuit diagram of a terminal block $T_B$ and a display $D_S$, shown in block form in Fig. 2;
Fig. 9 is a circuit diagram of a set of marking relays $R_M$, shown in block form in Fig. 2;
Fig. 10 is a circuit diagram of a marking computer $MC$, shown in block form in Fig. 2;
Fig. 11 is a circuit diagram of a waveform generator $WG$, shown in block form in Fig. 2;
Fig. 12 is a circuit diagram of a unisector control $UC$, shown in block form in Fig. 2;
Fig. 13 is a circuit diagram of a voltage reader $VR$, shown in block form in Fig. 2;
Fig. 14 is a circuit diagram of a unisector bank $U_B$ and a store $ST_2$, shown in block form in Fig. 2;
Fig. 15 is a circuit diagram of an access controller $AC$, shown in block form in Fig. 2;
Fig. 16 is a circuit diagram of a corrective information computer $CI$, shown in block form in Fig. 2;
Fig. 17 is a circuit diagram of a modulator $MD$, shown in block form in Fig. 2;
Fig. 18 is a block circuit diagram of the Type I coordinator showing how the circuits shown in Figs. 4 to 17 are connected together;
Fig. 19 is a diagrammatic representation of the exterior of the Type II coordinator, hereinafter referred to;
Fig. 20 is a diagram of two voltage waveforms illustrating the operation of the Type II coordinator;
Fig. 21 is a block circuit diagram of the Type II coordinator;
Fig. 22 is a circuit diagram of a unisector bank $U_B$, a terminal block $T_B$, and a display $D_S$, shown in block form in Fig. 21;
Fig. 23 is a circuit diagram of a unisector bank $U_B$, a terminal block $T_B$, and a display $D_S$, shown in block form in Fig. 21;
Fig. 24 is a circuit diagram of two unisector banks $U_B$ and $U_B$, two terminal blocks $T_B$ and $T_B$, and a response board $R_B$, shown in block form in Fig. 21;
Fig. 25 is a circuit diagram of a set of marking relays $R_M$, shown in block form in Fig. 21;
Fig. 26 is a circuit diagram of a waveform generator $WG$, shown in block form in Fig. 21;
Fig. 27 is a circuit diagram of two unisector banks $U_B$ and $U_B$, two terminal blocks $T_B$ and $T_B$, and a display $D_S$, shown in block form in Fig. 21;
Fig. 28 is a circuit diagram of an ambiguity modulator $AM$, shown in block form in Fig. 21;
Fig. 29 is a block circuit diagram of the Type II coordinator showing the interconnections of the circuits shown in Figs. 22 to 28, two further circuits, which are in essence the same as those shown in Figs. 10 and 12 respectively and five pairs of circuits, comprising two circuits in essence the same as those shown in each of Figs. 13 to 17 (the reference numerals designating terminals in Figs. 13 to 17 having been provided with either a subscript "b" or a subscript "c" as will hereinafter be explained);
Fig. 30 is a block circuit diagram of a radar training apparatus including the Type III coordinator hereinafter referred to;
Fig. 31 is a more detailed block circuit diagram of the Type III coordinator;
Fig. 32 is a circuit diagram of a selector $SE$, shown in block form in Fig. 31;
Fig. 33 is a circuit diagram of an access controller $AC$, shown in block form in Fig. 31;
Fig. 34 is a circuit diagram of a store $ST$, shown in block form in Fig. 31;
Fig. 35 is a circuit diagram of a set of output relays $OR$, shown in block form in Fig. 31;
Fig. 36 is a circuit diagram of a variance computer $VC$, shown in block form in Fig. 31;
Fig. 37 is a circuit diagram of a marking computer $MC$, shown in block form in Fig. 31; and
Fig. 38 is a block circuit diagram of the Type III coordinator, showing the interconnections of the circuits shown in Figs. 32 to 37, a circuit constituting a row access controller $AC$, shown in block form in Fig. 31 and being in essence the same as that shown in Fig. 33, with, however, the reference numerals designating its terminals primed, and three amplifiers $AA_1$, $AA_2$ and $AA_3$, shown in block form in Fig. 33.

The embodiment of a Type I coordinator will now be described, firstly in broad outline, with reference to Fig. 1, as it appears to an operator a block $T_B$ in training, then in more detailed functional form with reference to Figs. 2 and 3, and finally in still more detail with reference to Figs. 4 to 18.

The coordinator functions in a cyclic sequence of twelve "positions" in each of which an instruction is given to the operator and in which the operator is required to make a response to that instruction. Each position will be said to start at a certain time, to end at a later time and to be of a certain duration, which duration in general varies from position to position and varies for a given position for successive occurrences of that position. The twelve positions will be numbered consecutively $p_1$, $p_2$, and a general position will be indicated by the symbol $p$. Each two consecutive positions are separated from each other by a short fixed "moving-on" interval of duration $u$.

Referring to Fig. 1, the instructions are given to the operator by a "display" $D_S$, comprising eight lamps arranged in a hori...
horizontal row and numbered \( k_1 \) to \( k_6 \) from left to right, a general lamp being given the symbol \( k_n \).

In each position \( p_1 \) one of the lamps \( k_0 \) lights up. In response to this the operator is required to press a switch of a "response board" \( RB \), having eight press-button switches arranged in a horizontal row and numbered \( s_1 \) to \( s_8 \) from left to right, before the end of the position \( p_1 \).

A routine for the operator to learn is set up by making connections in certain terminal boards to be described hereinafter which determine which lamp lights up in each position \( p_1 \) and which switch is the correct switch to be pressed for each lamp \( k_0 \). In describing the coordination \( i \) will be assumed, merely by way of example, to set up in the following manner:

<table>
<thead>
<tr>
<th>Position in sequence</th>
<th>Lamp lit up</th>
<th>Switch to be pressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_1 )</td>
<td>( k_0 )</td>
<td>( s_1 )</td>
</tr>
<tr>
<td>( p_2 )</td>
<td>( k_0 )</td>
<td>( s_2 )</td>
</tr>
<tr>
<td>( p_3 )</td>
<td>( k_0 )</td>
<td>( s_3 )</td>
</tr>
<tr>
<td>( p_4 )</td>
<td>( k_0 )</td>
<td>( s_4 )</td>
</tr>
<tr>
<td>( p_5 )</td>
<td>( k_0 )</td>
<td>( s_5 )</td>
</tr>
<tr>
<td>( p_6 )</td>
<td>( k_0 )</td>
<td>( s_6 )</td>
</tr>
<tr>
<td>( p_7 )</td>
<td>( k_0 )</td>
<td>( s_7 )</td>
</tr>
</tbody>
</table>

I \( e \) will thus be seen that, with the particular routine assumed, the following sequence of switches has to be pressed:

\( s_1, s_2, s_3, s_4, s_5, s_6, s_7 \).

The function of the coordinator is to teach the operator to make the correct response for each position \( p_1 \) rapidly and thus the operator may be said to learn firstly which switch of the response board \( RB \), corresponds to each lamp in the display \( DS \), and secondly the sequence in which the lamps in the display \( DS \), light up and accordingly the sequence in which the switches of the response board \( RB \), have to be pressed.

A lamp 37 indicates to the operator that he has made a correct response and a lamp 38 indicates an incorrect response.

The teaching process is effected firstly by adapting the rate at which the operator is required to make responses to the operator's ability at each stage in the learning process, increasing the rate as he becomes more successful in making correct responses. This is done by decreasing the duration of the positions \( p_1 \). However it is not done merely by decreasing the average duration of the positions. Superimposed on such an increase in the rate of operation of the machine is a "patterned increase" which may be provided in one of two ways, selected by the setting of a switch.

In one of the two ways the coordinator remains in a position for a relatively short length of time when the operator has had a relatively high degree of success in responding in that position previously. In the other of the two ways the coordinator remains in a position for a relatively short length of time when the operator has had a relatively high degree of success in responding to the lamps which light up in that position (and may be in other positions, since some lamps light up in more than one position).

Thus the distinction between the two alternatives is that the coordinator takes account of the previous degree of success in responding, in the first case in a particular position and in the second case to a particular lamp. By "previous degree of success" is meant average success in a number of previous sequences and physically this averaging is effected by adding or taking away charge to or from a capacitor.

The distinction between the two alternatives is not fundamental. The two ways described are convenient ways of achieving the "patterned increase" and in the later stages of a learning process even the detailed operation of a coordinator will be little affected by which way is used.

The learning process is further assisted by a second "display" \( DS_2 \), having eight lamps in a horizontal row, numbered \( m_1 \) to \( m_8 \), from left to right and adjacent the switches \( s_1 \) to \( s_8 \) respectively. These light up to indicate to the operator directly which switch should be pressed, the lamp \( m_2 \), for example lighting up when the switch \( s_2 \) is to be pressed. The display \( DS_2 \) gives the operator corrective information.

However these lamps only light up slowly and not until their brilliance reaches a certain level do they assist the operator. In the initial stages of learning they are caused to reach this level fairly quickly and thus to give the operator considerable help. As progress is made they are caused to reach the level more and more slowly, corrective information thus being withdrawn until eventually the level is not reached at all before the end of each position and accordingly the operator is given no corrective information. Moreover this withdrawal of corrective information is "patterned" in the same way that the rate of increase in the rate of operation of the coordinator is "patterned".

 Provision is also made whereby the lamps of the display \( DS_1 \) may be caused to light
up in this manner, that is to say quickly during the initial stages of learning, and progressively less quickly as learning proceeds. Use may be made of this provision particularly in the later stages of the learning process when the operator is progressing towards the point where he knows the sequence in which the lamps light up.

Referring to Fig. 2 there is shown a functional block diagram of the Type I coordinator. Electrical connections between units of the coordinator are shown by full lines (some of which represent more than one wire) whereas control of a unit by a relay or relays in another unit is shown by a chain dotted line. A broken line is used in conventional manner to indicate that switches or uniselectors arms are mechanically ganged together. A number in a circle against a full line represents the number of wires constituting that connection when the number is other than one.

The twelve positions in which the coordinator operates are shown, and by a five-bank unisector U₁, U₂, U₃, U₄, U₅, having twelve positions and being stepped on by a "unisector control" UC₁.

The wiper of the first bank U₁ is connected through a switch SW₁ to either a transformer T₁, supplying to the wiper an unmodulated alternating voltage, or to the output of a modulator MD₁. The twelve output terminals from the bank U₁ are connected through a first terminal block TB₁ to the eight lamps of the display DS₁. Thus depending on the setting of the switch SW₁, the lamps can be caused to light up either steadily or in a manner depending on the output of the modulator MD₁, which output is a fifty-cycle alternating current amplitude modulated in a manner to be described later.

A 25 volt supply is connected to the wipers of the three banks U₂, U₃, and U₅ the output terminals of which are connected through a "permutator" PB₁, which is a terminal block with provision made for altering the connections within the block by means of switches, to a set of "control relays" CR₁. This set of relays controls three "selectors," SE₁, SE₂, and SE₃, each having an input terminal and eight output terminals. For each position of the sequence the input to each selector is connected through to one of the eight output terminals of each selector respectively, the routing through the selectors being controlled by the control relays.

The input to the selector SE₁ is a 25 volt supply. The output terminals of this selector are connected through a second terminal block TB₂ to the response board RB, which, as shown in Fig. 1, has eight press-button switches. In each position of the sequence the operator is required to press one of these switches, whereupon an output from the response board registers upon a set of "marking relays" MR₁, firstly the fact that a response has been made and secondly whether the response is correct or incorrect, and the marking relays MR₁ are set in appropriate states. The output from the response board RB, registering whether the response is correct or incorrect is dependent on the input to the response board RB₁ from the terminal block TB₁. The marking relays control the two lights 37 and 38 in Fig. 1 which indicate to the operator whether his response is correct or incorrect.

The state of the marking relays MR₁ determines the state of a "marking computer" MC₁, which computes a continuously varying marking variable θ, represented by a potential from its state at any instant. Normally θ decreases slowly, but when a correct response is made θ is increased by an amount depending on how long the response is made before the end of the position p₁ in which it is made.

Thus referring to the upper part of Fig. 3, θ is shown for two consecutive positions p₁ and p₁₊₁. The positions p₁ and p₁₊₁ begin at times t₁ and t₁₊₁ respectively and end at times t₁ + t₁ and t₁₊₁ respectively. A correct response is assumed to be made in the position p₁ at time t₁ + t₁ and an incorrect response is assumed to be made in the position p₁₊₁ at time t₁₊₁. The interval t₁₊₁ - t₁ is of duration δ₁ and the interval t₁₊₁ - t₁ is of duration δ₁₊₁. At times other than those in the last two said intervals, θ is increasing at a slow steady rate. In the interval t₁₊₁ - t₁ following the correct response at time t₁ + t₁, θ is caused to increase at a relatively rapid rate and in the interval t₁₊₁ - t₁ following the incorrect response at time t₁₊₁, θ is caused to decrease at a relatively rapid rate.

One output from the marking computer MC₁ (Fig. 2) is fed to a "waveform generator" WG₁ which generates a waveform Vₘ shown in the lower part of Fig. 3. At the beginning of the position p₁, the potential Vₘ starts to rise from a constant level Vs at a rate dVₘ/dt = (a + bθ) where a and b are constants. The position p₁ ends when the potential Vₘ reaches a variable trigger level Vₜ₁. The variations in the slope of the waveform Vₘ show the increase and decrease of the slope when θ increases and decreases by relatively large amounts respectively.

The trigger level Vₜ₁ is determined by a "voltage reader" VR₁ (Fig. 2) connected through a single-pole two-way switch SW₂ to a "store" ST₁ when the duration of the position p₁ is required to depend on the previous degree of success in responding to the lamp of the display DS₁, which lights up in that position and to a store ST₂ when the duration of the position p₁ is required to depend on the previous degree of success in responding in that position.

The waveform generator WG₁ also controls through the unisector control UC₁, the moving-on interval t₉ as the end of which the unisector control UC₁ moves the unisector on to the next position, during the moving-on
interval, the marking relays MR, are prevented from functioning.

The input to the voltage reader VR, at each position of the sequence is determined by the charge on a capacitor of either the first store ST₁ or the second store ST₂. The store ST₁ has eight capacitors connected to the eight output terminals of the uniselecter SE₁ respectively the input terminal of which is connected to one fixed contact of the switch SW₁. The store ST₂ has twelve capacitors connected to the twelve output terminals of the uniselecter bank U₂ respectively the input terminal of which is connected to the other fixed contact of the switch SW₂. The movable contact of the switch SW₂ is connected to the input to the voltage reader VR, and through an "access controller" AC₁, the state of which is dependent on the state of the marking relays MR₁, to an output from the marking computer MC₁.

The eight capacitors of the store ST₁ are in one-to-one correspondence with the eight lamps in the display DS₁ and thus with the switches of the response board RB₁. For convenience the capacitors will be numbered e₁ to e₈ where the capacitor e₁ corresponds to the lamp k₁, the capacitor e₂ to the lamp k₂, and in general the capacitor eₙ to the lamp kₙ. The charge held by each capacitor of the store ST₁ is, as will be hereinafter described arranged to be representative of the degree of success achieved by the operator in responding to the associated lamp, averaged over a number of sequences.

Assuming the computer is set up as previously described, in the position p₁, the input to the voltage reader VR, when the store ST₁ is in use, that is when the switch SW₁ is in the position shown in Fig. 2, l is determined by the capacitor e₁, in the position p₂ the input is determined by the capacitor e₂, and so on. When a capacitor eₙ holds a charge representing a high degree of success, the trigger level Vₑₙ is low and when the capacitor eₙ holds a charge representing a low degree of success the trigger level Vₑₙ is high.

The twelve capacitors of the store ST₂ are in one-to-one correspondence with the twelve positions p₂ to p₃ and will be numbered f₁ to f₁₂, where the capacitor f₁ corresponds to the position p₁, the capacitor f₂ to the position p₂ and so on. The charge held by each capacitor of the store ST₂ is, as will be hereinafter described, arranged to be representative of the degree of success achieved by the operator in the corresponding position in the sequence, averaged over a number of sequences.

When the store ST₂ is in use, that is when the switch SW₂ is in the other position from that shown in Fig. 2, and a capacitor f₁ holds a charge representing a high degree of success the trigger level Vₑ₁ for the position p₁ is low and when the capacitor f₁ holds a charge representing a low degree of success the trigger level Vₑ₁ is high.

Thus referring again to Fig. 3, the duration Δ₄ of the position p₄ depends both on the rate at which Vₑ₄ is increasing, which in turn depends on θ, and the height of the level Vₑ₄. If θ is large, and, if, for the position p₄, Vₑ₄ is low, then Δ₄ is short. When the store ST₁ is in use the level Vₑ₄ is determined by the previous degree of success in the position p₃. When the store ST₁ is in use the level Vₑ₄ is determined by the previous degree of success in responding to the lamp corresponding to the position p₃. Thus when the coordinator is set up as described above, in the position p₄ the level Vₑ₄ is determined by the previous degree of success in responding to the lamp k₃, that is the previous degree of success in positions p₃ and p₄.

The output from the voltage reader VR, is also fed to an input terminal of a "corrective information computer" CI₁ which also receives an input from the waveform generator WG₁ and provides the input to the modulator MD₁. The output of the modulator MD₁ is fed through the selector SE₂ and through a terminal block TB₁ to the second display DS₂.

The corrective information computer CI₁ adds a voltage proportional to the output from the voltage reader VR₁ to the rising waveform Vₑ₄ and in the modulator MD₁ the fifty-cycle output is amplitude modulated in response to these added voltages. The connections of the terminal block TB₁ are so made that in any position p₄ the modulator MD₁ is connected to the lamp of the display DS₂ corresponding spatially with the switch on the response board RB₁ which has to be pressed to provide a correct response in that position.

The output from the corrective information computer CI₁ is a potential proportional to Vₑ₄ (Fig. 3) superimposed on a step of height determined by the output of the voltage reader VR₁, and proportional to the level Vₑ₄ (Fig. 3). The output of the modulator MD₁ is an alternating current amplitude modulated in the same way and thus the lamp in the display DS₂ to which the modulator MD₁ is connected will increase in brightness during the period Δ₅. The minimum level of brightness at which the lamp actually supplies the operator with corrective information is determined by physiological and psychological factors and the corresponding level of output from the modulator will be called the level B₅.

Thus when the operator has achieved a very low previous degree of success in a position p₃ (and Vₑ₄ is thus very high) the amplitude of the output from the modulator MD₁ starts at a relatively high value, namely the height of the step derived from the voltage reader VR₁ which step is proportional to Vₑ₄ and increases therefrom. Thus the level B₅ is reached as soon as the period Δ₄ starts, or very soon.
afterwards, and the operator rapidly receives some corrective information. If he delays his response the lamp increases in brightness until he receives a large amount of corrective information.

Conversely when the operator has achieved a high previous degree of success in a position $p_i$ (and $V_i$ is thus low) the output from the modulator $MD_i$ starts at a relatively low value and increases therefrom. The level $B_i$ is only reached late in the period $\Delta \theta$ and in the ultimate it is not reached at all, the operator then receiving no corrective information.

The output from the modulator in the position $p_i$, of course depends on the previous degree of success in responding to the lamp of the display $DS_i$ corresponding to the position $p_i$ when the store $ST_i$ is connected to the voltage reader $VR_i$ and on the previous degree of success in the position $p_i$ when the store $ST_i$ is connected to the voltage reader $VR_i$.

Thus at the beginning of the process of learning a skill, the value of $\theta$ is low, the trigger levels $V_i$ are in general high and the output from the modulator $MD_i$ in general reaches the level $B_i$ quickly in each position $p_i$ of the sequence.

As progress is made in learning the skill, $\theta$ increases and thus the average rate at which responses are required to be made increases. Furthermore the trigger levels $V_i$ decrease and the amplitude of the output from the modulator $MD_i$ decreases but these decreases are different for the different positions $p_i$. Thus the coordinator adapts itself to the "pattern of learning" of the operator and in positions $p_i$ where he achieves a high relative degree of success gives him a relatively short period of time in which to make a response and a relatively small amount of corrective information.

The coordinator will continue to vary the variable $\theta$, the trigger levels $V_i$ and the amount of corrective information supplied to the operator until a stable state is reached where $\theta$ is high and constant (that is the slow continuous decrease of $\theta$ is just offset by the increase afforded by his correct responses), all the trigger levels are low and of the same height, and no corrective information is supplied to the operator.

Furthermore when the switch $SW_i$ is so set that the input to the lamps of the display $DS_i$ is from the modulator $MD_i$, the information given by the display $DS_i$ is, once the correspondence between lamps of the display $DS_i$ to switches on the response board $RB$, has been learned, may be regarded merely as telling the operator whereabouts he is in the sequence, decreases as the skill is learned. That is the lamps of the display $DS_i$ only light up slowly to reach a level of brightness which gives information to the operator after the beginning of a position $p_i$. If this information is decreased to zero a further lamp (not shown) is provided which lights up when the coordinator is in the position $p_i$ and indicates the start of the sequence.

The units of the coordinator will now be described in more detail, and in this detailed description the connections of the terminal blocks $TB_1$, $TB_2$, $TB_3$, and of the permutator $PE_i$ will be shown arranged to set up the coordinator as in the example described above.

In Fig. 4 the twelve output terminals 10 of the uniselecter bank $U_i$ are numbered $p_{10}$ to $p_{12}$ in correspondence with the positions of the sequence. The output terminals 10 are connected to twelve input terminals 11, respectively, of the terminal block $TB_1$ which input terminals are connected to eight output terminals 12 of the block $TB_2$. The terminals 12 are connected to one terminal of the eight lamps $k_1$ to $k_8$, respectively, of the display $DS_i$, the other terminal of each lamp being connected to earth.

In Fig. 5 the twelve output terminals 13, 14, 15 of the uniselecter banks $U_1$, $U_2$, $U_3$, respectively are in each case numbered $p_{13}$ to $p_{15}$. The output terminals 13, 14, 15 are connected in one-to-one correspondence with three sets each of twelve terminals 16, 17, 18 in the permutator $P_i$, respectively. The terminals 16 are connected to two terminals 19, 20, the terminals 17 to two terminals 21, 22 and the terminals 18 to two terminals 23, 24, the connections shown and the arrangement of the contacts of the relays $A$, $B$ and $C$ are shown in Fig. 6 being such that the capacitors of the store $ST_i$ number $e_i$ to $e_i$, from left to right in Fig. 6. It will be recalled that the capacitors $e_i$ to $e_i$ correspond to the lamps $k_1$ to $k_8$, respectively. The terminals 19, 21 and 23 are connected through three ganged switches $SW_3$, $SW_1$, and $SW_2$, respectively to the windings of three relays $A$, $B$ and $C$ respectively (forming the control relays $CR_i$ of Fig. 2), the other ends of which windings are connected to a $-25$ volt line.

The switches $SW_3$, $SW_1$, and $SW_2$ can be changed over to connect the terminals 20, 22 and 24 to the relays $A$, $B$ and $C$ respectively. This enables a ready alteration to be made in the sequence in which the selectors $SE_i$, $SE_i$, and $SE_i$ are set and thus to alter the sequence of switches on the response board $RB$, corresponding to the sequence of lamps lit up through the uniselecter bank $U_i$. When the switches $SW_3$, $SW_1$, and $SW_2$, are in the other position from that shown, the co-ordinator is of course no longer set up as in the example described above.

The three selectors $SE_i$ are themselves identical and in Fig. 6 the selector $SE_i$ is shown connected to the store $ST_i$. The selector $SE_i$ has an input terminal 27 connected to the switch $SW_2$ and eight output terminals 30 connected to one
terminal of the eight capacitors $e_1$ to $e_8$ respectively, the other terminals of the capacitors being connected to earth. In dependence on the setting of the relays A, B and C the input terminal 27 to $e_i$ through sets of relay contacts A3, B5, B6, C9, C10, C11 and C12 arranged as shown. Thus when the uniselector arm is in the position shown in Fig. 5, that is the position $p_2$, and the switches $SW_3$, $SW_4$ and $SW_5$ are in the setting shown in Fig. 5, the relays A, B and C are all de-energised. The terminal 27 is then connected to capacitor $e_i$, corresponding to the lamp $k_i$, which is on in position $p_2$ (Fig. 4).

When the uniselector arms are in the next position $p_3$, the lamp $k_i$ is on as will be seen from Fig. 4 and the relay A is energised and the relays B and C are de-energised (Fig. 5).

Thus, as will be seen from Fig. 6, the capacitor $e_i$ is connected to the terminal 27. The selector SE has an input terminal 25 (Fig. 2) connected to a +25 volt line, eight output terminals 28 (Fig. 7) connected to eight input terminals 31 of the terminal block TB. (Fig. 7) and sets of relay contacts A1, B1, C1, C2, C3, C4, (not shown, as the selector SE is constructionally the same as the selector SEi) corresponding to the sets of relay contacts A3, B5, B6, C9, C10, C11 and C12 (Fig. 6).

Referring to Fig. 8, the selector SE has an input terminal 26 connected to the output of the modulator MD, (Fig. 16), eight output terminals 29 connected to eight input terminals 35 of the terminal block TB, and sets of relay contacts A2, B3, B4, C5, C6, C7 and C8 (not shown, as the selector SE is constructionally the same as the selector SEi) corresponding to the sets of relay contacts A3, B5, B6, C9, C10, C11 and C12 (Fig. 6).

Thus referring to Fig. 7 the output terminals 28 of the selector SE are shown connected to the input terminals 31 of the terminal block TB, which has eight output terminals 32 connected respectively to one set of fixed contacts of eight two-pole, one-way press-button switches, namely the switches $s_i$ to $s_8$. The connections in the permutor PE and the terminal board TB, are such that when the lamp $k_i$ is lit up the 25-volt line is connected through the input terminal 25 (Fig. 2) of the selector SE, to the fixed contact of the switch $s_i$, when the lamp $k_i$ is lit up the connection is to the fixed contact of the switch $s_i$ and so on.

The set of movables contacts associated with the said one set of fixed contacts of the switches $s_i$ to $s_8$ are connected together to an output terminal 35. The other set of movable contacts of the switches $s_i$ to $s_8$ is connected to a +25 volt line and the other set of fixed contacts of the switches is connected to an output terminal 34. Thus the terminals 33 and 34 are dead when no switch is pressed. When any switch is pressed the terminal 34 is at a potential of +25 volts and when a correct switch only is pressed the terminal 33 is at a potential of +25 volts.

In Fig. 8 the output terminals 29 of the selector SE are shown connected to the input terminals 35 of the terminal block TB, which has eight output terminals 36 connected to one terminal each of the eight lamps $m_1$ to $m_8$, constituting the display DS. The other terminal of each of the lamps is connected to earth. The connections in the block TB, are the same as those in the block TB. Thus when the switch $s_i$ is the correct one to be pressed the output of the modulator MD, is connected to the lamp $m_i$, when the switch $s_i$ is the correct switch to be pressed the output of the modulator MD, is connected to the lamp $m_i$, and so on.

The terminals 33 and 34 (Fig. 7) are connected to two input terminals 63 and 64 respectively of the marking relays shown in Fig. 9, these terminals being connected respectively at one end of the windings of two relays E and F respectively. The other ends of the windings of the relays E and F are connected together to a -25 volt line, through a set of relay contacts L1 of a relay L.

A set of relay contacts N4 of a relay N (Fig. 11) is connected in series with a set of relay contacts F1 and a set of changeover relay contacts E1, between the +25 volt line and one end of the winding of each of two relays G and H, the other ends of the windings of which are connected to a -25 volt line. The said one end of the winding of the relay G is also connected through a set of relay contacts G1 and a set of relay contacts G3 (of the relay N (Fig. 11)) to the -25 volt line and the one end of the winding of the relay H is also connected through a set of relay contacts H1 and the set of relay contacts N3 to the +25 volt line.

For the duration of each interval $\Delta t$ (Fig. 3) the relay N (Fig. 11) is energised, as will hereinafter be described, and the sets of relay contacts N3 and N4 are closed. If a switch on the board RB, is pressed the relay F is energised since the terminal 64 is then at a potential of +25 volts. The set of contacts F1 is closed in consequence and either the relay G or the relay H is energised, depending on whether the switch pressed is correct or not. If the switch pressed is incorrect or not of contacts E1 remains as shown and the relay G is energised and if correct the relay E is energised since the terminal 63 is then at a potential of +25 volts, and the set of contacts E1 changes over so that the relay H is energised. The relay F is a slow-to-make relay in order that the set of relay contacts E1 shall have time to change over before the contact F1 closes if a correct response is made.

The relays G and H are self-holding by the
sets of contacts G1 and H1. Thus assuming, as before, that in the position p1 (Fig. 3) a correct response is made at time t5, the relay H is energised and remains energised until the time t6, when the relay N is de-energised and the sets of contacts N3 and N4 are opened. The relay H will thus remain energised during the interval δt6.

If (as already assumed) an incorrect response is made in the position p2.41 at time t5, the relay G is energised and remains energised until the time t6, that is during the interval δt6.41.

In order that only one response may be effectively made in any position of the co-ordinator, the relay L has its winding connected in series with sets of relay contacts G2 and H2 in parallel between the +25 and −25 volt lines. While either of the relays G or H is energised the relay L is energised and the set of contacts L1 is open. No further inputs can then be provided to the relays E and F by pressing any of the switches of the response board RB3.

The lamp 37 and the lamp 38 are connected in series with a set of relay contacts G3 and a set of relay contacts H3, respectively, between the +25 volt line and the −25 volt line. Thus when a correct response is made the lamp 38 lights up and when an incorrect response is made the lamp 37 lights up, indicating to the operator whether his response is correct or incorrect.

Referring now to Fig. 10, the marking computer MC comprises two triodes V4, V5. The triode V4 has its anode connected to a +350 volt line through a load resistor R1 and its cathode connected to earth. The control grid of the triode V4 is connected to earth through a resistor R5 and a capacitor C5, in series and directly to earth through a set of changeover relay contacts G4 when the relay G (Fig. 9) is de-energised. When the relay G is energised the grid is connected to the cathode of a triode V5. The triode V5 acts as a cathode follower, having its anode connected directly to the +350 line, its grid connected through a resistor R6 to the anode of the triode V4, and its cathode connected through two resistors R6 and R7 in series to a −150 volt line.

The grid of the triode V4 is connected through a resistor R8 and a set of changeover relay contacts H4 of the relay H to the junction of the resistors R8 and R9 when the relay H is de-energised and to the junction of two resistors R8 and R9 connected in series between earth and the −150 volt line when the relay H is energised. The grid of the triode V5 is also connected to earth through a capacitor C6. The triode V5 acts as a cathode follower, its anode being connected directly to the +350 volt line and its cathode being connected to earth through a resistor R6, and to the −150 volt line through a resistor R8 in parallel with two resistors R9 and R10, in series.

The variable θ is represented by the potential on the cathode of the triode V5. With the sets of contacts G4 and H4 in the position shown, that is when no response has been made, the input to the triode V5 is held at earth potential and the junction of the resistors R8 and R9 is at a steady negative potential, say E8. The capacitor C6, assumed to be initially charged as will appear hereinafter, discharges through the resistors R6 and R7 and thus the value of θ decreases. When a correct response is made the relay H is operated and the capacitor C6 is connected through the resistor R5 to the junction of the resistors R6 and R7, which junction is at a higher steady potential, say E9, than the steady potential E8. Thus the capacitor C6 charges up and θ increases, relatively quickly when θ is low and relatively slowly when θ is high. This increase in θ occurs for the duration of the interval δt6, at the end of which the relay N is energised and the relay H is de-energised.

When an incorrect response is made the relay H remains de-energised and the capacitor C6 is connected through the resistor R5 to the junction of the resistors R6 and R7, but the potential of this point is made lower than E8 by feeding back θ through the operated contacts G3 to the grid of the triode V4. θ is represented by a positive potential and thus the triode V4 is caused to conduct more and the triode V5 to conduct less. The extent to which this occurs depends on the value of θ and an error has a greater effect when θ is high, that is when the operator has been doing well, than when θ is low, that is when the operator has been doing badly.

The cathode of the triode V5, is also connected through a resistor R11 to the grid of a triode V6. This grid is also connected through a resistor R12, to the junction of two resistors R13 and R14. A variable resistor R20 and the resistors R15 and R16 are connected in series between earth and the −150 volt line. The cathode of the triode V5 is connected to a variable tap on the resistor R19 and the anode of the triode V5 is connected to a terminal 39. The triode V6 acts as a variable resistance passing a relatively large current when θ is high and a relatively low current when θ is low.

Four terminals 40, 41, 42 and 43 for connection through the access controller AC (shown in Fig. 14) to the store ST; or the store ST2 (as indicated in the block diagram in Fig. 2) are connected respectively to a variable tap on the resistor R19, the junction between two resistors R13 and R14 connected in series between earth and the −150 volt line, a variable tap on the resistor R18, and the junction of the resistors R15 and R16. The terminal 40 is connected to the terminal 45 through a resistor R17. A terminal 126 con-
connected to the cathode of the triode $V_6$. It is not used in this embodiment, but is used in the Type II coordinator to be described later.

The terminal 39 is connected to an input terminal 44 of the waveform generator WG shown in Fig. 11, the terminal 44 being connected to the grid of a triode $V_6$ and through a capacitor $C_6$ to the cathode of the triode $V_6$. The triode $V_6$ also has its grid connected to its cathode through a resistor $R_{6x}$ in series with a set of relay contacts $N1$ which is open when the relay $N$ is energised. The cathode of the triode $V_6$ is connected to the junction of two resistors $R_{6t}$ and $R_{6u}$ connected in series between the +350 volt line and earth.

The anode of the triode $V_6$ is connected to the +350 volt line through a resistor $R_{6s}$ and to the grid of a triode $V_6$ through a resistor $R_{6t}$. The triode $V_6$ functions as a cathode follower and has its anode connected direct to the +350 volt line and its cathode connected to earth through a resistor $R_{6s}$.

The cathode of the triode $V_6$ is connected to an output terminal 46 for connection to the corrector computer $C_6$, and through a resistor $R_{6t}$ to the grid of a triode $V_6$, which together with a triode $V_6$, resistors $R_{6s}, R_{6t}, R_{6u}$ and a relay $M$ connected together as shown constitutes a Schmitt trigger circuit of conventional type. The winding of the relay $M$ constitutes the anode load of the triode $V_6$, and the resistor $R_{6t}$ is variable for controlling the backlash of the circuit.

The relay $M$ is energised when the waveform $V_{in}$ (Fig. 3) reaches the trigger level $V_t$.

The grid of the triode $V_6$ is connected to the −150 volt line through a resistor $R_{6u}$ and to a terminal 45 through a resistor $R_{6t}$. The grid of the triode $V_6$ is connected to the junction of two resistors $R_{6t}$ and $R_{6u}$ connected in series between earth and the −150 volt line, through the resistor $R_{6u}$ and a resistor $R_{6t}$ in series.

The terminal 45 is connected to a terminal 47 of the voltage reader $VR$ (Fig. 13). Thus the instant at which the Schmitt trigger circuit changes state depends upon the potential on the terminal 47 of the voltage reader $VR$, and hence on the terminal 45, and upon the potential on the cathode of the triode $V_6$, which latter potential in turn depends on the charge on the capacitor $C_6$.

Thus when $\theta$ is high and the triode $V_6$, (Fig. 10) passes a relatively large current, the capacitor $C_6$ charges relatively rapidly, driving the grid of the triode $V_6$ in a negative direction and thus causing the potential on the cathode of the triode $V_6$ to rise relatively rapidly.

When the potential on the grid of the triode $V_6$ is above the potential on the grid of the triode $V_6$, the triode $V_6$ is conducting and the triode $V_6$ is non-conducting and conversely. When the triode $V_6$ is conducting the relay $M$ is energised. Thus during each interval $\Delta t$, the relay $M$ is de-energised. Each interval $\Delta t$ is terminated when the potential on the grid of the triode $V_6$ rises to the potential of the grid of the triode $V_6$, and the relay $M$ is energised.

When the relay $M$ operates a set of changeover contacts $M_1$ (Fig. 11) which connects one terminal of a capacitor $C_6$ to the +350 volt line through a resistor $R_{6u}$, when the relay $M$ is energised and to earth through a resistor $R_{6t}$ when the relay is de-energised. The other terminal of the capacitor $C_6$ is connected to earth through a resistor $R_{6u}$ and to the grid of a triode $V_6$ through a capacitor $C_6$ and a rectifier $X_l$ in series. The grid of the triode $V_6$ is connected to earth through a resistor $R_{6u}$.

The triode $V_6$ together with a triode $V_{10}$, resistors $R_{6u}, R_{6t}$ and $R_{10}$, a capacitor $C_6$ and the relay $N$ connected together as shown constitutes a Kipp relay of conventional type.

The winding of relay $N$ constitutes the anode load of the triode $V_{10}$.

The relay $M$ is de-energised in each interval $\Delta t$, and accordingly the capacitor $C_6$ is discharged through the resistors $R_{6u}$ and $R_{6u}$.

When the relay $M$ is energised the capacitor $C_6$ is charged through the resistors $R_{6u}$ and $R_{6u}$ and a positive pulse is applied to the grid of the triode $V_6$.

The triode $V_6$ then conducts and the triode $V_{10}$ is rendered non-conducting for a short interval, which is the interval $u$ in Fig. 3, and is of a duration determined by the constants of the Kipp relay. The relay $N$ is de-energised in this interval.

The waveform $V_{in}$ of Fig. 3 may now be discussed in more detail. It is the potential on the grid of the triode $V_6$ and the trigger levers $V_t$ and $V_{t,1}$ are potentials on the grid of the triode $V_6$.

When the potential $V_{in}$ has risen to the level $V_t$ at time $t_2$, the Schmitt trigger circuit changes state and the relay $M$ is energised. The length of time $\Delta t$, taken for this to occur (measured from the instant when the relay $N$ is energised and the set of relay contacts $N1$ closed, at which instant the waveform $V_{in}$ begins to rise from the level $V_t$) depends both on $V_t$ and the rate of increase of $V_{in}$ which depends on $\theta$.

When the relay $M$ is energised, an input pulse is applied to the Kipp relay and the relay $N$ is de-energised for a fixed interval $u$ beginning at time $t_2$ and ending at time $t_4$. The set of relay contacts $N_2$ is closed during this interval and the capacitor $C_6$ is discharged causing the potential on the cathode of the triode $V_6$ to fall. The relay $M$ is thus rapidly de-energised again.

Referring to Fig. 12 the unselector control $UC_6$ is shown, comprising an unselector coil 49 connected in series with a set of relay contacts $N2$ between the +25 volt line and the −25 volt line. When the relay $N$ is de-energised, that is during the interval $u$ the contact $N2$ is closed and the coil 49 is energised.
ged drawing back the ratchet (not shown) of the unisector. When the relay N is again energised the coil 49 is de-energised and the ratchet released to step the unisector on to the next position.

Referring to Fig. 13 which shows the voltage reader VR, an input terminal 50 is connected to the movable contact of the switch SW₁ (Fig. 2) and thus to either the store ST₁ or the store ST₄, and to an output terminal 51 of the access controller AC₁ (Fig. 15). The voltage reader VR comprises a triode V₁₂ acting as a cathode follower, its grid being connected through a resistor R₁₁ to the terminal 50, its anode direct to the +350 volt line and its cathode to earth through a resistor R₆₀ and to the −150 volt line through a resistor R₆₇. The cathode of the triode V₁₂ is connected to the terminal 47 already referred to through a resistor R₇₇. The capacitors of the store ST₁ or ST₄ are negatively charged, holding a relatively large negative charge when they are associated with a lamp or position in response to which there has been a high previous degree of success. The larger the negative charge, the lower the potential of the terminal 47, and hence of the terminal 45 of the waveform generator (Fig. 11), the potential on which terminal is the trigger level of the Schmitt trigger circuit.

The store ST₁ has already been described in detail. The store ST₄ is shown in Fig. 14. The wiper of the unisector bank V₁₃ is connected to one terminal of the switch SW₂ as previously described. The twelve output terminals 48 of the unisector are numbered p₁ to p₁₂, corresponding to the twelve positions of the sequence and are connected to one terminal of the twelve capacitors f₁ to f₁₂ respectively, the other terminals of which are connected to earth.

The charges on the capacitors of whichever store is in use are determined by the potentials on the terminals 40, 41, 42 and 43 of the marking computer (Fig. 10) and a set of resistors R₅₀, R₅₁, R₅₂ and R₅₃ and sets of relay contacts G₅ to H₅ of the access controller AC₁ (Fig. 15). The resistors R₅₀ to R₅₃ are connected between four terminals 53 to 56 and the sets of relay contacts as shown and the terminal 51 is connected to the resistor R₅₄. The terminals 53 to 56 are connected to the terminals 40 to 43 respectively. Thus the terminal 51 is permanently connected through the resistor R₅₄ to the junction of the resistors R₅₁ and R₅₂ of Fig. 10. In intervals when no response has been made and in intervals δ₅ following an incorrect response the terminal 51 is also connected through the sets of contacts H₅ and the resistor R₅₄ to the junction of the resistors R₅₃ and R₅₉ and in intervals δ₆ following an incorrect response also through the sets of contacts G₅ and the resistor R₅₅ to the movable contact on the resistor R₅₆. In periods δ₇ following a correct response in addition to the aforesaid permanent connection the terminal 51 is connected through the set of contacts H₅ and the resistor R₅₆ to the movable contact on the resistor R₅₇. The values of the resistor R₅₇ to R₅₉ and the potentials of the points to which the terminals 40 to 43 are connected are so chosen that the capacitor connected to the terminal 51 normally loses negative charge at a relatively slow rate (through the resistors R₅₇ and R₅₈), loses negative charge at a relatively fast rate in intervals δ₅ following an incorrect response and gains negative charge at a relatively fast rate in intervals δ₆ following a correct response. The movable contacts on the resistors R₅₇ and R₅₉ enable the effects which an incorrect and a correct response respectively have on the charge on a capacitor of the store ST₁ or ST₄ to be varied.

In Fig. 16 there is shown the corrective information computer CI which has an input terminal 57 connected to the output terminal 47 of the voltage reader VR (Fig. 13) and an input terminal 58 connected to the terminal 46 of the waveform generator WGC (Fig. 11). The potentials on these two input terminals 57 and 58 are combined in an adding network of resistors R₇₇, R₉₄ and R₈₉ and applied to the grid of a triode V₁₁. The triode V₁₁ acts as a cathode follower and has its anode connected to the +350 volt line and its cathode connected to the −150 volt line through a resistor R₆₇. An output terminal 59 is connected to the cathode of the triode V₁₂ through a resistor R₆₇. The potential on the terminal 57 is the trigger level V₆₇ and the potential on the terminal 58 is the rising potential on the cathode of the triode V₁₁ (Fig. 11). Thus the output at the terminal 59 in each interval δ₅ is a potential rising at a rate determined by the voltage reader VR, as previously described.

The output terminal 59 is connected to an input terminal 60 of the modulator MD (Fig. 17). The input terminal 60 is connected to the grid of a triode V₂₄ having its cathode connected to earth and its anode connected through a resistor R₆₉ to the primary winding of an output transformer Tₐ and the secondary winding of a mains transformer Tₑ to earth. Thus the current flowing through the terminal 61 is an alternating current modulated by the rising output at the terminal 59 of the corrective information computer CI (Fig. 16). The terminal 61 is connected to the input terminal 26 of the selector SE₄ and to one fixed contact of the switch SW₄.

In a modification (not shown) of the coördinator both the stores ST₁ and ST₄ are used together and the voltage reader VR determines a trigger level dependent on the...
added effects of an element of the store $ST_1$ and an element of the store $ST_2$. Thus, for example, in the position $p_1$, the input to the voltage reader $VR$ and thus the trigger level $V_t$ is determined by the quantities stored on the element $f_1$ and the element $e_r$.

It will be appreciated that an exact description of the way in which the system comprising the operator and the coordinator reaches a state of dynamic equilibrium is not possible. However, to conclude this description of the Type I coordinator the complete sequence of operations in the positions $p_1$ will be described, assuming here that $p_1 = p_2$.

Thus referring to Fig. 3, at time $t_1$ the relay $N$ is energised. The set of contacts $N_2$ open and the uniselecter control UC moves on the uniselecter banks $U_1$ to $U_2$ from the position $p_1$ to the position $p_2$. The set of contacts $N_1$ open and the waveform $V_m$ starts to rise from the level $V_n$ at a rate dependent on the value of $\theta$ then obtaining. At the same time the sets of contacts $N_3$ and $N_4$ close and allow the relays of the response board RB, to function.

The lamp $h_1$ slowly lights up (the switch SW being assumed to be in the setting shown in Fig. 2) and the lamp $m_r$ also slowly lights up indicating directly that the switch $s_r$ is the correct switch to be pressed. At time $t_2$ the operator presses the correct switch, namely $s_r$ and the relays $E$ and $F$ are energised. The set of contacts $E_1$ changes over and subsequently the set of contacts $F_1$ close. Accordingly the relay $H$ is energised. The set of contacts $H_1$, $H_2$ and $H_3$ close, holding on the relay $H_4$, energising the relay $L$ and lighting up the lamp $38$ respectively. The relay $L$ opens the set of contacts $L_1$ and the relays $E$ and $F$ cannot again be energised until $H$ has been de-energised.

The set of contacts $H_4$ changes over and the value of $\theta$ is caused to increase at a relatively rapid rate. Furthermore the set of contacts $H_5$ changes over and negative charge is added to the capacitor $e_r$ of the store $ST_1$ or the capacitor $f_1$ of the store $ST_2$, depending on the setting of the switch SW. The trigger level $V_t$ is determined by the potential across either the capacitor $e_r$ or the capacitor $f_1$, as the case may be and when the waveform $V_m$ reaches this level, at time $t_3$, the relay $M$ is energised.

This terminates the position $p_2$, the relay $N$ being de-energised. The set of contacts $N_1$ closes, causing the waveform $V_m$ to fly back to the level $V_n$. The set of contacts $N_2$ sets the uniselecter control, ready to move on the banks $U_1$ to $U_2$, to the position $p_3$ after the interval $\alpha$ at time $t_4$. The sets of contacts $N_3$ and $N_4$ open and the marking relays, including the relay $H$, are all de-energised.

The sequence of events is similar, mutatis mutandis, in the position $p_3$ in which an incorrect response is made at time $t_4$.

Turning now to the example of a Type II coordinator, Fig. 19 shows diagrammatically the lamps displayed to the operator and the press button switches to be pressed by the operator. In this embodiment the coordinator operates in a sequence of twelve positions, which will again be referred to as $p_1$ to $p_{12}$ and in each position $p_i$ a general lamp $h_n$ of twelve lamps $h_1$ to $h_{12}$ lights up. These lamps constitute a display $DS_1$. At the end of each position $p_i$ there is again a short fixed moving interval of duration $u$ before the start of the next position $p_{i+1}$.

As previously explained, in a Type II coordinator the form in which responses have to be made differs from that in which signals are given. The responses are made by pressing one of three row switches, $s_{r_1}$, $s_{r_2}$ and $s_{r_3}$, and (not necessarily simultaneously) one of four column switches $s_{c_1}$, $s_{c_2}$, $s_{c_3}$ and $s_{c_4}$. A full response is made only when one row and one column switch has been pressed. The row and column switches together constitute a response board RB. Each combination of one row switch and one column switch defines one of an array of twelve translucent screens $n_1$ to $n_{12}$. These bear distinguishing symbols, which are not however shown, in order not to confuse the figure. By way of example, the switches $s_{r_1}$ and $s_{c_1}$ define the screen $n_1$. A one-to-one correspondence is set up between the twelve lamps $h_1$ to $h_{12}$ and the twelve screens $n_1$ to $n_{12}$.

Thus as in the description of the Type I coordinator an example of the way in which the coordinator may be set up is given in Table I and the Type II coordinator will be described as set up in this way.
Corrective information is supplied to the operator by three row lamps \( m_{r_1}, m_{r_2}, \) and \( m_{r_3} \) and four column lamps \( m_{c_1}, m_{c_2}, m_{c_3} \), and \( m_{c_4} \), constituting a second display \( D_S'' \). A lamp 100 lights up when a correct response is made and lamp 101 when an incorrect response is made. A response is deemed incorrect when either an incorrect row or column switch is pressed or when both switches pressed are wrong.

In addition the coordinator has a third display \( D_S'' \), comprising twelve lamps \( m_{n_1}, m_{n_2}, \) to \( m_{n_{12}} \), the lamp \( m_{n_1} \), being under the screen \( n_1 \), the lamp \( m_{n_2} \), under screen \( n_2 \), and so on.

In the interval \( t \) following the end of a position \( p_i \) the lamp of the display \( D_S'' \), under the screen which should have been defined by a row and a column switch for a correct response lights up. Thus the operator, in cases where he makes an incorrect response or no response, is supplied with information as to the response he should have made. This information is of course different from the corrective information supplied by the display \( D_S \), as it is never supplied early enough to help the operator make a correct response in the position in which the coordinator then is.

The operation of the coordinator will now be contrasted with the operation of the Type I coordinator, with reference to Fig. 20.

Again a marking variable \( \theta \) normally decreases slowly, decreases relatively rapidly when an incorrect response is made (whether it be a row or a column response) until the end of the position in which the incorrect response is made and increases relatively rapidly when a completely correct response is made until the end of the position in which the completely correct response is made. Thus two consecutive positions \( p_i \) and \( p_{i+1} \) are again shown, starting at \( t_{i_1} \) and \( t_{i_2} \), respectively, and ending at \( t_{i_3} \) and \( t_{i_4} \), respectively. In the position \( p_i \) a correct row response is assumed to be made at time \( t_{i_1} \) and a correct column response at time \( t_{i_2} \), \( \theta \) accordingly increases from \( t_{i_1} \) to \( t_{i_2} \). In the position \( p_{i+1} \) an incorrect row response is assumed to be made at time \( t_{i_3} \) and a correct column response at time \( t_{i_4} \), \( \theta \) accordingly decreases relatively rapidly from \( t_{i_3} \) to \( t_{i_4} \).

Again the duration of the positions \( p_i \) is determined by a waveform \( V_m \) which rises at a rate dependent on \( \theta \) to a trigger level \( V_t \), which is, however, fixed in the Type II coordinator. Thus the increase in the rate of operation of the coordinator is a general increase as \( \theta \) increases, and not a "patterned" increase as in the case with the Type I coordinator.

Because in the Type II coordinator there are two marking categories, that is a row category and a column category (the operator may make a correct or incorrect response in either category), it is not satisfactory to measure intervals of time corresponding to the intervals of time \( \delta t_i \) (Fig. 3) from the instant at which a response is made to the end of the position in which the response is made. Accordingly in each position \( p_i \) two further instants of time are defined by two subsidiary trigger levels \( V_{L_{10}} \) and \( V_{L_{10}} \) and will be called the row limit time and the column limit time respectively. These two times are at \( t_{i_1} \) and \( t_{i_2} \) in the position \( p_i \) and at \( t_{i_3} \) and \( t_{i_4} \) in the position \( p_{i+1} \).

These two trigger levels are determined by two stores \( S_R \) and \( S_C \), respectively, each comprising, as will be described, twelve capacitors storing negative charges whose magnitude is a measure of the previous degree of success averaged over a number of sequences in making a row response or a column response as the case may be, in each position \( p_i \). Apart from the slow leakage of charge occurring from the capacitors, the charge on a row capacitor is only altered in an interval between a row response (e.g. \( t_{i_1} \)) and the row limit time (e.g. \( t_{i+1} \)) and then only if the row response is made before the said time.
an alteration in the negative charge is made, it is increased in magnitude if the response is correct and decreased in magnitude if the response is incorrect. Similar remarks, mitatis mutandis, apply to column responses.

Thus referring again to Fig. 20, in the position \( p_1 \) no alteration is made in the charge of the row capacitor because although a correct row response is made (at time \( t_{e1} \)) it is not made before the time \( t_{e1} \). The magnitude of charge on the column capacitor is increased in an interval \( \delta t_{e2} \) beginning at time \( t_{e1} \) at which a correct column response is made and ending at the column limit time \( t_{e2} \). In the position \( p_{15} \) the magnitude of the charge on the row capacitor is decreased in an interval \( \delta t_{e4} \) following the incorrect row response at time \( t_{e4} \) and the magnitude of the charge on the column capacitor is increased in an interval \( \delta t_{e6} \) following the correct column response at time \( t_{e6} \).

Thus trigger levels \( V_{c1} \) and \( V_{c4} \) are determined by the charge on the row and column capacitors, respectively, associated with the position \( p_1 \), the levels being relatively low when the charge is of relatively great magnitude.

Furthermore the corrective information given to the operator by the display DS is withdrawn in a “patterned” manner dependent on the charges on the capacitors of the two stores in a manner essentially the same as that in the Type I coordinator.

Referring now to the block circuit diagram Fig. 21, the twelve positions of the coordinator are determined by an eight bank, twelve position unisector having banks \( U_1 \) to \( U_{12} \) controlled by a unisector control \( U_{C1} \).

The first bank \( U_1 \) feeds the display DS through a terminal block \( T_B \) and determines which lamp of the display DS lights up in each position. The intensity with which the lamp lights up and the intensity of a background illumination of all the lamps, which causes ambiguity in the instructions to the operator, are determined by an “ambiguity modulator” \( \Delta M \). When \( \theta \) is high the intensity of the background illumination is made high and vice versa. The intensity of the selected lamp is arranged to increase from a level proportional to the average value of \( V_{c1} \) and \( V_{c4} \) in the position \( p_1 \). Thus as the operator progresses the coordinator gives him instructions in an increasingly ambiguous fashion. Moreover this increases in ambiguity is “patterned” in the sense used above.

The unisector bank \( U_1 \) feeds the display DS through a terminal block \( T_B \) and determines which lamp of this display lights up.

The selected lamp lights up in the interval \( n \) after a position \( p_1 \) since the wiper of the unisector bank is connected to a source of potential through a set of relay contacts \( N_\alpha \) of a relay \( N_\alpha \) (Fig. 24) which is closed in the intervals \( n \), as will be described hereinafter.

The unisector banks \( U_1 \) and \( U_2 \) feed the response board \( R_B \), (constituted by the switches \( S_1 \) to \( S_9 \) and \( S_{10} \) to \( S_{12} \)) through two terminal blocks \( T_B \) and \( T_B \), respectively.

The output from the response board \( R_B \) is fed to a set of marking relays \( M_R \) which controls the state of a marking computer \( M_C \), which is in essence the same as that described for the Type I coordinator, and which computes the variable \( \theta \) from its state.

One output from the marking computer goes to a waveform generator \( W_G \) generating the waveform \( v_{w} \) (Fig. 20) and controls the rate of rise of the waveform \( v_{w} \) in each position \( p_1 \). The waveform generator controls the unisector control \( U_{C1} \) in the same way as the generator \( W_G \) controls \( U_{C1} \) in the Type I coordinator.

Another output from the marking computer is fed through an access controller \( A_C \) and the unisector bank \( U_{12} \) to the store \( S_T \) and through an access controller \( A_C \) and the unisector bank \( U_{12} \) to the store \( S_T \). The access controllers \( A_C \) and \( A_C \) are in essence the same as the access controller \( A_C \) of the Type I coordinator, but the state of the access controller \( A_C \) is determined by two relays of the marking relays \( M_R \) one of which, as will hereinafter be described, is energised in any interval \( \delta t_{e1} \) in the position \( p_1 \), which of the relays is energised depending on whether the interval \( \delta t_{e1} \) is initiated by a correct or an incorrect response. Likewise the state of the access controller \( A_C \) is determined by two relays of the marking relays \( M_R \) one of which, as will hereinafter be described, is energised in any interval \( \delta t_{e1} \) in the position \( p_1 \).

Two voltage readers \( V_R \) and \( V_R \) are in essence the same as the voltage reader \( V_R \) of the Type I coordinator and have their inputs connected to the stores \( S_T \) and \( S_T \), respectively through the unisector banks \( U_{13} \) and \( U_{13} \), respectively. The outputs from the voltage readers \( V_R \) and \( V_R \) are the trigger levels \( V_{c1} \) and \( V_{c4} \) respectively and are fed to the waveform generator \( W_G \), to the ambiguity modulator \( \Delta M \) and to a corrective information computer \( C_I \) and a corrective information computer \( C_I \), respectively.

The corrective information computers \( C_I \) and \( C_I \) are in essence the same as the corrective information computer \( C_I \) of the Type I coordinator and add the trigger levels \( V_{c1} \) and \( V_{c4} \) respectively (obtained from the voltage readers \( V_R \) and \( V_R \), respectively) to the waveform \( v_{w} \) obtained from the waveform generator \( W_G \). The outputs from the corrective information computer \( C_I \) and \( C_I \) are fed to a modulator \( M_D \) and a modulator \( M_D \) respectively. The modulators \( M_D \) and \( M_D \) are in essence the same as the modulator \( M_D \) of the Type I coordinator and their outputs are fed to the display DS through the unisector banks \( U_{12} \) and \( U_{12} \).
respectively and terminal boards TB₁ and TB₂ respectively.

The display DS₂ is also controlled by two relays of the waveform generator WG₂ which allows the row lamps m₁ to m₉ to light up only after the row limit time and the column lamps m₁ to m₉ to light up only after the column limit time.

The ambiguity modulator AM₂ is connected to the outputs of the voltage readers VR₁ and VR₂ and to outputs of the marking computer MC₂ and the waveform generator WG₂, and controls the lamps of the display DS₂ in the manner hereinbefore described, in response to the input signals thus obtained.

Considering now the detailed construction of the coordinator and referring first to Fig. 22, twelve output terminals 102 of the unisector bank U₂ are connected respectively to twelve input terminals 103 of the terminal block TB₂. The twelve lamps h₁ to h₁₂ of the display DS₂ are connected in series with twelve resistors Rₓ to R₁₂ respectively between earth and a terminal 104. Twelve output terminals 105 of the terminal block TB₂ are connected to the junctions respectively of the lamps h₁ to h₁₂ and the resistors Rₓ to R₁₂.

When a potential is applied to the terminal 104 (from the ambiguity modulator AM₂—Fig. 28), all the lamps h₁ to h₁₂ light up with a background illumination. A suitable potential applied to the wiper of the blank U₁ (from the ambiguity modulator AM₂) causes one lamp to light up with a greater intensity than the others, this lamp indicating the response which is to be made. As will be seen, the connections in the terminal block TB₂ are such that in each position p₁ the lamp hₙ which lights up with a greater brightness is that shown in Table I. In the position shown, namely p₁₉, this lamp is h₉.

Referring to Fig. 23, the wiper of the unisector bank U₂ is connected through the set of relay contacts Na₁ to the +25 volt line. The twelve outputs 106 of the bank U₂ are connected to twelve input terminals 107 respectively of the terminal block TB₂. Twelve output terminals 108 of which are connected to one terminal of the twelve lamps m₁ₙ to m₁₉ respectively of the display DS₂. The other terminals of these lamps are connected to earth.

It will be seen that for the duration of an interval n following a position p₁, whilst the set of relay contacts Na₁ is closed, the lamp of the display DS₂, which is under the screen nₙ corresponding to the position p₁ lights up (Table I). Thus following the position p₁, the lamp mₙ lights up. In this connection it will be appreciated that, as in the Type I coordinator the unisector steps on from a position p₁ to a position p₁₊₁ at the beginning of the position p₁₊₁.

Referring now to Fig. 24 the same principle is used to energise the switches of the response board RB₂, as is used in the Type I coordinator, although a "permutator", a set of "control relays" and a "selector" are not used, the upper half of each of the row switches s₁ to s₉ being connected to the +25 volt line through the unisector bank U₂ and the terminal block TB₂. The response board RB₂ has four output terminals 109, 110, 111 and 112. As will be seen from the diagram these terminals are energised under the following conditions: terminal 109 when any row switch is pressed, terminal 110, when a correct row switch is pressed, through the unisector U₂, terminal 111, when any column switch is pressed, and terminal 112, when a correct column switch is pressed, through the unisector U₂.

The terminals 109, 110, 111 and 112 are connected to four input terminals 113, 114, 115 and 116 respectively of the marking relays MR shown in Fig. 25. As will be seen from this figure a set of row relays Er, Fr, Gr, Hr and Lr and a set of column relays Er, Fr, Gr, Hc, Hr and Lc both in essence duplicate and function in like manner to the set of relays E, F, G, H and L of the Type I coordinator (Fig. 9). Thus the relay Gr is energised through the sets of contacts Na₂, Fr₁ and Er₁ in an interval beginning with an incorrect row response in the position p₁ and ending with the end of the position p₁. Likewise the relay Hr is energised through the sets of contacts Na₂, Fr₁ and Er₁ in an interval beginning with a correct row response in the position p₁ and ending with the end of the position p₁. However the lamp 101 indicating a correct response (corresponding to the lamp 37 in Fig. 9) is connected in series with sets of relay contacts Hr₄ and Hc₄ and is alight only in an interval beginning with the later response of both a correct row response and a correct column response and ending with the end of the position p₁. It will be appreciated that, as in the Type I coordinator, the unisector steps on from a position p₁ to a position p₁₊₁ at the beginning of the position p₁₊₁.

It will be seen that for the duration of an interval n following a position p₁, whilst the set of relay contacts Na₁ is closed, the lamp of the display DS₂, which is under the screen nₙ corresponding to the position p₁ lights up (Table I). Thus following the position p₁, the lamp mₙ lights up. In this connection it will be appreciated that, as in the Type I coordinator the unisector steps on from a position p₁ to a position p₁₊₁ at the beginning of the position p₁₊₁.

Referring now to Fig. 24 the same principle is used to energise the switches of the response board RB₂, as is used in the Type I coordinator, although a "permutator", a set of "control relays" and a "selector" are not used, the upper half of each of the row switches s₁ to s₉ being connected to the +25 volt line through the unisector bank U₂ and the terminal block TB₂. The response board RB₂ has four output terminals 109, 110, 111 and 112. As will be seen from the diagram these terminals are energised under the following conditions: terminal 109 when any row switch is pressed, terminal 110, when a correct row switch is pressed, through the unisector U₂, terminal 111, when any column switch is pressed, and terminal 112, when a correct column switch is pressed, through the unisector U₂.

The terminals 109, 110, 111 and 112 are connected to four input terminals 113, 114, 115 and 116 respectively of the marking relays MR shown in Fig. 25. As will be seen from this figure a set of row relays Er, Fr, Gr, Hr and Lr and a set of column relays Er, Fr, Gr, Hc, Hr and Lc both in essence duplicate and function in like manner to the set of relays E, F, G, H and L of the Type I coordinator (Fig. 9). Thus the relay Gr is energised through the sets of contacts Na₂, Fr₁ and Er₁ in an interval beginning with an incorrect row response in the position p₁ and ending with the end of the position p₁. Likewise the relay Hr is energised through the sets of contacts Na₂, Fr₁ and Er₁ in an interval beginning with a correct row response in the position p₁ and ending with the end of the position p₁. However the lamp 101 indicating a correct response (corresponding to the lamp 37 in Fig. 9) is connected in series with sets of relay contacts Hr₄ and Hc₄ and is alight only in an interval beginning with the later response of both a correct row response and a correct column response and ending with the end of the position p₁. It will be appreciated that, as in the Type I coordinator, the unisector steps on from a position p₁ to a position p₁₊₁ at the beginning of the position p₁₊₁.

Furthermore the lamp 101 indicating an incorrect response (corresponding to the lamp 38 in Fig. 9) is connected in series with sets of relay contacts Gr₄ and Gc₄ in parallel and is alight in an interval beginning with either an incorrect row response or an incorrect column response and ending with the end of the position in which the response is made. A relay K in parallel with the lamp 101 is energised in such an interval and operates a set of changeover contacts in the marking computer MC₂ to be described hereinafter.

Two further row relays are provided, namely a relay Pr having its winding connected in
series with two sets of relay contacts Gr3 and Sr1 and a relay Qr having its winding connected in series with a set of relay contacts Hr3 and the set of relay contacts Sr1. The set of relay contacts Sr1 are of a relay Sr of the waveform generator shown in Fig. 26 and are closed at the beginning of a position p1 and remain closed until the row limit time is reached as will be hereinafter described. Accordingly in a position p1, the relay Pr is energised for the duration of an interval beginning with an incorrect row response made before the row limit time is reached and ending with the row limit time and the relay Qr is energised for an interval beginning with a correct row response made before the row limit time is reached and ending with the row limit time.

Two relays Qc and Pc and sets of relay contacts Sc1, Gc3 and Hc3 act for column responses in the same way as the relays Qr and Pr and the sets of contacts Sr1, Gr3 and Hr3 act for row responses. The sets of contacts Sc1 are of a relay Sc again in the waveform generator WGc. The relays Pr and Qr control the access controller AC and the relays Pc and Qc control the state of the access controller AC. The circuit diagram of the marking computer MCc is not drawn separately as it is the same as Fig. 10 except that the set of relay contacts G4 are now a set of relay contacts of the relay K shown in Fig. 25, and will be referred to as K1 and the set of relay contacts H4 are now a set of relay contacts of the relay J1 and will be referred to as J1. The variable θ (Fig. 20) is again the potential on the cathode of the triode V3 (Fig. 10). The output terminal 39 is connected to an input terminal 117 of the waveform generator WG, (Fig. 26) corresponding to the input terminal 44 of the generator WG, of Fig. 11.

In the waveform generator WG, triodes V103, V102, V101, V108, and V109, relays Ma and Na, sets of relay contacts Ma1 and Na1 and associated resistors R5 to R60, capacitors C1 to C6, and rectifier X2 correspond respectively to the triodes V1, V2, V3, V4, V5, and V10, the relays M and N, the sets of relay contacts M1 and N1 and the associated resistors, capacitors and rectifier of the waveform generator WG1, with the one difference (apart from any in component values) that the terminal 45 (Fig. 11) is now connected to the +350 volt line. Thus the trigger level of the Schmitt trigger circuit comprising triodes V1, and V4, is fixed and is the trigger level V4 shown in Fig. 20. The waveform Vm in Fig. 20 is the potential on the grid of the triode V17. The relay Na is, like the relay N, energised during the intervals t. An output terminal 118 for connection to the corrective information computers Cl and Cl, is connected to the cathode of the triode V10.

The waveform generator WG, also comprises two further Schmitt trigger circuits similar to that comprising the triodes V1 and V4 in Fig. 11. The first of these comprises triodes Vm, and V19, resistors R1150, R150, and R1146 and the relay Sr connected together as shown. The control grid of the triode V19 is connected to the -150 volt line through a resistor R1151 and to a terminal 119 through a resistor R1152. The control grid of the triode Vm, is connected to the cathode of the triode V19 through a resistor R1142 and to the junction of two resistors R1141 and R111 connected between earth and the -150 volt line through a resistor R112.

Thus the relay Sr is energised in a position p1 when the waveform Vm reaches the potential on the grid of the triode V19, which is arranged, as will be hereinafter described, to be the trigger level V19(t1), and remains energised until very shortly after the end of the position p1, when owing to the closing of the set of contacts Na1, and the consequent discharge of the capacitor C1 which leads to the fall in the potential on the cathode of the triode V19, the relay is de-energised.

The second of the further Schmitt trigger circuits comprises triodes V1a and V1b, resistors R1132 to R1131, the relay Sc and a terminal 120 which components correspond exactly to the triodes V1, and V2, resistors R1131 to R1130, the relay Sr and the terminal 119. The relay Sc is energised in a position p1 when the waveform V1a reaches the potential on the grid of the triode V1b, which is arranged, as will be hereinafter described, to be the trigger level V1a(t1), and remains energised until very shortly after the end of the position p1. The uniselector control UCc is the same as the uniselector control UCc (Fig. 12) except that the set of relay contacts N2 is now a set of the relay Na and is named Na2.

The trigger levels V1a(t1) and V1b(t1) are determined by the potentials on the terminals 119 and 120 respectively which potentials are provided by the voltage readers VR1, and VR2, respectively. Each of these is the same as the voltage reader VR shown in Fig. 13, but for convenience the terminals 47 and 50 will be given subscripts r and c according to whether they belong to the reader VR, or the reader VR. This same convention will be adopted for the access controllers AC1 and AC2, the corrective information computers Cl and Cl, and the modulators MD1 and MD2, all of which are in essence the same as the access controller ACc of Fig. 15, the corrective information computer Cl of Fig. 16 or the modulator MD of Fig. 17 as the case may be.

The stores ST1 and ST2 are in essence the same as the store ST2, of Fig. 14. The terminals 40, 41, 42 and 43 of the marking computer MCc of Fig. 10 are connected to the four terminals 53, 54, 55, and 56, respectively of the access controller ACc of Fig. 15 and
to the four terminals $53_a$, $54_a$, $55$, and $56$, respectively of the access controller $AC_1$ of Fig. 15.

In the access controller $AC$, the sets of relay contacts $G_2$ and $H_4$ in Fig. 15 become sets of relay contacts $Pr1$ and $Qr1$ respectively, and in the access controller $AC$, the sets of contacts $G_5$ and $H_5$ become sets of contacts $Qr1$ respectively.

The terminals $51_L$ and $51_L$ of the access controllers $AC$ and $AC_1$ respectively are connected to the wipers of the uniselecter banks $U_{50}$ and $U_{51}$ respectively and to the terminals $50$ and $51$, of the voltage readers $VR$, and $VR_1$ respectively.

The terminal $118$ of the waveform generator $WR_5$ is connected to the terminals $58$ and $59$, of the corrective information computers $CL_1$ and $CL_1$, respectively (Fig. 16) and to a terminal $123$ of the ambiguity modulator $AM_1$ (Fig. 28). The terminals $47$, and $47$, of the voltage readers $VR_1$ and $VR_2$ of Fig. 13 are further connected to the terminals $57$ and $57$, of the two corrective information computers respectively and to two input terminals $121$ and $122$ respectively of the ambiguity modulator $AM_1$ (Fig. 28). The output terminals of $59$, and $59$, of the corrective information computers are connected to the input terminals $60$, and $60$, of the modulators $MB_1$ and $MB_2$ respectively of Fig. 17, the output terminals $61$, and $61$, respectively of which are connected to the wipers of the uniselecter banks $U_{12}$ and $U_{12}$ respectively, which are shown in Fig. 27. In Fig. 27, the output terminals of the bank $U_{12}$ are connected through the terminal block $TB_4$ (which has the same connections as the terminal block $TB_5$ of Fig. 24) to one terminal of each of the three lamps $mr_1$ to $mr_4$, respectively, of the display $DS_4$, the other terminals of which are connected to earth through a set of relay contacts $Sr2$ which are closed in a position $p_1$ only after the row limit time for that position has been reached. Similarly, the outputs of the bank $U_{12}$ are connected through the terminal block $TB_5$, to one terminal of each of the lamps $mc_1$ to $mc_5$ respectively, the other terminals of which are connected to earth through a set of relay contacts $Sc2$.

It will be appreciated that the inputs to the two groups of lamps of the display $DS_4$ increase from levels dependent on variable trigger levels ($Vt_{10}$ or $Vt_{10}$) at a rate dependent on $\theta$ in the same way as the inputs to the lamps of the display $DS_5$ of the Type I co-ordinator increase from a level dependent on the variable trigger level $Vt$ (Fig. 3) at a rate dependent on $\theta$. However on account of the sets of contacts $Sr2$ and $Sc2$ the corrective information in the two categories (row and column) is never presented in time for responses to be made which vary the charges on the capacitors of the stores $ST_1$ and $ST_2$, although of course row and column responses made after the row limit times and the column limit times respectively alter the marking variable $\theta$.

Turning now to the ambiguity modulator $AM_1$ shown in Fig. 28, this comprises two stages, each of which is basically similar to a corrective information computer (Fig. 16) feeding a correcting modulator (Fig. 17). The first stage comprises a network of adding resistors $R_{529}$, $R_{529}$, $R_{52}$ and $R_{52}$ from which a potential which is the sum of potentials proportional to the trigger levels $Vt_{r1}$ and $Vt_{c1}$, and the waveform $Vv_m$ (Fig. 20) is applied to the control grid of a triode $V_3$ acting as a cathode follower. The triode $V_3$ has its anode connected to the $+150$ volt line and its cathode connected to the $-150$ volt line through a resistor $R_{59}$ and to the control grid of a triode $V_{50}$ through a resistor $R_{59}$.

The triode $V_{50}$, together with a resistor $R_{59}$ and two transformers $T_1$ and $T_2$, constitute a modulator, the secondary winding of the transformers $T_1$ and $T_2$ feeding a modulating amplifier. The modulating amplifier provides a modulated 50 c.p.s. output potential to a terminal $124$ and a similar output potential to the cathode connected to the wiper of the uniselecter bank of a rectifier $X_3$. The terminal $124$ is $U_{50}$, a modulated potential of increasing amplitude thus being applied to the lamp of the display $DS_4$.

The anode of the rectifier $X_3$ is connected to earth through a resistor $R_{529}$ and a capacitor $C_{52}$ in parallel. Accordingly a negative rectified potential is integrated across the capacitor $C_{52}$ and this potential is applied to one end of a resistor $R_{529}$. A further input terminal $125$ is connected to the terminal $126$ of the marking computer of Fig. 10, which terminal is at the potential $\theta$, and accordingly the potential $\theta$ is applied to the terminal $125$. This terminal is connected to one end of a resistor $R_{529}$ and the other end of this resistor and the resistor $R_{529}$ are connected to earth through a resistor $R_{529}$ and to the control grid of a triode $V_{50}$. Accordingly the potential on the grid of the triode $V_{50}$ is the algebraic sum of a negative potential of amplitude proportional to the amplitude of the envelope of the output at terminal $124$ and a positive potential proportional to $\theta$. The triode $V_{50}$, with a cathode lead resistor $R_{529}$ acts as a cathode follower feeding a modulator comprising a triode $V_{57}$, two resistors $R_{529}$ and $R_{529}$, two transformers $T_1$ and $T_2$ and an output terminal $127$.

It will be seen that the amplitude of the modulated output at the terminal $127$ is increased when $\theta$ increases but decreased when the amplitude of the modulated output at the terminal $124$ is high. Furthermore the 50 c.p.s. carriers of the terminals $124$ and $127$ are arranged to be in phase. The terminal $127$ is connected to the terminal $104$ of the display $DS_4$ in Fig. 20. Thus all the lamps of the display $DS_4$ are lit with a brightness which is...
relatively high when  is high unless the trigger levels  and  are high for the position  in which the co-ordinator is at any instant, but this brightness decreases throughout the duration of the position  whilst the lamp selected by the unisecondor is lit with a brightness which is relatively high when the trigger levels  and  are high and which increases throughout the duration of the position .

Turning now to the Type III co-ordinator, this will be described in detail in conjunction with a brief description of a radar training apparatus employing the co-ordinator. Fig. 20 is a block diagram of the complete apparatus, one of the blocks representing the operator OP. The apparatus comprises a P.P.I. display unit DI with a cathode ray tube screen 200 on which a target aircraft is represented by a double spot of light 201 and a pursuing aircraft by a single spot of light 202. The positions of these spots of light are controlled by a radar simulator RS, that of the single spot 202 in response to adjustment of controls of the simulator by the operator and that of the double spot 201 in response to an input to the simulator from the Type III co-ordinator CO. Both the operator and the co-ordinator receive information from the P.P.I. display unit, the operator visually and the co-ordinator electrically.

The operator, by manipulation of the controls of the radar simulator attempts to bring the single spot 202 into coincidence with the double spot 201. The co-ordinator determines an “escape strategy” for the spot 201, adapting this strategy to the operator’s ability. It will be appreciated that this strategy cannot be a purely evasive strategy in which the spot 201 always moves directly away from the spot 202, as the operator would always then know what the spot 201 would do at any instant.

Thus, for example, the category MI corresponds to the spot of light 201 in the upper right quadrant. The other correspondences are listed in Table II below.

However each marking category in actual fact corresponds to a pure strategy, since for example, when the category MI obtains it implies that the operator has been successfully following the strategy which brings the spot 202 into the relationship with the spot 201 defined by this category.

Of the weighting functions  and , , , and , at any instant a selected one is made proportional to the marking variable  and the others are made zero.

Before proceeding with the description of Fig. 31 and the detailed description of the parts of the co-ordinator, a general description of the nature and mode of operation of the trainable assemblage employed therein will be given. The assemblage is of very wide applicability in training co-ordinators wherein a strategy has to be determined.

The assemblage comprises a store with sixteen capacitors acting as storage elements. The capacitors are charged negatively by a negative potential which increases in magnitude with an increasing degree of success of the operator.

Each capacitor is connected in series with a thermistor, which controls the access of charge to the capacitor.

Each thermistor is indirectly heated by a resistor. The potential applied to each resistor is determined by two “access controllers”. Thus the sixteen capacitors are arranged in
The four columns correspond to the four marking categories M1 to MIV and the four rows to the four strategies SI to SIV. The two access controllers each provide four output potentials, which are the potentials applied to the heating resistors. Thus the first output potential provided by the column access controller and the first output potential provided by the row access controller are combined in an adding network to provide the potential to the heating resistor associated with the capacitor in the first column and the first row. Whilst a simple adding network is employed to derive the potential applied to the heating resistor and at any instant the two potentials from the access controllers are added, the term "combined" has been used in preference to "added". This is because over a period of time the effect of the adding network is not in general produce an effect which is the sum of the separate effects of the separate potentials, but rather an effect which is between additive and multiplicative. This is so because the heating resistor is a leaky heat-sink. If a high potential has been applied to the adding network from the column access controller the heating resistor is made heat the heat only slowly leaks away. Therefore for some time thereafter the access of charge to the associated capacitor is relatively high. The heating resistor, thermistor and capacitor form a link in a feedback loop to and from the row access controller and whilst the access of charge to the capacitor is high, the loop gain of this loop is high. If therefore a high potential is provided from the row access controller whilst the loop gain is high the effect of this potential is multiplied with the effect of the potential from the column access controller which caused the loop gain to be high.

Feedback circuits are provided in each access controller the effect of which is to cause different output potentials to become high in succession. In the absence of forcing inputs, hereinafter described, all possible states of the output vector from each access controller (the vector whose components are the output potentials from the controller) occur at some instant, and over a very long period of time with the same frequency. Thus in the absence of forcing inputs the access controllers behave in a random manner.

The four potentials provided by the row access controller are employed as the output of the co-ordinator, as well as for controlling the access of charge to the rows of capacitors. Thus the four potentials are of magnitude \( \alpha, \beta, \gamma \) and \( \delta \) and are applied to control the spot 201 (the target aircraft) in the manner already indicated.

As so far described the co-ordinator determines a random sequence of strategies and in the absence of any input the behaviour of the output from the column access controller is similar. The co-ordinator behaves in this manner in order to find a pattern of behaviour of the operator, that is to say some change in the values of the input variables which correlate in any manner, which is possibly a very complicated and time-dependent manner, with the strategies it has adopted and the changes which give rise to them. In order to maintain this search process it is necessary to make the co-ordinator pass through all possible states. Thus, in the absence of an input, apart from changing its output vector, the machine must change through all possible states of receptiveness, since, being in ignorance of what strategy the operator will adopt, it must pass through states which render it sensitive to receiving any of the strategies. Further these states of receptiveness must be conditional upon each possible strategy that is determined by the co-ordinator and each possible time relationship between all of the changes mentioned.

A pattern is imposed on the strategies by providing forcing inputs to the two access controllers. The forcing input to the column access controller is such as to tend to make high the output potential corresponding to the marking category determined at any time (in a manner to be described hereinafter). The forcing input to the row access controller tends to prevent any output potential becoming high when any capacitor in the row of capacitors, the access of charge to which is partially determined by that potential, has a large quantity of charge on it. This latter forcing input is derived as a feedback from the rows of capacitors.

Thus if the co-ordinator has followed a strategy in which the operator has done well, the output will be high, and since when a particular strategy is emphasised the access to the corresponding row of capacitors is made high, one or more of the capacitors of this row will charge up relatively rapidly. This in turn will provide a forcing input to the row access controller and the co-ordinator will tend to change the strategy.

It may be of assistance to point out that there is an analogy between the co-ordinator and the mathematical process of solving a vector (the input vector to the store) in terms of a matrix (the matrix of the magnitudes of the charges on the capacitors of the store) to give a resultant vector (the output vector). The analogy is only partial, mainly account of the way the different variables involved are dependent on the previous history of the co-ordinator.

Now referring to Fig. 31, which is a block
diagram of the Type III co-ordinator CO, four input terminals 203, 204, 205 and 206 are provided, to which are applied, from the display D of Fig. 30, four potentials representative of $X$, the $x$-co-ordinate of the spot 201; $X'$, the $x$-co-ordinate of the spot 202; $Y$, the $y$-co-ordinate of the spot 201; and $Y'$, the $y$-co-ordinate of the spot 202, respectively, measured on a set of Cartesian co-ordinates in the plane of the screen 200. The potentials may, for example, be derived from potentiometers, the positions of whose movable contacts represent co-ordinates of the spots of light.

Two subtracting amplifiers $AA_1$ and $AA_2$ (which may be of any suitable known form) are connected to the terminals 203 and 204 and the terminals 205 and 206 respectively and provide output potentials of amplitude $p(X-X')$ and $p(Y-Y')$ respectively, where $p$ is a constant. These potentials are fed firstly to an adding amplifier $AA_3$ which (using any suitable known circuitry) provides an output potential $q[(X-X')^2 + (Y-Y')^2]$, where $q$ is a constant. Thus the potential $\phi$ is a measure of the deviation of the spot 202 from the spot 201. Alternatively the adding amplifier $AA_3$ may provide an output potential $\phi = q[(X-X')^2 + (Y-Y')^2]$, which is then a better measure of the deviation. The potential $\phi$ is fed as one input to a marking computer $MC_2$. The potentials $p(X-X')$ and $p(Y-Y')$ are fed secondly to a "selector" $SE_2$ and set the state of two relays DD and LL therein (shown in Fig. 32 to be described hereinafter). The relay DD is energised only when $p(Y-Y')$ is negative and the relay LL is energised only when $p(X-X')$ is negative.

The relays DD and LL together may assume four states, each of which defines one of the four relationships between the spot 201 and 202 previously referred to, namely which quadrant of a set of Cartesian co-ordinates with their origin at the spot 202 the spot 201 is in. These states and the relationships they define are listed below in Table II, together with the symbols MI to MIV used to denote these four different relationships, each of which defines a marking category, and is in direct correspondence with a previously adopted pure strategy as previously described.

<table>
<thead>
<tr>
<th>State of relays</th>
<th>Quadrant of spot 201</th>
<th>Marking Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD de-energised</td>
<td>Upper, right</td>
<td>MI</td>
</tr>
<tr>
<td>LL de-energised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD energised</td>
<td>Lower, right</td>
<td>MII</td>
</tr>
<tr>
<td>LL de-energised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD de-energised</td>
<td>Upper, left</td>
<td>MIII</td>
</tr>
<tr>
<td>LL energised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD energised</td>
<td>Lower, left</td>
<td>MIV</td>
</tr>
</tbody>
</table>

The marking computer $MC_2$ also receives an input from two access controllers $AC_2$ and $AC_3$ to be described later with reference to Fig. 33, from which it computes a variable $\phi'$, again represented as a potential, representative of the expected deviation of the spot 201 from the spot 202. A marking variable $\theta$, varying between 0 and a fixed limit is computed, and is a measure of the difference between $\phi$ and $\phi'$, that is between the measured and the expected deviation of the spot 201 from the spot 202. $\theta$ is made small when the difference between $\phi$ and $\phi'$ is large, and large when the difference is small. Thus when $\theta$ is large the operator is achieving a high degree of success and conversely. The marking computer provides two outputs, one a positive potential and the other a negative potential, both representative in magnitude of $\theta$. The negative potential is fed to a store $ST_1$, and the positive potential is fed to the selector $SE_4$ and to an output terminal 207.

The store $ST_2$ comprises sixteen capacitors, as will be described with reference to Fig. 34, arranged in four columns corresponding to the marking categories MI to MIV and four rows corresponding to the four pure strategies SI to SIV.

The negative potential representative of $\theta$ acts as a charging potential for the capacitors. The access of charge to the capacitors is controlled, however, by the two access controllers $AC_2$ and $AC_3$. In physical terms this means that the resistances through which the capacitors are charged are varied by the access controllers.

The access controller $AC_2$ is a column access controller and, as will be explained in the description relating to Fig. 33, comprises four control devices controlling the access of charge to the capacitors of the four columns respectively. Each of the four control devices is controlled firstly by a feedback from the other three devices and secondly by a forcing input.
which is the positive potential proportional to \( \theta \), fed from the marking computer \( MC_t \)
through the selector \( SE_t \), to one of the control devices. At any instant the positive potential
is fed to the control device corresponding to the marking category defined at that instant
by the relay DD and LL. In the absence of this forcing input the devices, on account of
the feedbacks, go through a succession of states
in which the access of charge to capacitors in
different columns is made relatively high. In
physical terms, when the access to any capaci-
tor is high, the resistance through which it
charges is relatively low. The forcing input
favourites making the access to the appropriate
column relatively high to an extent propor-
tional to the magnitude of \( \theta \).

The access controller \( AC_x \) is a row access
controller, identical with the access controller
\( AC_x \) and comprising four control devices con-
trolling the access of charge to the capacitors of
the four rows respectively. Again each con-
trol device receives a feedback input from
each of the other three devices and a forcing
input. The forcing input to the four devices
are negative potentials fed from the store \( ST_t \)
to the access controller \( AC_x \) and proportional
to the sum of the potentials across the capaci-
tors of the rows of capacitors respectively.

The output circuits of the control devices of
the controlled \( AC_x \) are connected to the store
\( ST_x \) to control the access of charge to the
rows of capacitors thereof and are also con-
ected to a set of output relays \( OR_x \). The set
\( OR_x \), hereinafter described with reference
Fig. 35, comprises four relays associated with
the four devices of the row access controller
\( AC_x \) respectively. Each relay is energised
when the output potential from the correspond-
ing device is above a certain level and de-
energised when the output potential is below
that level. The output from the co-ordinator
is taken from four terminals 208, 209, 210
and 211 and connected to the output circuits
of the four control devices respectively of the
controller \( AC_x \) and also from the terminal
207.

The potentials on the terminals 208 to 211
are the values of \( x, \beta, \gamma \) and \( \delta \) respectively.

In the absence of any forcing inputs, both of the access controllers will pass through a succession of states and thus the output vector, that is the vector whose four components are represented by the four output potentials respectively, from the row access controller
\( AC_x \), will vary in random manner as previously indicated. However the forcing inputs to this access controller will impose some order on its behaviour, since any row of capacitors across which a relatively large total negative potential is stored will provide a large negative forcing input to the associated device in the row access controller. The output from this device is then suppressed and thereby the
pure strategy corresponding to this device is
suppressed. Furthermore the access of charge
to the row of capacitors is reduced, charge
tending to be added to other capacitors of the
store.

Thus the co-ordinator determines a sequence
of mixed strategies. The average rate at which
the strategies change is indirectly controlled
by a "variance computer" \( VC \), which com-
putes a quantity which is analogous to the
variance of the magnitudes of the negative
charges of the sixteen capacitors of the store
\( ST_x \), and will be referred to as the "variance ".

Quotient marks are used since it is not a
true variance as usually defined, that is as the
mean square deviation of quantities about their
mean. When the "variance" is high, that is
when the magnitudes of the charges on the
capacitors are distributed over a large range,
in each of the access controllers \( AC_x \) and \( AC_y \),
the resistance of a triode forming part of a
common cathode load of the four devices in
the access controller is made low

When the resistance is low the effect of any
sudden variation in the potential applied to
the input of any device is greater than that of
less suddenly varying inputs. Thus the access
two controllers tend to seize upon any well
defined characteristic in the forcing inputs
to them very readily when the "variance" is
high, but not to do so when the variance is
low.

The variance computer \( VC \) is a Kipp
relay circuit of conventional form which is
triggered each time any of the relays DD,
LL and four relays RR, SS, TT and UU
shown in Fig. 36 (and being the four relays of the output relay), previously referred to is de-energised. Each time the Kipp relay
is triggered it provides an output pulse of
constant width and amplitude, and these
pulses are integrated in both the row and
column access controllers to give the
"variance ".

The input to the marking computer \( MC_t \),
referred to above, from which it computes the
variable \( \phi \) is taken from the two access con-
trollers \( AC_x \) and \( AC_y \). Two potentials, from the
access controllers respectively, each sub-
stantially proportional in magnitude to the
"variance" are added together and the result-
ing potential is used in the manner described
above to compute \( \phi \).

There now follows a detailed description of the co-ordinator, omitting however the
amplifiers \( AA_t \), \( AA_y \) and \( AA_y \), which may be
of any suitable known type as previously stated.
Fig. 32 shows the selector \( SE_t \), comprising
two Schmitt trigger circuits of conventional
form. The first Schmitt circuit comprises triodes \( V_{t5} \)
and \( V_{t6} \), resistors \( R_{t55} \) to \( R_{t56} \), and the winding
of the relay DD, serving as the anode load
of the triode \( V_{t5} \). The second circuit comprises
triodes \( V_{t5} \) and \( V_{t5} \), resistors \( R_{t55} \) to
\( R_{t56} \) and the winding of the relay LL, serving
as the anode load of the triode \( V_{t5} \). The
circuits have input terminals 212 and 213 respectively connected to the output circuits of the amplifiers AA and AA and both circuits are so biased that their relay windings are energised when the potential on their respective input terminals is below earth potential.

The selector further comprises an input

terminal 214 connected to an output terminal 266 of the marking computer MC shown in Fig. 37. The terminal 214 is connected through a resistor R_{48} and sets of relay contacts DDI, LL1 and LL2 to one of four output terminals 215, 216, 217 and 218 as shown in Table III below:

<table>
<thead>
<tr>
<th>State of relays</th>
<th>Marking category</th>
<th>Terminal to which terminal 214 is connected</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD</td>
<td>de-energised</td>
<td>de-energised</td>
</tr>
<tr>
<td>LL</td>
<td>energised</td>
<td>de-energised</td>
</tr>
<tr>
<td></td>
<td>de-energised</td>
<td>energised</td>
</tr>
<tr>
<td></td>
<td>energised</td>
<td>energised</td>
</tr>
</tbody>
</table>

The output terminals 215, 216, 217 and 218 are connected to four input terminals 219, 220, 221 and 222 respectively of the column access controller AC, which will now be described with reference to Fig. 33. The controller comprises four identical control devices each having a pair of triodes, V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} respectively. The four triodes V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} and V_{d}, V_{a} respectively, in parallel with four grid-leak resistors R_{d}, R_{a}, R_{d}, R_{a} and R_{d}, R_{a} respectively to earth. The four input terminals 219, 220, 221 and 222 respectively, and their anodes connected to the grids of the four triodes V_{d}, V_{a} and V_{d}, V_{a} respectively and through resistors R_{d}, R_{a}, R_{d}, R_{a} and R_{d}, R_{a} respectively to the +350 volt line. The four triodes V_{d}, V_{a} and V_{d}, V_{a} respectively having their anodes connected to output terminals 223, 224, 225 and 226 respectively, and through resistors R_{d}, R_{a}, R_{d}, R_{a} and R_{d}, R_{a} respectively to the +350 volt line. Their cathodes are connected through a small resistor R_{22} to a terminal 227 and the anode of a triode V_{p} which has its cathode connected to earth and its grid connected through an integrating network comprising a capacitor C_{p} and two resistors R_{27} and R_{27} to an input terminal 228.

The feedback is provided from the control device comprising the triodes V_{p} and V_{p}, to the other three control devices by the three resistors, R_{27}, R_{27} and R_{27}, connected between the anode of the triode V_{p} and the grids of the three triodes V_{p}, V_{p} and V_{p} respectively. Similarly feedback signals are provided from the other control devices by resistors R_{57} to R_{57}.

Thus an input is provided to each of the four said control devices by feedback signals from the other devices and by the forcing input applied to one of the input terminals 219, 220, 221 and 222.

The input to the terminal 228 is the pulses provided by the variance computer VC and these are integrated on the capacitor C_{b}, to give the "variance". When the "variance" is high, the triode V_{p} conducts highly and the devices of the access controller pass through a succession of states in which different control devices provide a high output potential at a high rate. The output potentials of the control devices are provided at the terminals 223, 224, 225 and 226.

The row access controller AC is the same as the column access controller AC and accordingly is not drawn separately. When occasion arises to refer to elements of the controller AC, the same reference letters and numerals will be used as were used for the controller AC, but primed.

The store ST is shown in Fig. 34 and comprises four column bus-bar 229, 230, 231 and 232 connected to four input terminals 223, 234, 235 and 236 respectively, these terminals being connected to the four terminals 223, 224, 225 and 226 respectively of the column access controller AC. The store has four row bus-bars 237, 238, 239 and 240 connected to four input terminals 241, 242, 243 and 244 respectively, these terminals being connected to the four terminals 223, 224, 225 and 226 respectively of the row access controller AC. Four row output bus-bars 245, 246, 247 and 248 are connected to four output terminals 249, 250, 251 and 252.
respectively, these terminals being connected to the four input terminals 219, 220, 221 and 222, respectively, of the row access controller C. A further input terminal 253 is connected to a terminal 267 of the marking computer MC (Fig. 37), the negative potential representative of \( \theta \) being applied from this terminal.

The functional parts of the store are sixteen identical circuits of which one only will be described, namely the top left hand one in the drawing. A capacitor \( C_1 \) is connected in series with an indirectly heated thermistor \( R_{he} \), and a resistor \( R_{he} \) between earth and the terminal 253. Thus the capacitor \( C_1 \) is connected to a charging potential through two charging resistors.

The heating resistor of the thermistor \( R_{he} \) is shown as \( R_{he} \) in a box, and has one end connected to earth and the other end connected through a resistor \( R_{he} \) to the column bus-bar 229 and through a resistor \( R_{he} \) to the row bus-bar 237.

If the potential on both the bus-bars 229 and 237 is high the resistor \( R_{he} \) gets hot and the resistance of the thermistor \( R_{he} \) decreases whereby the access to the capacitor \( C_1 \) is increased. When the access to the capacitor \( C_1 \) is high, the potential across it moves relatively rapidly towards the potential representative of \( \theta \) on the terminal 253. The access to any capacitor of the store depends on the potentials of the associated row and column bus-bars.

The junction between the capacitor \( C_1 \) and the thermistor \( R_{he} \) is connected through a high resistor \( R_{he} \) to the row output bus-bar 245. From this it can be seen that the potential on each of the terminals 249, 250, 251 and 252 is proportional to the sum of the potentials across the four capacitors of the row respectively. The potentials on these four terminals are applied as the forcing inputs to the respective control devices of the row access controller \( AC_r \).

It should be pointed out here that whilst the use of high resistors in the manner indicated is satisfactory for deriving a potential proportional to the sum of potentials across four capacitors, for larger numbers of capacitors a different method would be necessary, such as a method involving scanning the capacitors, allotting equal intervals of time to each capacitor, and thus producing a varying output potential time-averaged for the capacitors.

The set of output relays OR is shown in Fig. 55 and comprises four Schmitt trigger circuits 254, 255, 256 and 257 of conventional type having the windings of four relays RR, SS, TT and UU respectively as one of their anode loads. The four trigger circuits are provided with four input terminals 258, 259, 260 and 261 respectively, and these are connected to the terminals 223, 224, 225 and 226 respectively of the row access controller \( AC_r \). Each of the relays RR, SS, TT and UU is energised or de-energised according to whether the potential on the input terminal of its trigger circuit is below or above a level determined by the biasing conditions of the trigger circuit. Each of these relays has a set of contacts which, with a set of contacts of each of the relays DD and LL, is used in the variance computer.

Thus in Fig. 36 one terminal of each of six capacitors \( C_0 \) to \( C_5 \) is connected respectively through one of six sets of changeover relay contacts RR1, SS1, TT1, UU1, DD2 and LL3, either to a -100 volt line or through one of six resistors \( R_{re} \) to \( R_{re} \) respectively to a +100 volt line. The other terminals of the capacitors \( C_0 \) to \( C_5 \) are connected together through a resistor \( R_{re} \) in series with a resistor \( R_{re} \) and a rectifier \( X_c \) in parallel to earth.

The junction of the resistors \( R_{re} \) and \( R_{re} \) is connected to the grid of a triode \( V_{i1} \), which together with a triode \( V_{i2} \), resistors \( R_{re} \) to \( R_{re} \) and a capacitor constitutes a Kipp relay of conventional form. An output terminal 262 connected to the anode of the triode \( V_{i2} \) is connected to the terminals 228 and 228' of the column and row access controllers, \( AC_c \) and \( AC_r \) respectively.

Whenever one of the relays RR, SS, TT, UU, DD and LL is operated or released, a positive or negative voltage pulse is applied to the network comprising the capacitors \( C_0 \) to \( C_5 \) and the rectifier \( X_c \). The rectifier is so poled that only negative pulses are applied to the grid of the triode \( V_{i1} \) and for each pulse so applied a negative pulse of constant amplitude and duration is provided at the terminal 262. These last-name pulses are integrated in the column and row access controllers, \( AC_c \) and \( AC_r \) respectively by the network comprising the capacitors \( C_0 \) to \( C_5 \) and the resistor \( R_{re} \), and the network comprising the capacitor \( C_0 \) and the resistor \( R_{re} \). Thus the potentials applied to the grids of the triodes \( V_{i2} \) and \( V_{i1} \) are the "variance" of the charges on the capacitors of the store \( ST_k \), and accordingly the potentials at the output terminals 227 and 227' are measures of the "variance".

The terminals 227 and 227' are connected to two input terminals, 263 and 264, of the marking computer MC, as shown in Fig. 37. The terminals 263 and 264 are connected through two resistors \( R_{re} \) and \( R_{re} \) respectively to the grids of two triodes \( V_{i2} \) and \( V_{i1} \), respectively, the grids of which are also connected to earth through two capacitors \( C_0 \) and \( C_5 \), respectively. The cathodes of the triodes \( V_{i2} \) and \( V_{i1} \) are connected respectively to the junction of two resistors \( R_{re} \) and \( R_{re} \) connected between earth and the +350 volt line and the junction of two resistors \( R_{re} \) and \( R_{re} \) connected between earth and the +350 volt line. The anodes of the triodes are connected together through a common anode load \( R_{re} \).
to the +350 volt line and to the input to a subtracting amplifier AA. It will be seen that the input to this subtracting amplifier is a potential representative of the "variance" and this potential is used as a measure of the expected deviation $\phi$ of the pursuing aircraft (spot 202) from the target aircraft (spot 201). Another input to the subtracting amplifier AA, is provided from the terminal 265 which as previously described is connected to the output of the adding amplifier AA, which output is the potential $\phi$ representative of the actual deviation of the pursuing aircraft from the target aircraft. The subtracting amplifier AA, provides as its output a positive potential at terminal 266 and a negative potential at terminal 277, both potentials representing $\phi$ in magnitude, varying inversely with the difference ($\phi-\bar{\phi}$).

Whilst the storing means used in the trainable assemblage are conveniently capacitors, as in the embodiments of the invention described, they are not necessarily so. They may be mechanical devices wherein, for example, the displacement of a pointer or the angular position of a wheel represents the stored quantity. Furthermore they may comprise digital storing devices which can store only quantities differing by discrete amounts, rather than continuously variable quantities.

It will be appreciated that the type of store and access control devices described with reference to the Type I and Type II co-ordinators can also be adapted to serve in apparatus concerned with continuously variable responses (such as in the case of a "pursuit skill"). Likewise the type of store and access control devices described with reference to the Type III co-ordinator may be adapted to serve in apparatus concerned with discrete variables.

Among the many modifications which may be introduced into the apparatus is that of adapting the marking device to take more account of errors of one type than of another type. This is an appropriate modification when, in the skill concerned, certain errors are regarded, for instance on economic grounds, as more important than others. In practice such a modification can be achieved, for instance, by varying the values of appropriate resistors in circuits corresponding to different marking categories.

The term "optimum value of the degree of success of an operator" has not been formally defined as it can never be an absolute quantity. It is a quantity which is, in general, different for different operators and for the same operator at different times. It may be relatively low for an operator having a low intelligence quotient or a slow reaction time, or for an operator for whom it is normally relatively high but who is tired.

In the embodiments of the invention described the only kinds of signals representative of the operator's responses that have been considered have been those which have been derived from actual mechanical responses of the operator. For certain purposes it may be advantageous to derive such signals from a device which measures some physiological variable of the operator, for instance the integrated electro-myogram from the frontalis muscle of the operator. Furthermore the signals may be derived under the control of an observer who estimates the value of some psychological variable of the operator.

Likewise the data supplied to the operator may comprise data supplied by the direct operation upon a physiological variable of the operator. For instance one or more drugs may be injected into or otherwise administered to the operator. Again some data may be supplied to the operator by means of sub-threshold signals which are known to register upon a man's mind even though he does not consciously perceive them.

Use of physiological or psychological variable in one or more of the manners indicated may be of value when it is desired to induce certain states in the operator or to derive information about the operator's suitability to perform a certain job. Such use may be made of apparatus according to the invention for purposes of testing for managerial selection, for instance, or for the purposes of experimental psychology.

Apparatus according to the invention is suitable for testing an operator since as already indicated the trainable assemblage can come to have characteristics related to those of the operator. Thus any test carried out with apparatus according to the invention differs from a normal psychological test in that the apparatus takes account of the individual characteristics of the operator.

Apparatus according to the invention may also be used to set up a situation in which the operator is under stress, for instance for the purposes of treatment of psychological disorders. A stress situation may be readily achieved by providing apparatus which applies a stress-promoting variable, such as noise in a pair of headphones, and makes the value of this variable inversely proportional to a variable representing the operator's degree of success.

In many cases, particularly when apparatus according to the invention is being used for purposes such as managerial selection, experimental psychology and psychological treatment, it will be advantageous to attach a monitoring device to the apparatus and thereby obtain a continuous record of some variable, such as that representing the operator's degree of success.

WHAT WE CLAIM IS:—

1. Apparatus for assisting an operator in performing a skill, comprising a marking device adapted to be supplied with input signals representative of the response of an
operator to data supplied to him, and to
generate output signals, representative of the
operator's degree of success in responding to
the data, in at least four channels, each corres-
ponding to a different category, each category
being determined by one or more characteris-
tics of the skill, a trainable assemblage having
its input coupled to the marking device in such
a manner as to have its state determined by
the output signals and to generate, in depen-
dence upon such state, from time to time
or continuously, control signals suitable to
control one or more parameters of the data-
supplying means in such a way as to tend
to increase the said degree of success to an
optimum value, and to maintain the degree of
success at this optimum value.

2. Apparatus according to Claim 1, wherein
the marking device comprises means adapted
to provide successively or simultaneously in
each of said channels a potential whose mag-
nitude is representative of the operator's
degree of success in all categories over a
period of time.

3. Apparatus according to Claim 1 or 2,
wherein the trainable assemblage comprises
at least four capacitors, the state of the assem-
blage being representable by a vector having
four or more components which are the mag-
nitudes of the charges on the four or more
capacitors respectively.

4. Apparatus according to Claims 2 and
3, wherein the said potential is applied through
the said channels to the capacitors as a charg-
ing potential, the channels containing resis-
tance devices and wherein means are pro-
vided to control the access of charge to the
capacitors by varying the resistance of the
resistance devices in dependence, at least
partially, upon the output signals provided by
the marking device.

5. Apparatus according to Claim 4, wherein
the means for controlling the access of charge
to the capacitors are also adapted to vary the
access of charge in a random manner.

6. Apparatus according to Claim 1, 2, 3,
4 or 5, comprising means adapted to supply
the said data to the operator, responsive means
adapted to receive responses of the operator
and to apply the input signals to the marking
device and means for applying the control
signals to the data-supplying means.

7. Apparatus according to Claim 1, 2, 3 or
4, adapted to teach the operator to perform a
skill, in which the data supplied to the oper-
tor consists of discrete indications to which
the operator is required to make correspond-
ing discrete responses.

8. Apparatus according to Claims 6 and 7,
wherein the control signals vary one or more
parameters of the data-supplying means in
such a manner that the intensity and/or the
duration of the different indications is varied
in a "patterned manner".

9. Apparatus according to Claims 6 and 7,
wherein the control signals vary a parameter
of the data-supplying means in such a manner
that the frequency of occurrence of different
indications is varied in a "patterned manner".

10. Apparatus according to Claim 1, 2, 3
or 4, adapted to teach the operator to perform
a skill, in which the data supplied to the
operator consists of discrete indications spaced
apart in time, each indication requiring a
plurality of discrete responses to be made
thereby to the operator.

11. Apparatus according to Claims 6 and
10, wherein the control signals vary a parameter
of the data-supplying means in
such a manner that the number of discrete
responses which are required to be made for
each indication is varied.

12. Apparatus according to any of Claims
1 to 5, adapted to teach a skill, wherein a
body of data is presented to the operator
continuously, in response to which the oper-
tor is required to determine a strategy.

13. Apparatus according to any of the pre-
ceding claims, comprising means adapted to
provide corrective information to the operator
and to withdraw the corrective information
progressively as the operator's degree of
success increases.

14. Apparatus according to Claims 6, 7
and 13, wherein the means adapted to pro-
vide corrective information are adapted to
indicate directly to the operator which respon-
ses is the correct one to be made.

15. Apparatus according to Claims 6 and
7, having means adapted to introduce
ambiguity into the discrete indications, pro-
gressively as the operator's degree of success
increases, by causing indications other than
the correct indication to be provided to the
operator as well as the correct indication, but
with an intensity less than that of the correct
indication.

16. Apparatus according to Claim 7 or 10,
wherein the discrete indications are provided
in a recurrent sequence, and wherein the
marking device is adapted to receive as the
said input signals, signals indicating correct
and incorrect responses and to provide output
signals including a potential representative
of the operator's degree of success, which poten-
tial is varied in one sense in response to
signals indicating correct responses and in
the other sense by signals representing incor-
rect responses.

17. Apparatus according to Claim 7, 10 or
16, comprising means adapted to fix limit
times before which responses must be made
by the operator if such responses are to have
any effect upon the marking device.

18. Apparatus according to Claims 16 and
17, wherein the marking device comprises a
set of relays adapted to take different states
characterized by the combinations in which
its relays are energized and de-energized, the

set of relays normally being in a first state, being in a second state for an interval of time beginning with a correct response and ending with the limit time for that response, and being in a third state for an interval of time beginning with an incorrect response and ending with the limit time for that response.

19. Apparatus according to Claim 18, wherein the marking device comprises an integrating amplifier, adapted to provide a potential representative of the operator's degree of success, having its input circuit connected in first, second and third configurations when the set of relays is in the first, second and third states respectively.

20. Apparatus according to Claims 16 and 17, wherein the trainable assemblage comprises a plurality of capacitors, each capacitor corresponding to a different indication and wherein means are provided to apply to the marking device a potential representative of the operator's degree of success through the said channels to the capacitors, each channel including a resistor or resistive network, and the potential being applied for an interval of time starting with a correct response to the indication corresponding to the capacitor and ending with the associated limit time for that response.

21. Apparatus according to Claims 17, 18, 19 or 20, wherein the means adapted successively to fix limit times comprise a trigger circuit and means for applying to the trigger circuit a triggering potential rising from a datum level at a rate substantially proportional to the magnitude of a potential representing the operator's degree of success, the trigger circuit triggering when the triggering potential reaches a trigger level and thereby defining one of the limit times.

22. Apparatus according to Claim 21, wherein the means for applying the triggering potential comprise a capacitor which is charged through the conducting path of an electron discharge tube having at least one control electrode, to which a potential representing the operator's degree of success is applied.

23. Apparatus according to Claim 21 or 22, wherein the trigger level for each response is determined by a reading amplifier having its input circuit connected successively to the appropriate capacitors of the assemblage.

24. Apparatus according to any one of Claims 16 to 23, wherein connections within the apparatus appropriate for the different indications and responses are made through a unisector.

25. Apparatus according to any one of Claims 17 to 23 and Claim 24, wherein the means adapted to fix limit times further provide signals which are applied to advance the unisector.

26. Apparatus according to Claim 16, wherein a complete response to each indication requires two or more individual responses, each of which may be correct or incorrect, there thus being two or more marking categories.

27. Apparatus according to Claim 26, comprising means adapted to fix successively occurring pluralities of limit times, each plurality of limit times corresponding to a different indication, the responses in different marking categories to an indication having to be made before an associated limit time of the plurality of limit times corresponding to that indication if such responses are to have any effect upon the marking device.

28. Apparatus according to Claim 27, wherein the marking device comprises a plurality of sets of relays, each set corresponding with one marking category and having different states characterised by the combinations in which its relays are energised and de-energised, each set of relays normally being in a first state, being in a second state for an interval of time beginning with a correct response in the corresponding category and ending with the limit time for that response and being in a third state for an interval of time beginning with an incorrect response in the said category and ending with the limit time for that response.

29. Apparatus according to Claim 27 or 28, wherein each plurality of limit times includes a further limit time later than the limit times associated with the responses in the different marking categories.

30. Apparatus according to Claim 29, wherein the marking device comprises a further set of relays adapted to take different states characterised by the combinations in which its relays are energised and de-energised, the further set normally being in a first state, being in a second state for an interval of time beginning with the last response of a number of correct responses constituting a complete response to an indication and ending with the further limit time associated with the indication to which the responses are made, and being in a third state for an interval of time starting with any incorrect response and ending with the further limit time associated with the indication to which the response is made.

31. Apparatus according to Claim 30, wherein the marking device comprises an integrating amplifier, adapted to provide a potential representative of the operator's degree of success, having its input circuit connected in first, second and third configurations when the said further set of relays is in the first, second and third states respectively.

32. Apparatus according to any of Claims 27 to 31, wherein the trainable assemblage comprises a number of sets of capacitors, a different set corresponding to each marking category, a different capacitor in each set corresponding to each indication, and wherein
means are provided to apply a potential representative of the operator's degree of success to each capacitor through a resistor or resistive network for an interval of time starting with a correct response in the marking category corresponding to the capacitor and ending with the limit time determined for that marking category and indication.

33. Apparatus according to Claim 29, 30 or 31, wherein the means adapted to fix pluralities of limit times comprise a plurality of trigger circuits and means for applying to the trigger circuits a triggering potential rising from a datum level at a rate substantially proportional to the magnitude of a potential representing the operator’s degree of success, one trigger circuit triggering when the triggering potential reaches a fixed trigger level and thereby determining the further limit time, the other trigger circuits triggering when the triggering potential reaches trigger levels determined by the previous degree of success in the different marking categories respectively and thereby determining the limit times associated with the different marking categories.

34. Apparatus according to Claims 32 and 33, wherein the variable trigger levels are determined by a plurality of reading amplifiers having their inputs connected successively to the capacitors of the assemblage corresponding to successive indications.

35. Apparatus according to any one of Claims 16 to 34, wherein connections within the apparatus appropriate for the different indications and responses are made through a unselector.

36. Apparatus according to Claim 6 and any one of Claims 16 to 35, wherein the response means comprise a plurality of manually operable members and wherein a like plurality of lamps for supplying corrective information are provided to identify the operable members respectively, modulating means being provided to cause a lamp identifying an operable member to light up when that member is to be operated in order to make a correct response, and to vary the manner in which the lamps light up in such a way as to withdraw the corrective information thereby provided as the operator’s degree of success increases.

37. Apparatus according to Claims 23 and 36 wherein the modulating means comprise an adding amplifier adapted to provide a resultant potential which is the sum of a potential proportional to the output potential provided by the reading amplifier corresponding to the same marking category and a potential proportional to the triggering potential, and a different modulator corresponding to each adding amplifier adapted to provide an alternating current amplitude-modulated by the resultant potential provided by the corresponding adding amplifier.

38. Apparatus according to Claims 34 and 36, wherein the modulating means comprise a different adding amplifier corresponding to each marking category adapted to provide a resultant potential which is the sum of a potential proportional to the output potential provided by the reading amplifier corresponding to the same marking category and a potential proportional to the triggering potential, and a different modulator corresponding to each adding amplifier adapted to provide an alternating current amplitude-modulated by the resultant potential provided by the corresponding adding amplifier.

39. Apparatus according to Claim 6 and any one of Claims 16 to 38, wherein each indication is provided by a lamp which lights up to give the indication, and wherein means are provided to cause the intensity with which the appropriate lamp lights up to decrease as the operator’s degree of success increases.

40. Apparatus according to Claim 39, wherein means are provided to cause all lamps to light up with a background intensity of illumination, whereby ambiguity is introduced into the indications.

41. Apparatus according to Claim 6 and any one of Claims 16 to 40, comprising warning means adapted to warn the operator a short time before data is supplied that data is to be supplied and to decrease the length of time between the warning and the supply of the data as the operator’s degree of success increases.

42. Apparatus according to Claim 41, wherein the warning means comprise a lamp and are adapted to illuminate the lamp in order to warn the operator.

43. Apparatus according to Claim 41, wherein the data is supplied visually and the warning means are adapted to provide the operator with a brief preview of the data a short time before it is formally displayed.

44. Apparatus according to any of Claims 1 to 6 or to Claim 12, adapted to teach a skill wherein the operator's degree of success may be represented at least partially by comparing an observed quantity with an expected quantity, the apparatus comprising means adapted to provide a potential representative of the expected quantity and subtracting means adapted to provide a potential representing a compensated marking variable, representative of the difference between the expected quantity and the observed quantity.

45. Apparatus according to Claim 44, adapted to teach a skill wherein the two said quantities are deviations, the observed deviation being the distance between an escaping pointer, spot or light or the like and a pursuing pointer, spot of light or the like whose motion is controlled by the responses of the operator.

46. Apparatus according to Claim 44 or 45, wherein the trainable assemblage comprises a plurality of capacitors to which the potential representing a compensated marking variable.
is applied as a charging potential through variable resistors.

47. Apparatus according to Claim 46, wherein different capacitors correspond to different marking categories and wherein means are provided to make the access of charge relatively high to a capacitor or capacitors corresponding to the marking category appropriate at any instant.

48. Apparatus according to Claim 46 or 47, wherein different capacitors correspond to different strategy categories, and access-control means are provided to make the access of charge relatively low to a capacitor or capacitors corresponding to a strategy whose employment has increased the degree of success of the operator.

49. Apparatus according to Claim 48, wherein the access-control means are controlled by feedback signals from the capacitors.

50. Apparatus according to Claim 46, 47, 48 or 49, wherein the access of charge to the capacitors is controlled by one or more access controllers each comprising a plurality of control devices, each control device partially or wholly controlling the access of charge to the capacitors of a group of capacitors and being provided with feedback signals from the other devices in such a manner that the access controllers tend to vary the access of charge to different groups of capacitors in a random manner and wherein forcing inputs are provided to the control devices to favour or inhibit the access of charge to specified groups of capacitors.

51. Apparatus according to Claim 50, wherein each control device comprises an amplifier which amplifies voltage signals with substantially no change of phase, the control devices of the access controller being connected to the terminal of a source of operating potential through a common resistive network.

52. Apparatus according to Claim 51, wherein the common resistive network includes the conducting path of an electron discharge valve having at least one control electrode, means being provided to apply to the said control electrode a potential controlling the flow of current through the valve and hence the rate at which the control devices change to different states in which the access of charge is made relatively high to different groups of capacitors is varied.

53. Apparatus according to Claim 52, wherein the variable potential applied to the control electrode is dependent upon the variance of the magnitudes of the charges on the capacitors of the trainable assemblage derived by means adapted to scan the capacitors continuously, to differentiate the voltage waveform thereby derived and to integrate the pulses produced by differentiation.

54. Apparatus according to Claim 47 or 48 and Claim 52, wherein the variable potential applied to the control electrode is derived by means adapted to provide a voltage pulse of substantially constant amplitude and width whenever predetermined signals in different marking and/or strategy categories rise above or fall below predetermined levels and to integrate the said voltage pulses.

55. Apparatus according to Claim 53 or 59, wherein the potential representative of the expected quantity is the said potential applied to the control electrode, or a potential proportional thereto.

56. Apparatus according to any one of Claims 46 to 55, wherein the said variable resistors through which the charging potential is applied to the capacitors are thermistors indirectly heated by further resistors.

57. Apparatus according to any one of Claims 50 to 55 and Claim 56, wherein the further resistors have applied thereto output potentials of different control devices or sums of output potentials of different combinations of control devices.

58. Apparatus according to Claim 6 and any one of Claims 44 to 57, comprising sensitivity control means adapted to vary the extent of the effect which the operator's responses have upon the response means in dependence on the said marking potential.

59. Apparatus according to Claim 58, wherein the response means comprise a knob, or the like, adjusted by the operator and the sensitivity control means comprise a servo-mechanism adapted to vary the gear-ratio in a drive between the knob, or the like, and the device, the knob, or the like, actuates.

60. Apparatus according to Claim 6 comprising responsive means adapted to measure a physiological variable of the operator and to provide input signals representative of the variable to the marking device.

61. Apparatus according to Claim 60, wherein the responsive means are adapted to measure the integrated electromyogram from the frontalis muscle of the operator.

62. Apparatus according to Claim 1, in combination with means for supplying to the marking device input signals provided by an observer, determining a psychological variable of the operator representative of his responses.

63. Apparatus according to Claim 6, wherein in the data-supplying means comprise means adapted to vary directly a physiological variable of the operator.

64. Apparatus according to Claim 63, wherein the data-supplying means comprise means adapted to administer a drug to the operator.

65. Apparatus according to Claim 6, wherein in the data-supplying means are adapted to provide information to the operator by means of sub-threshold signals.

66. Apparatus according to any one of the preceding claims comprising a monitoring device adapted to provide a record of one or more variables of the apparatus.
67. Apparatus substantially as hereinbefore described with reference to and as shown diagrammatically in Figs. 1, 2 and 4 to 17 of the accompanying drawings.

68. Apparatus substantially as hereinbefore described with reference to and as shown diagrammatically in Figs. 10, 12 to 17, 19 and 21 to 29 of the accompanying drawings.

PROVISIONAL SPECIFICATION

Apparatus for assisting an Operator in performing a Skill

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Nearly all systems which require a body of data to be transmitted to human operator are inefficient. The inefficiency arises because the human operator has statistically non-stationary characteristics which are continually changing in a way which cannot be discerned—i.e., his characteristics cannot be represented as a set of transfer functions—and their change cannot be described. As a result, it is not possible to code the information with which he is presented so that it is optimally matched into his characteristics, and even a type of display which is designed to suit human operators, "on the average" is bound to deviate very far from the ideal for "any individual" or for the same individual at different stages in a control process.

In this description we shall be concerned with the acquisition and the performance of human skills. At the outset I should like to emphasize that there is no hard and fast distinction between the process of learning a skill and that of its actual performance. Although the examples which are used to describe the systems will be chiefly applicable to learning rather than performance, almost any performance gives rise to relevant contingencies which are unlearned, and the skill remains but partly learned throughout. Whenever this is the case the systems may equally well be applied to code the information which the human operator receives and to enable him to give a more efficient performance or to exert more efficient control.

Consider initially, the learning of a manual skill. In order to teach this skill a training routine is devised which will consist, in essentials, of (1) The presentation of a number of different contingencies—and, (2) For each contingency a set of more or less complete instructions about what should be done in order to be—according to some arbitrary or mechanical criterion, "correct", at that stage. The training routine will necessarily suffer from one or more of the following type of defect:

(a) The rate at which things have to be dealt with may be insufficient to saturate the human operator's attention—he will become "bored" and will attend, instead, to irrelevant data.

(b) The information given to him may make the task too simple—it will be redundant—and this may lead to results similar to (a).

(c) The rate of presentation or the complexity of the situation may be such that the human operator can do nothing about it.

Ideally the task he is set at each stage should be sufficiently difficult to maintain his interest and to create a competitive situation yet never so complex that it becomes incomprehensible. A private tutor in conversation with his pupil seeks, in fact, to maintain this state—which is not unlike a game situation.

Since it is well established (ref. Dr. Hick and others. Q. J. Exp. Psych) that the human operator behaves, functionally, as a discontinuous sampling servomechanism under the circumstances of skilled performance and that he has a finite channel capacity for information transfer (using the term in the Dr. Shannon sense), we may express the conditions (a), (b) and (c) as simply those for efficient transfer in any communication system—namely that the channel capacity shall be utilised for the transfer of relevant information—given the additional proviso that is not it will become saturated with data that is "noise" with reference to the skill, that the redundancy of the data must be minimised and the equivocality of the information be no greater than a value which can be removed by the receiver—given the further proviso that the receiver must indulge in some decision making or equivocating removing process which if not a relevant process is "noise" and deleterious.

The non-stationary character of the human operator does not allow us to evaluate the redundancy, equivocation, etc, etc. Nevertheless it is clear that the conditions are reasonable enough. If we regard a functionally demarked portion of the human
operator's brain as a non stationary decision making assemblage we see that there will in general be a large number of states of the system, evoked by one or more definite sensory input signals, which will lead to a particular response operation as an output—for instance there will be many states of this assemblage which mean the signal A leads to the response X as is required by a particular skill and called correct. But the state of the assemblage cannot be discerned, nor, indeed, if it could, would there be any way of deciding upon which of these states it was best to establish when, say, teaching the relationship A leads to X. Most certainly the best state will be determined by all other members of the set A, B, . . . N and the set X, Y, . . . etc, etc, which define the logical structure of the skill. Certainly, also, the “best” state will change and will be different at different stages in the learning process. Clearly the “best” state is another expression of the human operator's preferred way of conceptualising the skill or of grouping the data. The best state is likely to be achieved if the system is minimally constrained by corrective information, given, of course, that there is a reasonable chance of the correct operations being performed.

The conditions of the last paragraph are the growth maximising conditions which allow the human operator as much freedom to adopt his own preferred conceptual structure. Indeed it is a commonplace that a skilled person is not simply a man who has learned a set of relations involving signals and response operations, but a person who has learned them in a particular way—in a way which is determined not only by the data and the circumstances under which it must be employed—but also by his individual characteristics.

To match the information into the human operator is equivalent to satisfying these conditions or to encouraging this individual growth process. We shall now consider the device which acts as a statistical coding or matching system.

Since most of my work has been concerned with learning situations the devices are called “TRAINING CO-ORDINATORS” and the resulting system a “COORDINATED SYSTEM”. Briefly, a “TRAINING CO-ORDINATOR” or automatic training device consists of an assemblage which like the human operator is non stationary and conditionable or trainable. It is arranged, in the system, to be trained by the performance characteristics of the human operator so that, with reference to the skill, it comes to have characteristics related to his own. Its changes of state are then used to select from a set of possible contingencies which may occur during the performance of a skill and also to code and ultimately to completely obviate a body of corrective data—defining the correct method of dealing with each contingency. Thus it patterns a training routine to suit the particular human operator and maintains the situation always difficult enough to maintain his interest and never too complex to be incomprehensible to him. In practice it is possible to reduce the training time required, to make it rather independent of the form of the data, to improve retention, and as predicted to maintain interest by setting up a partly competitive game—of the type outlined by Prof. Brain—between the Training Co-ordinator and the Human Operator.

The characteristics of the non stationary assemblage are best illustrated by examples of which several will be presented in detail. Before embarking upon these we note, however that a Training Co-ordinator consists of the following parts.

1. A display and a control arrangement for the human operator—in general those which are ordinarily used when the skill is performed.

2. A means of measuring the human operator's performance. The immediately measured variables may be response time averaged with reference to each kind of contingency—in which case the functioning of the system is rationalised by an extension of Dr. Hick's Law. This kind of measure is not a necessary feature. Amount and rate of movement, deviation of a controlled object from a moving object, etc., etc., will do equally well. It must, essentially however, be possible to change the scale of the measurement by means of a feedback derived from the non stationary assemblage.

3. A means of marking the human operator's actual performance against some arbitrary or mechanical criterion of an ideal performance. In general a switching function is arranged to mark the human operators actual response and one such switching function is generated whenever any one of the contingencies or signals are selected.

4. A set of possible contingencies from which selections are made by the output from the non stationary assemblage—these contingencies may be biased—some as unlikely and some as unlikely and they may or may not be tied by a conditional probability matrix to sets of previous responses.

5. A means of representing what should be done, given a particular contingency, in the form of a display which is presented to and of coding and withdrawing this information.

In the simplest case the representation is direct and the coding and withdrawal amounts to changing the relative intensity or exposure interval of the corrective information associated with each of the contingencies. Likewise in some displays using continuous physical variables the coding amounts to relat...
tive changes in representation scale, for various aspects of the training procedure.

In general the corrective information will be represented in several partial information categories—or represented along several dimensions. In this case the coding will change not only the relative intensity or importance of the information from different contingencies but also the relative importance or the order or exposure interval in a temporal exposure sequence of the corrective cues. For instance if the correct solution is one point out of sixteen possible points any one can be represented in terms of four binary variables. The exposure of these and their order in a temporal exposure sequence can then be determined by the co-ordinator, the exposed time decreasing to 0 as the skill is learned and their relative exposure times decreasing according to the response biases exhibited by a particular man.

(6) A non stationary conditionable assembly which first of all re-scales—or compensates the input—performance measuring variables which, after marking, it receives as its input. Secondly it makes selections from the set of possible contingencies in the training routine and finally it codes the corrective information associated with each contingency before it is presented to the human operator in the display.

A schematic diagram of a Training Co-ordinator is shown in Fig. 1 of the accompanying drawings.

**TYPE 1 CO-ORDINATOR**

**PURPOSE OF THE SYSTEM**

A system of this type is used to train a human operator in the performance of a manual skill, usually part of a repetitive job. The particular feature of Type 1 systems is that the information which he receives at the beginning of the training routine is supplied in the same form as the response which he is required to make. Thus, in a Type 1 system, there is a direct relationship between the signals which define a correct response and the response itself—the human operator is not asked to make any translation.

**THE JOB**

In the demonstration model which will be used to illustrate Type 1 systems the human operator is required to press the appropriate one of eight micro switches arranged in a row whenever the display changes. The display consists of a row of eight lights, and in the initial state of the system one only of these is "ON" at any moment. This one light indicates the correct response. The machine itself passes the change in the display, and thus the rate at which the job must be performed. Initially the pace is constant and the rate of presentation is sufficiently slow to allow the human operator to reach the correct response without difficulty before the machine moves on to the next signal.

The machine scans through a sequence of 12 items. In any position in this sequence any one of the eight alternative signals may be arranged by establishing previous connections—some of the signals necessarily occurring more than once. The human operator is provided with a signal—by means of a separate light—which indicates the origin of the sequence. The machine repeats the sequence continually.

When the connections which set up the required series of events are established, a further set of connections are made. These, via the response switches, indicate whether or not any response which is made at a given position in the sequence is correct or an error. The human operator is provided with this information when the machine moves on to the next position in the sequence.

When the human operator’s performance improves the rate at which the signals are presented increases. From the outset, however, he is asked to make correct responses as rapidly as he can, and if possible, to anticipate the co-ordinator. The situation is, in this sense, competitive. Since missing a response is counted similarly to an error he is told to guess where he thinks there is some chance of his being correct rather than doing nothing. The job outlined is of no inherent merit. It has been employed because it is the simplest and most general arrangement but in practice the signals and the responses are presented in the form which the human operator will normally use. The response array might, for example, be a keyboard, and the signals arranged in a corresponding fashion—for the signals may be actuators on the keys themselves, to give the human operator tactile information about the correct response.

Nor are there any limitations upon the length of sequence or the number of alternative responses which can be employed in the system. Any number of alternatives less than (as in the present instance) or equal the number of positions in the sequence is quite easy to arrange, though in the latter case each alternative will occur only once in the sequence.

**INPUT AND OUTPUT VARIABLES TO THE CO-ORDINATOR**

The co-ordinator obtains the following items of data from the human operator’s performance.

(1) Whether or not, at each position in the sequence, taken separately, the human operator manages to make a response.

(2) Whether, if he does manage to do so, the response which he makes is correct, or if it is an error.

(3) In the case of a correct response a
measure of the interval between the instant at which he responds and the instant at which the Co-ordinator moves on to the next position in the sequence.

(4) A measure of the average number of correct responses which the human operator makes per unit time.

As a function of these variables the device changes the representation of the display information. The precise manner is difficult to set out, since the assemblage is "indeterminate"—in the sense that one of Dr. Grey Walter's "Tortoises" is indeterminate — It will be best to describe the initial and final states of the systems, commenting upon the transition which takes place without much effort to be exact and then to discuss the action of the Co-ordinator as such. In this way the variables which are changed in the display representation will become apparent at the outset.

(1) Initial State

In the initial state of the system the human operator is provided with completely unambiguous representation to each response. The rate at which the co-ordinator exposes the sequence is fairly slow, and an equal amount of time is devoted to each position.

As soon as the human operator starts to play the machine—to compete with it—he will provide a number of correct responses and errors. These are received by the co-ordinator and in subsequent presentations of the sequence those positions in which he has given a correct response are passed over more rapidly than the others, whilst those which have been subject either to no response or to an error response tend to be emphasized because the co-ordinator exposes these signals for a longer time. This operation can be looked upon as a redistribution of the time allocated to each of the positions in the sequence, out of a total sequence exposure time. The extent to which the interval allocated to a previously correct response position is reduced is initially determined by the human operator's response time. Since, however, this is measured in terms of the allowed interval (as in (2) and in (3)) the result is not simple—for the reduced interval reduces, also, the human operator's chance of making a correct response at this position. Moreover, a further operation is performed.

Through it, the total sequence exposure time is reduced as determined by the average number of correct responses (as balanced against errors and no responses) which the human operator makes per unit time—the higher his correct response rate, the higher becomes the rate at which he is required to respond, on the average.

Finally, as his correct response rate increases, the ambiguity with which the signals occur is increased. Instead of only one signal light occurring at each position in the sequence, several, or at a later stage, all of the signal lights appear. All except the appropriate light dim out during the interval allowed for the exposure but the rate of dim depends upon the human operators correct to error balance. Thus, at the time when a new position is first exposed there may be an a priori one in eight choice which would have to be made by the human operator if he responded as rapidly as he could and was to be sure of getting the correct alternative.

The degree of choice is reduced during the interval until no choice is required—but this may be too late for him to make any response for this position. Briefly, the rate at which the correct light becomes unambiguously specified is determined by the human operator's error, increasing with it and vice versa. The real difficulty at each stage is determined not only by this but by the duration of the interval. Thus, all in all, the variables of display ambiguity, of time per position in the sequence, and of average rate at which responses must be made if the are to be correct are dependent upon one another and not readily separable. Perceptually—to the human operator—they do not appear as distinct.

(2) Final State

If the correct response rate of the human operator is plotted against time, it is seen to decrease. It undergoes periodic fluctuations until it reaches its final value. At this stage the human operator, whilst making responses at the required rate, is unable to derive any information from the display except for the sequence origin light. All of his responses are correct—and the distribution of intervals spent upon each position has become—after passing through a stage when it was patterned into a rhythmic form by his preferences, substantially equal. To maintain this final state the human operator is consistently performing the previously arranged sequence of operations, given a fixed minimum of information (this need not, incidentally, be no information as is arranged in the present case), without errors (or with an allowable predetermined distribution of errors, if desired), and at a rate rather greater than the minimum which is deemed to be necessary for efficient performance.

He has, thus, learned the skill. In practice the learning time is reduced to less than half of its normal value. It becomes, moreover, surprisingly independent of the type of sequence or of the form in which the display and response arrangements are set up—chiefly because the information is grouped and withdrawn in correspondence with the conceptual grouping which any particular human operator chooses to adopt. Due to the
The Co-ordinator

To consider the transition from the initial state of the system it will be necessary to look at the way in which the input variables are used by the co-ordinator to modify the display.

The description will represent this procedure graphically.

Consider, then, a sequence of n items—

the sequence positions—which are exposed in a temporal order, as indicated schematically in Fig. 2 of the accompanying drawings.

Any of the signals and correct response correlates may be associated with these positions, according to the skill to be taught—but once these signals are assigned to positions they remain in these positions and need not be further considered. Thus it will be sufficient to look at the positions themselves, and whether a correct response or an error is produced, if any responses, when the human operator deals with them on any particular occasion. Consider any one, say the i-th position. At some instant t(s) the human operator makes a response, unless there is “no response” to this “position”. At some instant t(n) the co-ordinator moves on to expose the next signal—in the j-th position. These instants are illustrated in Fig. 3 of the accompanying drawings.

A timing circuit which is started by any correct response and which is stopped when the co-ordinator moves on to the next position in the sequence, measures the interval between these events—namely—\( t(n) - t(s) \) for any correct response. The duration of these intervals are collected separately for each of the positions, i, j, . . . , etc., etc. The average value of these intervals over several sequences is collected, for each position separately—and these averages will be denoted as \( T(i) \), \( T(j) \), . . . , etc., etc.

There is, in the co-ordinator, a relay which goes “ON” for any correct response, regardless of the signal with reference to which it is made, and a further relay which goes “ON” for any error. These relays have contacts which feed into an averaging device, and this device computes the balance of the average number of correct responses against errors per unit time. Thus the value of this average, denoted as \( \theta \), will increase for rapid correct responses, will decrease for only a few correct responses, and will decrease at a considerable rate for any errors which are made.

Now, the time interval \( \Delta t \)—\( t(n) - t(m) \), which the co-ordinator spends upon the i-th position is determined as follows. A potential, \( V \), is made to increase linearly with time during the interval, as indicated in Fig. 4 of the accompanying drawings.

A trigger circuit which moves the co-ordinator on to the next position, clears the timing device, and returns \( V \) to a value of \( k \) is made to undergo a transition at the points A and B.

It returns to a value of \( k \) for a short interval \( u \) during which the co-ordinator moves on to the next position in the sequence. The rate at which \( V \) increases with time, \( \frac{dV}{dt} \), is proportional to \( k - s \theta \),

where \( k \) and \( s \) are constants. The point at which a trigger circuit is actuated depends upon the value of \( \theta \) for the i-th position \( T(i) \), for the j-th position \( T(j) \), etc., etc. In practice it is convenient to connect the T(i) store to the second-level determining—input of a trigger circuit during the i-th position, to connect the store of T(i) to the same point during the j-th position, etc., etc.

Clearly, the value of an interval, \( \Delta t \), is proportional to \( \theta T(i) \) for the i-th, to \( \theta T(j) \) for the j-th position in the sequence.

There are two points which need emphasizing—namely—

1. That whilst it is reasonable to look upon the average correct response rate variable, \( \theta \), as a determining, via \( \frac{dV}{dt} \), the average rate at which the human operator must deal with signals, \( \theta \) also functions as a weighting variable. It weights all of the input measures.

2. A further point relevant to weighting—and of particular importance if the system is studied on the foundation of Dr. Hick's response time law. The measured interval \( t(n) - t(m) \) can be looked upon as a measure of response time since this, latter, quantity is simply \( t(n) - t(m) \). But the total interval \( t(n) - t(m) \) is compensated by the feedback operations described—the overall feedback in \( \theta \) and the separate feedbacks in T(i), T(j), . . . , etc., etc. The compensation can be regarded as analogous to a rescaling procedure whereby \( t(n) - t(m) \), or, more generally, \( \Delta t \) which enters into

Input Measure = \( \Delta t \) - Response Time becomes a single co-ordinator measuring scale unit, and the above relationship becomes equivalent to

Input Measure = \( 1 - \text{Response Time} \)
as measured by this non stationary assemblage— the co-ordinator.

Finally, the ambiguity of the signal is determined as follows. The unselector, dekatron selector, or other scanning element which exposes the positions in the sequence makes a connection—in the latter case energizes a diode limiter—which actuates preferentially one predetermined signal only for each position in the sequence. In practice the actuation is, however, only preferential for all of the signals are actuated to some extent. Consider the diagram in Fig. 5 of the accompanying drawings, which diagram is similar to the previous one (Fig. 4). The shaded region shows the potential applied to a set of modulators which determine the intensity of all of the signals. Thus the signals all occur, at \( t(m) \)—but all of them are reduced to 0 between \( t(s) \) and \( t(m) \) as shown at the \( i \)-th position in the diagram, or at \( t(p) \) as shown in the \( j \)-th position in it. From the device already considered, an average any error variable is computed. It is this variable which is switched to the signal appropriate to the \( i \)-th position, when the scanning device is at the \( i \)-th position, to the \( j \)-th signal at the \( j \)-th position, and in a similar manner for the entire sequence. The import of this is that the signal appropriate to the position in question will never have an intensity less than a value \( S \), which is determined by the average number of errors made per unit time. The greater is \( S \), the greater the significance of the signal in the display, other things being equal.

It should be noted, however, that other things are not equal if the co-ordinator is working and that the ambiguity of the signal is determined not only by \( S \) but also by \( \theta \) and \( T(i) \) for the \( i \)-th, \( T(j) \) for \( j \)-th position signals. Even this simplifies the position too much—for—by ambiguity is implied not only the relative intensity of the relevant signal with respect to the others, but the interval of time spent at increasing relative intensity before \( t(n) \). It is this which determines the human operator's chance of making a correct response to the signal at a given level of ambiguity—which forces him to adopt more risky strategies and to rely upon his memory—and it is this complex of physical display variables which is compensated against some psychological difficulty variable when the human operator interacts with the co-ordinator.

During the last paragraph, the phrase signal modulator was used, for the sake of a general viewpoint. In one machine, where the signals are neon lamps, the signal modulators are replaced by a resistance network, and a couple of cathode followers, in an extinction circuit. In practice this kind of economy can often be employed.

**TYPE 2 CO-ORDINATOR**

**THE PURPOSE**

This kind of machine is used in a system which operates a training routine where the signals and the required responses are given in different forms. Thus the human operator is required to do a translation from one form to the other, if he is to perform the job successfully. Even in the simplest of systems, such as the one which will be used to illustrate Type 2 Co-ordinators, an ability to effect this translation may be either the whole of, or only one part of the skill which he must acquire.

**THE SYSTEM**

In the demonstration model a job is set up as follows.

A sequence of signals is determined, *a priori*. These signals are represented in two ways—(1) Along a line—(2) In a matrix. There are 12 different kinds of signal, and 12 positions in the sequence, so that each position is unique to one class of signal. The human operator is asked to respond as rapidly as he can, but he is required to respond only in the latter form—namely—by specifying the row and the column reference of the correct item in the matrix representation. He is provided with three "ROW" microswitches and four "COLUMN" microswitches. By pressing down for an instant the appropriate pair—they need not be, and rarely are, pressed down simultaneously—he will specify one of the twelve possible alternatives. If correct, he is given an indication via a white light-marked e—if his response is an error, either by having made the incorrect row selection, or the incorrect column selection, or both—he receives an indication via the red light marked e'. There are thus two different kinds of error, either one or both of which may be committed for any signal.

Alongside the 3.4 array of lights in the display are three row "CLUE" lights, and four column "CLUE" lights.
Whenever the human operator notes a change in the upper display he is required to place the appropriate signal into the matrix—or to transfer the appropriate item from the upper to the lower display—this is done, as noted already, by a double manual operation performed on a manual response board in which the microswitches are arranged in the same way as the "Clue" lights in the "Display".

As in a Type 1 Co-ordinator System he is asked to anticipate the co-ordinator whenever he can do so.

The skill which he is taught at the end of the training routine will depend upon the arrangement of upper lights, and to some extent upon the circuit parameters of the co-ordinator. As in a Type 1 system the sequence is exposed in a regular way, to start with. Thus, if only a single routine is considered, the human operator may regard the upper display as giving him information about his position in this sequence—in other words he may remember a sequence of events in the matrix display. Alternatively, and always if the arrangement of the upper display is altered during several different training routines, he will tend to deal with the problem as one of relationships between the upper and lower (or matrix) signals (or as a transfer of item problem). It is interesting to note that this analysis of the problem is rather unreal, so far as this kind of system is concerned. We may, indeed, be able to deduce from the human operator’s performance which type of concept he has used but when he is actually playing the competitive game, and learning, the human operator is not himself aware of using either type, explicitly. Moreover, it can be demonstrated that a report given afterwards—such as "I used the Clue Lights but not the Upper Display"—is often false. As with the other "Co-ordination" Systems, it is not an explicit set of relationships which is learned but a skill. The meaning of the relationships which are introduced at the outset becomes, in a sense, the skill.

### INITIAL STATE

The Type 2 Co-ordinator presents a predetermined sequence of signals at a rate which allows the human operator plenty of time to make a correct response—one item per five seconds is quite a satisfactory starting rate. At the outset the signals in the upper display are unambiguously specified, and the clue lights for the row reference and the column appear immediately that the co-ordinator begins to expose a signal. Thus the human operator can afford to neglect the upper display since he is given two completely specified one to one responses. When he makes the correct response, or in the absence of a response, when the machine has waited for the exposure duration, a small light behind the letter in the lower matrix display comes on for a short constant interval of time. In the case of an error—when the red error light will appear also—this provides the human operator with an indication of which item he should have specified at this position in the sequence.

### THE TRANSITION

A description of the stages between the initial and final states of the system is beset with the same difficulties which were encountered in connection with Type 1 Co-ordinators. Since Type 1 Co-ordinators are in any case comparable, a similar plan will be adopted. The transition will be considered in broad terms. Later the functions of the machine which bring it about will be looked at in greater detail. Fig. 6 of the accompanying drawings illustrates features of the operation of the co-ordinator. As soon as the human operator begins to make correct responses the following operations take place in the co-ordinator.
(1) He is deprived of information about which signal in the upper display is the relevant signal at any given position in the sequence. As in Type I Co-ordinators, the ambiguity of the upper display increases, though complete specification is obtained rather quickly if he makes any errors.

(2) Depending upon his response time and his error to correct balance he is deprived of the information which comes via the clue lights and which converts the job into one which does not require him to effect a translation. The process will be clarified by the following instances:

(i) Suppose for the i-th signal he had made a correct row specification, but an error had been made with reference to the column specification. Then, in future sequences, the i-th signal would be presented with the row light tending to disappear—it would be retarded by a degree dependent upon the mean value of a response time measure taken for all correct responses in the i-th position in the sequence. Thus, if he could not work out the translation—or could not do so in time—he would have to wait longer to obtain the information which removes the necessity for him to respond to this row variable. On the other hand, the column specification, at which he had previously made an error in the translation, would be increased for the row clue light would appear rather sooner following the initial signal than it had previously.

(ii) If for the i-th signal, both row and column responses are correct, then the row and the column clue lights are both retarded until, eventually, they do not appear before the machine moves on. Thus the i-th signal has to be dealt with from memory—or by guesswork—or to be missed. If an error is made in either or both the row or column specification, the clue lights are reinstated to an appropriate extent.

(iii) Had both been best with a large number of errors, both row and column lights would tend to appear with the primary signal, as soon as the co-ordinator assumed that position in the sequence.

(3) Thus, a patterning is laid down in terms of the relative appearance times of the row and column clues. The significance of any error or of a correct response is determined by the mean response time measure with respect to each position in the sequence taken separately, by the previous disparity—or response distribution between row and column for that position in the sequence, and also by a correct response rate variable, \( \theta \), which is obtained as in the Type I Co-ordinator System.

Unlike the Type I Co-ordinator, the amount of time which is spent at each of the positions in the sequence is not changed—except by \( \theta \) which determines the average time for any position. The specific patterning is laid down in terms of the row and column clue lights—and determines the amount of time for which a problem of such and such a complexity is presented. Clearly, this patterning comes to mirror any preferences which the human operator has for remembering either the row or the column references of each of the items taken separately.

(3) An average response rate variable, \( \theta \), is computed as in the previous systems. The average rate at which the human operator is required to deal with the signals is determined by the value of this variable, which, as above, fixes the amount of time which is spent on any position in the sequence. It should be emphasized that both the ambiguity of the upper part of the display, and the exposure times of the clue lights are dependent upon its value.

**Final State**

In the final state of the system the ambiguity of the upper display is such that the human operator receives negligible information from it—or, if an auxiliary signal is provided to indicate the start of the sequence, it need not provide any information. The clue lights for both the row and the column references will be considerably retarded and in order to maintain this state of the system the human operator will have to make a correct response before they appear—thus not using the clue light information. The value of \( \theta \) will be greater than a certain predetermined value and he will be required to respond at not less than the appropriate rate. He must respond without making any errors, or only a predetermined and small number of them. Thus, he will have necessarily learned the skill which is defined by the predetermined relationships and the rate at which this knowledge of them has to be employed.

**The Co-ordinator**

In many ways this is similar to the previously described co-ordinator. Thus, a trigger circuit is actuated when an increasing positive potential, \( V \), exceeds a certain value. Unlike the previous case, where this value was determined by \( T(i) \), or \( T(j) \), etc., depending upon the position in the sequence, this value is constant. As before, however, the rate at which \( V \) increases is determined by \( \theta \).

\[
\frac{dV}{dt} = k + II \theta.
\]

Further, the average correct response rate variable, \( \theta \), is computed in a comparable manner—both row and column responses being, in this case, grouped together. (In a variant form of the co-ordinator only items which have received BOTH row AND column correct responses contribute to the increase of \( \theta \).)
When the trigger circuit is actuated the value of V returns to k for a period of fixed duration, u. In this Type 2 Co-ordinator the interval u is used to expose the light which shows which should have been the correct response in the matrix representation part of the display. Only after this is done are the timing circuits cleared and the unislector moved on to the next position in the sequence (as occurred before).

Previously a number of average measures—T(i), T(j) . . . etc., etc., were collected. In a Type 2 Co-ordinator—two of such measures, one with respect to the row response, one with respect to the column response, are collected for each position in the sequence. They will be denoted as

T(i), T(j), . . . . T(n).

The unislector switches these to two different trigger circuits, the store which is connected in this way depending upon the position in the sequence. One of these triggers actuates the row clue light, and one of them actuates the column clue light, and they receive an input from the appropriate stores. Both trigger circuits receive a common input from V.

The stores are loaded in much the same way as in Type 1 Co-ordinators. The remarks made in that context, about the dependence of the measure—the rescaling of the co-ordinators measure—by θ, might be repeated here. The effect of T(i), T(j), etc., and of T(i), T(j) etc., upon the input measures with reference to the i-th and the j-th positions in the sequence comparable to the case which has already been dealt with—and becomes equivalent if the "chance" of the human operator making the "correct" response in time, is taken, instead as the amount of decision which he is required to make if he does make a correct response—this amount being determined chiefly by the row and column light appearance.

The waveform V is shown in Fig. 6 which is a sequence diagram of two typical items i and j in a Type 2 Co-ordinated System. Only correct responses are shown, thus, both of the increment pairs (Δxi(j), Δt'i(j)) and (Δxi(j), Δt"i(j)) are added to the corresponding averages, namely (T(i), T(j)) and (T(i), T(j)).

GENERAL CONSIDERATIONS

As in the case of Type 1 Co-ordinators, the actual training routine which has been used to describe Type 2 Co-ordinators is trivial. All of the remarks which were made upon the previous occasion are, however, equally applicable. Any length of sequence, any number of alternatives can be used—generally the form of the response and the display are those commonly encountered in the job—and, uniquely to Type 2 Systems, any number of discriminative categories or stages in a translation process, or contributive sources of information may be employed.

In a perfectly good sense—any number of dimensions may be employed in the specification of a signal.

In this same sense we see that a Type 1 Co-ordinator works in a unidimensional system, that a Type 2 Co-ordinator works in a multidimensional system, and that the class of co-ordinator which will be described in connection with a tactical game or a tactical situation works in a system where the average number of dimensions is determined by the state of the co-ordinator, in much the same way that the average rate of performance is determined in Type 1 Co-ordinators and Type 2 Co-ordinators.

Before describing this class of system, a set of training routines which can be conducted using only Type 1 and Type 2 co-ordinators will be considered, very briefly. One such application, of considerable importance these days, is the set of training routines which are employed when training personnel to the operating stores.

The summary below is a not too far fetched programme demonstrating the parts of the job to which the different types of co-ordinator would be applied. Needless to say, numerous different sequences, derived from the same statistics which determine the ordinarily employed typing exercises are required at each stage.

1. (1) Learning Keyboard Relationships with respect to Rest Keys. Type 2 Co-ordinator. Method. Initially, visual or tactile information given to indicate motion needed on receipt of letter signal. Dimensions with reference to fingers employed. Information withdrawn and signal rate increased as time goes on and performance improves.


3. (3) Irregular Sequences. Type 2 Co-ordinator. Marking of performance with reference to fingers and rest keys.

4. (4) Commercial English passages. Type 1 Co-ordinator. Sequences with words not letters as the signals. Suitable statistical arrangement of sequences which are used. Here the responses are made on an ordinary typewriter, the keyboard of which is fitted with microswitches. The display might be visual or, alternatively, it might provide tactile information via solenoid actuated movement clues on the keyboard itself. In (1) we are concerned to define the response classes or dimensions in terms not of "Rows" and "Columns" but of fingers—more precisely—sets of possible motions from each of eight.
rest keys and the possible kinds of deviation to which these are subject. In (2) we are concerned with using the keyboard microswitches directly connected—and knowing whether a response on a given key—hence a given microswitch—is either an error or a correct response—or if it is missed. Since the machine does not need to deal with kinds of deviation from the ideal it can be of Type 1. In (3) we are clearly concerned with a translation process once again—or at least—with training people to avoid the effect of “noise” or “disturbance” applied (by using unfamiliar or difficult sources of signals) whilst they are doing the translation process (which they are assumed to have learned). In (4) the simpler system can again be used, though the sequences are now complex.

As with ordinary tuition there would be no hard and fast demarcation, and students might run through all of the types of system to refresh their skill.

Finally, although it is only necessary to use Type 1 Co-ordinators and Type 2 Co-ordinators, it would be desirable to use the kind of systems which will now be described for stages (3) and (4).

Using it would maintain a higher level of interest—since it replaces the “sequences” employed as signal sources up to the present—with a source of information which has characteristics i.e., “structure” determined, largely, by the human operator’s own performance.

TYPE 3 CO-ORDINATOR

PURPOSE

Type 1 and Type 2 systems are applicable where a sequence (the predetermined sequence set into the machine) is a part of the job which is done when the human operator executes his skill. The application may be extended to cover training routines for jobs in which the probability of certain contingencies is known beforehand—at least in a number of cases. All in all, however, their application is confined to the very wide class of training routines—or simulated jobs—where (a) When some contingency occurs, some fairly well defined response is required, and (b) Where the order in which events occur is not under the control of the human operator.

There exists a class of occupation which does allow the individual a certain choice about order. It is a very important class, particularly in view of “automation”, since it includes the type of control job for which a human operator must always be employed (even though he is simply giving a master programme to a computing machine which performs the lower order calculations automatically). Practical examples appear whenever a human operator is required to make some decision about a “whole”—the totality of data which he receives from a large set of instruments, or a variety of signals sources—and where the decision could not be adequately made merely by adding up in some determinable way the decisions taken about each one separately. I shall call these situations, without any attempt to be rigorous, “Tactical” situations, or tactical jobs. I am not suggesting a hard and fast demarcation line between, say, TYPING (for which Type 1 and Type 2 machines could act as tutors) and CHEMICAL PLANT CONTROL (which is a tactical job of the type under discussion). It cannot be drawn, because Typing at a partially learned stage has tactical-like-characteristics and these are certainly emphasized by a co-ordinated training system. The distinction refers to the constraints which are built into the co-ordinator, the criteria of what is correct and what is in error, and what the ultimate ideal performance amounts to. In the former category of job we know that an ideal typist is a human operator who, given an input sequence of Business English, converts it into print, without any errors and at a rate limited by the typewriter’s mechanical or his manual dexterity. No such precise statement can be made about a Chemical Plant Controller, an Aeroplane Pilot, or a television producer. About the former example we know only—(a) A set of rules like the rules of a game which define (i) What does what—for instance what instrument refers to what process, and what control effects what kind of change (ii) Which sorts of signal from the instruments should be regarded as danger signals and which sorts of change should be regarded as detrimental. (b) A number of limits, usually set by the rate at which changes may occur in the process which is being controlled, and by consideration of which is the customary scale of the MECHANICAL URGENCY of signals and the MECHANICAL IMPORTANCE of effecting certain changes may be set up. But simply because we are concerned with decisions, many of which are about the “whole” rather than the “parts” of the system, a good chemical plant controller cannot be defined as a man who obeys the rules as rapidly as he can, up to his muscular, or his perceptual limits. We judge the good controller “on results”, which are not directly related to his “keeping the rules” or otherwise. He is a man who achieves maximum yield for minimum disasters per unit time and who is required to estimate the relative advantage of yield over and against possible disasters according to (say) economic data which he receives (usually) from outside the system. Exactly how he does the job is, in some cases, unknown—even to the human operator himself (notably a test pilot is unable to say HOW he does many of the manoeuvres which he clearly performs). In all cases (truly tac-
tical cases which are not degenerate) there is incomplete knowledge on this point, though certain of the strategies which the human operator might adopt, which do not lead to immediate disaster, and which could, \textit{a priori} be good strategies may be excluded on the grounds that if they were persisted in then they would have unfortunate consequences.

Thus we shall be concerned to familiarize a human operator with a situation in which a number, say $N$, contingencies may occur. This is the first part of the task—and requires a co-ordinator such as UNIT 1, which will be described—which sets up the array of contingencies presented during the training routine so that it corresponds with some measure of the human operator’s ability to deal with them. As his performance improves the array of contingencies which are presented will be modified and will tend towards the actual distribution found in a given job. (Alternatively, it can maintain the frequencies of occurrence for all the contingencies at their actual values, but weight their representation—for instance by giving an order of priority to them in a presented sequence).

The second requirement is clarified when we examine how the information—the signal that defines a contingency—is to be given. It is axiomatic that in this class of situation (as was the case in the TYPE 2 CO-ORDINATOR systems) no contingency is a clearcut and “atomic” event. The signal which indicates its occurrence may, of course, be “atomic”—say the appearance of a light—but it will always be possible to give partial information—like the row and column references in TYPE 2 CO-ORDINATOR systems. In these systems the reason why the signal could not be clearcut in meaning was quite plain—namely—that the signal and the response were represented differently, and a translation process was required. The basic feature persists without making any restrictions upon the actual type of signal or of response which is made when the job is being done. This feature is that the human operator, within the terms of the situation, remember at least as many kinds of information about the different contingencies as there are categories of partial information. Thus, in a tactical situation, the Co-ordinator must be concerned with and modify the distribution of the ways in which information regarding the contingencies (partial information, that is to say), about the array of contingencies which it sets up, UNIT 2 performs this function.

Although there are many points of similarity between this, and the previous training systems—it is probably best to look at the tactical game situation in a rather different way, if only to emphasize the freedom of choice at the human operator’s disposal. The display—the totality of possible signals—forms an alphabet from which the co-ordinator, by means of selective operations, makes words or signal groups. These occur with varying frequencies so that the display becomes a language source—and it matters very little whether one regards it as a private tutor who is speaking to the human operator—or just as the human operator’s environment.

Within the terms of the environment the human operator is perfectly free to make whatever action he wishes—and such an action becomes more like a strategic move than a response (although the distinction between the strategic move, here, and the response in a Type 1 or a Type 2 Co-ordinated System disappears on more rigorous examination). Having selected some course of action the human operator may follow it through either correctly or he may make an error (the assumption of “correct or an error” is not necessary, degrees of correctness may readily be incorporated, but it will simplify the description). Whether or not the action which the human operator does in fact take, having selected a particular strategy, is deemed correct will be determined by the RULES which were mentioned a page ago. Whether or not, under particular conditions of his “environment”, the human operator has selected a good or bad strategy is determined by higher order tactical rules, which are not directly accessible and refer to the “whole”. A simple and very general tactical situation game has been set up in which the number of possible contingencies, $N$ is 16. A description of this will clarify the requirements for all such training systems, however specialized they may be. The display and response arrangements will be described, first of all and the Co-ordinator will be described under the headings of UNIT 1 and of UNIT 2 which have already been distinguished functionally.

**Display and Response Arrangements**

The display represents 16 relationships. Symbolically these are expressed as the relationships between signals in one 4.4 matrix and another 4.4 matrix. The response operations permitted are also a set of 16 relationships, which the human operator expresses by selecting any one at a time out of 16
micswatches in a 4.4 array, and finding its
unique associate in another array of 4.4 micswatches. The switches and the signals are
placed in one to one spatial correspondence.
The unique response correlate for each of the
micswatches in the array "X" is a mic-
switch in the array "Y" defined by the
"ASSOCIATION ARRAY"—namely—the
"GAME RULES".
A practical example would be:—

ARRAY "X".

When signal—

A,B,C,D.
E,F,G,H.
I,J,K,L. is generated, then signal n,g,f,m. is generated,
M,N,O.P.

d,e,h,b.
k,j,c,l.
p,i,a,o.

as given by the relationships—

ARRAY "Y".

ASSOCIATION

A,d,B,e,C,h,D,b,
E,k,F,i,G,c,h,i,
L,n,J,g,K,L,m,
M,p,N,i,O,a,P,o

which determine the "RULES".

As before, the two sets of sixteen micswatches are in a one to one correspondence
with the display sets of signals.

Occurrence of a contingency in the tactical
situation—in many ways analogous to selection
of a given position in the sequence in the
case of the previous systems—implies

(1) Potential generation of the signals in
the display which indicate the relationship
required for its solution (whether or not any
or all of this information is ACTUALLY
supplied depends upon other factors).

(2) Setting up a "CORRECT RESPONSE"
tempel—namely—a connection whereby (sup-
pose the human operator to select the X
member switch belonging to this contingency)
the only response marked as "CORRECT"
by the Co-ordinator is the Y member switch
defined by the association array.

PLAYING METHOD

The Co-ordinator can be programmed in
various ways to achieve different structures
of game. The simplest of these is to arrange
for EITHER the human operator OR the
Co-ordinator, but not both, to "play" at any
given time.

In this case the solution of the tactical
situation is very similar to the sort of "game"
with which we are familiar—rather than being a
"game" in a theoretical sense only. It is
necessary, as the price of setting up this
"game" situation, to impose certain con-
straints in order to avoid absorption states of
the system.

Nevertheless, it is probably the simplest
programming to describe, and it will be adop-
ted for this purpose.

The human operator is provided with a
foot switch, in addition to his two 16 way
response boards. When the foot switch is
depressed, a number of relays are actuated,
together with the necessary delay mechanisms,
and the situation is changed from
"MACHINE PLAYING" to "HIM PLAY-
ING". The reverse takes place after a fixed
interval of time—the "MOVE DURATION"
—the passage of this time (i.e., "how long he
has left in which to make a response") being
indicated by an audible signal.

The human operation is free to press the
foot switch and thus to make a move whenever
he wishes. Having done so he may select any
one of the 16 alternatives in the "X" array.
Following this he must give some termination
response in the "Y" array—and only one
such response will be correct at any stage.
Whether his response is correct or an error—
the machine is cleared by it, and he is now free
to make any other selection he wishes. As men-
tioned, certain constraints must be applied.

(a) The duration of the move interval must be
fixed.
(b) The order of X, then Y—then X, then
Y—must be fixed.
(c) It is necessary to arrange an exclusion
circuit so that the human operator may make
any given selection only once during any move
interval—thus he may play any number up
to and including sixteen selections during a
move—but none of them more than once
during that move.
(d) The various states of the system—"You
must select now"—"You has selected and a
response associate must be selected"—"You
found the correct associate"—"The associ-
ate you found was an error"—Make next
selection anytime you wish"—must be sig-
nalled to the human operator.
Thus during the MACHINE PLAYING interval—the machine makes selective operations upon the display alphabet as determined by a UNIT 1, of the Co-ordinator. During the HIM PLAYING interval human operator makes selective operations upon his response board.

The human operator may be provided with a SCORE variable, represented in the display, and intended to show his success. (In fact, as will be considered later, this variable need not be REPRESENTED). It is the variable analogous to \( \theta \) in the previous machines, and represents—in terms of games theory—the utility gain to the system as a result of the previous sets of moves. Its computation will be discussed at a later stage. Its value ranges from 0 to 1, and it increases with correct responses, made rapidly. It decreases in value with an error, or with time wasted. If the system is set up as an explicit game it is necessary to weight the decrease of \( \theta \) with an assumed "HIM PLAYING" move making—time more heavily than with the time during which the "MACHINE IS PLAYING" and the human operator is gaining information from it. The object of the game is to maximise the value of \( \theta \), and it will be shown how, when \( \theta \) is maximised, the human operator is able to deal with the tactical situation at the required rate and in the best possible way.

UNIT 1 CO-ORDINATOR

The UNIT 1 determines the selective operations which are made upon the display alphabet, when the system is in the "MACHINE PLAYING" state. It receives an input from the human operator's previous response, and a further input from the computed variable \( \theta \).

Consider, first of all, the position when the system is held in the "HIM PLAYING" state. Whenever the human operator makes an "X" selection, a relay, corresponding to this particular "X" selection is actuated and this opens up a store—for the I-th selection, the I-th store, for the J-th selection, the J-th store, etc., etc. Let \( t(m) \) be the instant at which the selection is made and let \( t(x) \) be the instant at which the corresponding response associate, whether correct or an error, is selected. Then, during the interval \( t(x) - t(m) \) for the I-th selection, the average upon the I-th store is decreased in value at a rate \( K^2 \theta \), and likewise for the J-th and other store averages. At the instant \( t(x) \) or very shortly afterwards the store in question receives (1). If the response associate which has been selected is correct—an increment to a + signal from a + signal value \( K^2 \theta \), otherwise, (2). If the response was an error, a decrement of charge removed from it, of the same value.

(When there exists some a priori criterion of the significance—say the economic significance—of an error, then the values of the added and subtracted increments, and the increments with reference to the different stores, may be suitably weighted).

In the above, \( K^2 \) and \( K^3 \) are constants.

Let the averages on the different stores be called \( T(I) \), \( T(J) \), etc., etc.

Associated with each class of signal is a relay in the anode circuit of a corresponding trigger device. (A common cathode trigger for instance). Thus there are 16 trigger circuits in this machine, one for the I-th, one for the J-th class of signal, etc., etc.

A potential proportional to \( T(J) \) is applied to one input of the I-th trigger circuit, a potential which is proportional to \( T(J) \) is applied to the J-th trigger circuit, etc., etc.

The second input of each trigger circuit is taken, via a high resistance, to a cathode follower output point. The anode return of each trigger circuit which does not contain a relay would, normally, be taken to a positive potential via a resistance of comparable value to the relay's resistance. Instead, this anode resistance is split. A part of it is individual for each trigger circuit, a part of it is common to them all. Thus the common resistance, and the separate resistances plus the trigger impedance form a potential divider, the potential at the lower end of the common resistance decreasing as the trigger circuit relays are actuated (assuming the correct sense of input connections to be established). Call this potential U.

When the system is in the state "HIM PLAYING" the potential on the cathode follower output point assumes a value the output of the cathode follower is held at a value \( v \), such that all of the trigger circuit relays are "OFF"—i.e. not actuated—regardless of the values of the store averages.

During the "MACHINE PLAYING" interval a periodic forcing input which must be made a function of \( U \) and of \( \theta \) is applied to the cathode follower.

Perhaps the simplest form is the triangular waveform generated by setting limits determined by the state "All On" and "All Off"—(with reference to the 16 relays). \( dv/dt \) is made proportional to \( \theta \) (as in the previous systems). As \( V \) increases more of the trigger circuits come "ON". As they do so \( U \) increases, and this increase is applied as a feedback to the negative sense to decrease the rate of change of \( V \). Thus \( dv/dt \) is determined by \( \theta \) and by the population of transitions in a given region on the scan—the effect being to scan slowly over a region where the transition probability is high, rapidly otherwise. On receiving a signal from a series of series contacts that all of the relays are "ON" the sense of \( dv/dt \) becomes negative, and vice versa on receiving the all "Off" signal—thus a triangular scan is generated.

Other types of forcing input—such as a sinusoidal waveform—have been employed.
As will be shown later, \( \theta \) itself may be used as the input.

If, whenever a relay is in the "On" condition, the associated signal is delivered, we have a device which gives a signal an exposure interval which is determined by its store average, by \( \theta \) and by the aggregate of store averages. The device also tends to accentuate any grouping of signals in the scan sequence.

It is probably fair to regard the exposure interval as being proportional to the probability of information being obtained from this particular class of signal, when the store averages are arranged to suppress the first grid potentials on the triggers. The resulting compensation is then in the sense of reducing the signal probability of an item as the human operator's average correct response rate for this item increases—i.e., the better he gets at dealing with this contingency the more difficult it becomes for him to find out what is that he SHOULD DO. This mode of operation is used in the present machine.

On the other hand, an output in the form of the frequency of occurrence of contingencies is often useful. This is readily obtained if the forcing input is made a random fluctuation of mean zero—especially when read by \( \theta \) (the U feedback being also applied). Attached to each of the trigger circuits is an impulse contact which feeds a constant duration delay circuit—one to each contingency. Thus whenever a transition occurs an impulse (which actuates the relay appropriate for a constant duration) is generated.

In this way the weighted random input function performs a selective operation upon a configuration of elements which is determined by \( T(T, T, \ldots, \text{etc.}, \ldots) \).

**Partitioned Feedback And Other Issues**

As \( \theta \) increases, the average rate of presentation increases due to the increasing scan velocity. If the second mode of operation is used, this increase on the part of the co-ordinator is limited by the human operator's ability—at a given stage in his learning process—to deal with the required aggregate of signals per unit time.

If the first mode is used, this limit is not so real—especially when the signals are given a visual presentation, and when, in consequence, "retinal integration" must be taken into account.

The difficulty is overcome by partitioning the \( \theta \) feedback.

\( \theta \) is used as before to control the mean scan velocity—but the feedback coefficient of this loop is reduced. A further loop is established, such that, when \( \theta \) increases the discernibility of the display information is caused to decrease. The physical variable which \( \theta \) have a device which gives a signal an exposure interval which is determined by its store average, by \( \theta \) and by the aggregate of store averages. The device also tends to accentuate any grouping of signals in the scan sequence. The resulting compensation is then in the sense of reducing the signal probability of an item as the human operator's average correct response rate for this item increases—i.e., the better he gets at dealing with this contingency the more difficult it becomes for him to find out what is that he SHOULD DO. This mode of operation is used in the present machine.

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In this way the weighted random input function performs a selective operation upon a configuration of elements which is determined by \( T(T, T, \ldots, \text{etc.}, \ldots) \).

**Overall Effect**

The overall effect is to provide the human operator with a source of information which becomes adapted to his own characteristics. As his SCORE—namely \( \theta \)—increases, and as he gets better at the job of controlling this tactical situation, so the situation becomes more difficult for him to deal with.

Aspects of the situation which he finds perplexing are accentuated, so that he is forced to practise their solution. But as he is forced to practise, so, also he is given more specific information about what he OUGHT TO do in order to be correct.

**Limiting States**

Clearly enough, the human operator cannot truly "beat" the machine in this game, unless he "knows" the situation, as he is required to do, and uses his knowledge in order to give a consistently good performance. Should his performance deteriorate, the system will become instable, and will revert to a previous state in which it is giving the human operator more information about the correct procedure.

There exists, however, the possibility of the human operator not only knowing nothing about what he ought to do, but not being able (except by an ENTIRELY trial and error approach) to gain such knowledge. To prevent this we adopt what appears to be, at first sight, a rather arbitrary expedient. We make the lack of information time dependent—so that the statement about the human operator—"He is forced to either guess or to rely upon his memory, if he is to move"—would be replaced by "He is forced to guess or to rely upon his memory if he is to move within a certain time, otherwise, he can wait and as a result of this delay obtain a complete specification of the correct move."

This statement obtains, already, in the case of the "MACHINE PLAYING" state of the system. That it does not do so during the "HIM PLAYING" state is entirely due to the game structure which has been imposed by the chosen "either it or him—not both—"
type of programme. In practice, we arrange that should the human operator select a particular “X” item, and be unable to make either by use of his memory, or by an 5 “inspired guess”, any “Y” selection, then the appropriate Y cell is exposed to him after a certain delay period.

The actual procedure, and the importance of making the human operator pay the price of a time delay, in order to get certain specification (rather than simply denying him this specification absolutely) will become clear when we look at the functions of UNIT 2. For the moment it will be sufficient to note that 10 (1) The duration of this delay period is necessarily made proportional to the value of \( \theta \) at each state in the game.

(2) That the whole procedure is justifiable and non-arbitrary if the system is examined on a theoretical basis. For here, when we draw the game matrix in its simplest form, the human operator’s pure strategies appear as “RISK” and “NO RISK” (in the context of a particular stage in the learning process).

Likewise the co-operator’s pure strategies appear as “COMPLETE SPECIFICATION” and “SPECIFICATION AFTER A PERIOD WHICH DOES NOT ALLOW THE HUMAN OPERATOR TO MAKE A SUCCESSFUL MOVE WITH REFERENCE TO THE AGGREGATE” (in the context of a particular state of the co-operator). The strategies of making no move, or no specification, can never become prudential strategies in a partially competitive game of this type.

**PRACTICAL USE**

There are, very broadly, two ways in which the game can be used. In the first place the co-operator is introduced to the human operator as a “private tutor”, which is examined to give him just as much data as he needs in order to manipulate the tactical situation—and as a result of his successful manipulation to increase the value of the score variable \( \theta \). He is told that the characteristics of the co-operator will be modified as a result of his performance, and he is observed, in practice, to “train” the “co-operator” so that its characteristics suit his personal abilities.

The second method is to introduce the co-operator as part of a story or a control situation. The story or situation will be designed to simulate the real life circumstances under which he is required to exercise his skill.

An imaginary instance will serve to illustrate the kind of situation which can be set up using a co-operator which determines the frequency of occurrence of events (rather, that is to say, than the exposure intervals).

The imaginary situation deals with projectiles. The co-operator is envisaged as able to send projectiles, which will impinge upon the human operator’s domain, from any of 16 sites. The human operator is free to oppose this barrage by sending projectiles back at the co-operator from any of 16 sites. We constrain the situation—via the association array—by setting up a certain set of relationships, such that if and only if the human operator aims his projectiles correctly will they have any beneficial effect (and reduce the incidence of the co-operator’s projectiles). We program the co-operator’s part of the programme its game structure—so that a continual stream of projectiles are being hurled at the human operator. He sets out to reduce this stream—to reduce the rate at which signals are sent for him to deal with—or to reduce the value of \( \theta \), by playing back. It is feasible to represent \( \theta \) in the display as an inverse measure of the damage which the human operator’s domain is suffering. But in practice, it is hardly necessary to do so, for the human operator can tell from the feel of the situation how well he is doing.

When he “aims a projectile in return”, he “selects an item in the X-Array, and finds some destination for it, in the Y-Array”. As time goes on he adopts groups of operations—and it is of interest to note that his choice of strategy is neither entirely short term nor entirely determined by the most frequently occurring—a priori the most damaging “pro-jectiles”. In other words, supposing that, as a result of his previous moves the projectile (I) was impinging upon him very often he would not necessarily play counter (I), namely (I).

His strategies are determined by his ability to control the situation as a whole, and to maintain his control over a given period. Broadly speaking, as the groups of operations which he adopts become larger so does his policy become longer term. The immediate choice of strategy is determined by the state of his knowledge of the control job. If, in the instance cited, he did not know the relationship i-I—precisely he might well refrain from playing counter I since to do so would remove the information defining i-I. Thus the strategies he adopts will often appear, to an outside observer, to be inefficient. They are the best strategies for this particular human being at this particular stage in his learning process, when he is involved in a job that has been continually compensated, with reference to his performance. For brevity call these strategies the best SYSTEM STRATEGIES.

In that case a rigorous definition of the co-operator’s function is that it catalyses the kind of play which uses the best SYSTEM STRATEGIES and causes the human being to learn a skill efficiently on this account.

The initial state of the system is one in which the human operator sustains considerable “damage”—the value of \( \theta \) being fairly low. The final state is a stationary condition in which the human operator is playing
strategies such that he is employing an efficient tactic with respect to the skill defined by the constraints (A-I), (J-L), etc., etc., and it corresponds to some value of \( q \) which we can set as the required minimum. But the transition from one state to another is much more difficult than the sequence type arrangements—and a logical description was hardly possible even there. The kind of casual statement which was made in the last example—about the I-I information—is apt to be false if applied to any actual instance. Consequently no attempt will be made to treat the transition of the tactical game situation in an analytic manner.

THE FUNCTIONS PERFORMED BY THE CO-ORDINATOR'S UNIT 2

Recapitulation of Text

As considered up to this point the system is operating with UNIT 1 as the only explicit component—on examination some other unit is implied—but that is all. The explicit UNIT 1 determines the statistical structure of the source—the human operator's environment—by determining either (a) The frequency with which each class of signal in the display, each letter in the display alphabet—will, on the average occur, or (b) The average duration of time during which these signals are exposed. Apart from this it determines the average rate at which any signals occur—or*—by a simple modification of the scanning technique described at the beginning of the last section it can determine—instead of the average rate, the average effective alphabet size at each stage.

Concept of a System Dimensionality

The UNIT 2 of the co-ordinator determines the way in which the information which is conveyed by the signals is represented to the human operator. As already mentioned there is some similarity—though not complete equivalence—between the phrases "The dimensions of the message space" and the "ways of representing the message." Since there is a matter of argument I shall adopt an arbitrary definition of the term "DIMENSION" as used in the present context—whilst admitting that my definition is by no means satisfactory. Let "DIMENSION" mean any class of data in the display concerning which the co-ordinator can accept a pressure of some relevant control operation which the human operator is allowed to make.

Given this, Type 2 systems are two dimensional. The human being is provided with both row and column clues, and his response operations may be right or wrong in either or both of these two ways. We note, however, that mere provision of the row and column

* As in the last of the scanning diagrams we determine the range or deviation amplitude of the scan,
A related to d expressed as A.B.C.D.
B related to e expressed as i. o. i.
C related to h expressed as i. o. o. i.
D related to b expressed as i. i. o.

etc., etc.

Let each of the categories A, B, C, D be a channel of partial information which is represented in the display and which bears one dichotomous statement when exposed—i.e. 1 Bit—of information. The display, for instance, may consist of (64) lamps—each in a separate holder—arranged in groups of four each, there being 16 such groups. This is one method used in practice in our demonstration machine.

According to the association array we make any single lamp* in a group of four either blue or yellow, the former colour indicating i, the latter colour, meaning o. The positions of the four lamps are read as follows.

A
B
C
D

The groups are represented on the X-ARRAY—

A.B.C.D.
E.F.G.H.
I. J. K. L.
M.N.O.P.

So that, as above, the first line will be—in colour code in practice—the following.

i   i   i   i
o   i   i   o
i   o   o   i
i   o   i   o

The co-ordinator's UNIT 2 accumulates the following averages:

S(A), S(B), S(C), S(D), and a further overall average N. S(A) determines the probability dependent on a particular class of signal—say the I-th-class of signal in the display—that the correct correlate of the I-th-class, say i, will be specified with respect to its A dimension, or representation category. The term probability may be rewritten—given a suitable re-arrangement of the system—as the relative exposure interval of the category A at that instant. S(B) determines similar values for B S(C) for C, and S(D) for D.

The average N determines the average number of categories which will be exposed—i.e.—the average specification of i, given I, and it is related to S(A), S(B), S(C) and S(D), so that if the value of N at some instant provides for the exposure of, say U categories then those U with the greatest S averages will be the U which are in fact exposed.

* In practice there are 2. (64) lamps in the display, there being pairs of yellow and blue lamps only the appropriate one of which is connected at the outset;

N is made inversely proportional to \( \theta \).
Thus, at the outset, or when the value of \( \theta \) is low—all of them will be exposed—and if \( \theta \) appears in the display and i will be completely specified, if J, then j will be completely specified. Ultimately, when \( \theta \) is high, none of them will be exposed. F is a linking coefficient and determines the specification which is given at a particular rate. Its effect is most marked at the higher rates.

(In most of the machines F is not fixed but is made proportional to the value of \( \theta \) averaged over an empirically determined interval).

THE INPUT TO UNIT 2 OF THE CO-ORDINATOR

There are broadly speaking two ways of deriving an input.

(A) Suppose that we modify the “story” or “situation”—the one about projectiles—so that the human operator is told that he is provided with four signal stations. By combining the information from these signal stations—the display categories—he will be able to discern where a projectile which impinges upon him has come from, but, as he gets better at doing so his signal stations tend to become inefficient. (In a simple system of this type they never transmit misleading information—only NO information—).

His method of response remains the same, however, and he aims back by making a one out of sixteen selection and a one out of sixteen response to it. The method of marking his selection (built into the co-ordinator) is different. Instead of marking his response to his own selection as “right” or “wrong” we set up a switching function whenever he makes an X-ARRAY-selection and this switching function is the binary representation of the appropriate Y-ARRAY-response. Call this the temple.

Next, whenever, after the X-ARRAY-selection he makes some actual Y-ARRAY-response we set up a further switching function—namely the binary representation of the Y-ARRAY-cell which he has selected (and which may be either correct or an error).

The binary number corresponding to his response selection is then compared with the temple. According to the correspondence between the two we note that the human operator may either be right or wrong in any or all of four different ways.

Suppose for instance that the temple corresponds to

\[
\text{A.B.C.D.} \quad \text{i.o. i.o. o.i.}
\]

Then the correct response would also yield and this would be marked as

\[
\text{L. L. L. L.}
\]

115

110

105

100

95

90

85

80

75

70

65
On the other hand, assuming the same temple, namely - - i. o. i. o. The response would be an error in B and in D.

and would be marked - - 1, 2, 1.

Let the response time be \( \xi(x) \) then the averages \( S(A), S(B), S(C), S(D) \), are added to or penalized to an extent \( \delta.\xi(x) \), or, \( -\delta.\xi(x) \) according to the marking of the response.

(B) The alternative method of deriving an input requires us to alter the human operator's mode of response. We define, by means of the display—and using some analogy such as signal stations—the course of a projectile.

When the human operator aims back he is now required, instead of making a one in sixteen X-ARRAY-selection followed by a one in sixteen Y-ARRAY-selection, to make one in sixteen X-ARRAY-selection and four separate one in two decisions upon a group of four pairs of switches which set up the switching function for the temple directly. The order in which he makes these decisions is not constrained, nor is the time at which he makes them. Let us call the overall times at which, starting at his X-ARRAY-selection, he makes the Y responses \( t(A), t(B), t(C), t(D) \), respectively. Then the marking for the correct response as above will be

\[
\theta t(A) / \theta t(B) / \theta t(C) / \theta t(D)
\]

which increments are added to the averages \( S(A), S(B), S(C), S(D) \).

Likewise, for the partial error response as above, the marking will be \( -\theta t(A) / -\theta t(B) / -\theta t(C) / -\theta t(D) \), which increments are added or subtracted to the respective averages directly. The rationale of weighting the response time measure with \( \theta \) has not been justified at this point because the case is analogous to those already considered at length.

**FUNCTIONAL PROPERTIES**

Suppose that the human operator makes either all completely correct or all completely error, or some of both but no partially correct responses. Thus he exhibits no bias towards a particular kind of an error. In this case, as his performance improves and \( \theta \) increases, and as \( \theta \) decreases so \( N \) increases—a point will be reached at which instead of receiving information in all of the display categories for a particular class of signal—he will receive information in no categories—i.e.—no information. The categories are not manifest and will not become manifest until he exhibits a bias by making preferential errors—or—in the case of (B) preferentially distributed response times.

As soon as he does so, however, his chance of obtaining a particular category of information from the display will increase or decrease. If he makes errors with respect to a particular category, his chance of obtaining information in this category about a particular item will increase, if he is consistently correct it will decrease—and a similar remark applies to his response time distribution in the reverse sense—.

Thus the “dimensions” become available as he uses them—until then they remain “latent” in the display. In (B) they are necessarily explicit for they correspond to stages in a multiple response operation (as noted at the time however the human operator is free to respond in any order with any timing—and may respond coincidentally—. In practice the human operator will often play the four decision pairs like a chord).

**MODIFIED SYSTEM**

A page ago, when the scanning operation which determines which of the categories will be exposed was being discussed, a weighting coefficient, \( F \) was introduced. \( N \) is made proportional to \( F.\theta \).

If a co-ordinator is set up with \( F \) prefixed— the averages \( S(A), S(B), S(C), S(D) \), determines simply the chance of the respective category of information, referred to ANY signal class, appearing in the display.

Although such a procedure was adopted during the experimental stages of development it is not consistent with the general theory of these co-ordinators—chiefly because, within that theory, \( F \) should be a variable dependent upon the average on the score for the class of signal to which the information refers.

In the type of machine which has been used for the purpose of a practical example, this can be arranged directly by making \( F \) proportional to the potential on \( T(J) \). If the \( I \)-th signal is exposed, to \( T(J) \), if the \( J \)-th signal is exposed, etc., etc. When UNIT 1 of the co-ordinator is arranged to determine the exposure intervals of the various classes of display signals (rather than the chance of these signals occurring in the display) it is necessary to arrange a feedback which weights each of the averages \( T(I), T(J) \), according to the coincident exposure interval and to make \( N \) an increasing function of \( \theta \) and the exposure interval. The result of this is to expose all of the classes of information relevant to a particular selection in the X-ARRAY— if the human operator waits long enough before making a response selection in the Y-ARRAY—. After this selection, \( N \) reverts to its normal value, and remains dependent on \( \theta \) until the next selection.

**A SUMMARY**

To summarise:—

The human operator receives information from a display in four categories—effectively
dimensions—These become apparent only when he exhibits a preference for dealing with particular categories of contingency. The probability of occurrence of the sixteen classes of signal in the display are likewise determined by his preference for dealing with each of them, whereas the average probability of ANY signal occurring in the display is determined by the variable \( \theta \). Looked at in terms of games theory there is a sense in which we can speak about the best "SYSTEM STRATEGIES" as distinct from the best "PROBLEM STRATEGIES"—leading to an immediate correct solution—or the best "HUMAN OPERATOR strategies". The outcome of operating the best "SYSTEM STRATEGIES" may be said to yield a distribution of "System Utilities". Now, one can regard the averages for the stores on the signal classes, namely, T(I), T(J), etc., etc., as being distributions of \( \theta \) at any given instant, and likewise S(A), S(B), etc., etc., the averages which determine the occurrence of the different categories of information.

It appears possible to regard this array as the distribution of "System Utilities" at any given instant—determining the system utility gain which will result from playing a particular system strategy. This possibility arises because of the interaction between the human operator and the co-ordinator, on account of which we speak of the variables as being compensated. This, in turn, leading to the idea of a non stationary (in the statistical sense of non stationary) machine which appears stationary with reference to a (by definition) non stationary assemblage—the human operator.

Thus it is not unreasonable to suppose that a recording, in terms of suitable parameters, of the moment to moment state of the system (which is a perfectly straight-forward thing to do) may yield a very objective measure of the human operator's characteristics—as a kind of mental test—. If the constraints applied to the system define a skill the test would be an "aptitude" test. If the system is constrained to maximise the sum of the difference moduli between the averages it will be a stress test.

Further applications are envisaged. Whilst it is difficult to justify this theoretical framework at any rate without a great deal more data on performance, enough has already been collected to be certain of the practical usefulness of such a technique. The following diagrams will serve to clarify:

1. Tactical situation co-ordinator with exposure interval modulation
2. Signal probability modulation. The latter is shown with a display for (3). Mode A and (4). Mode B.

**SOME COMMENTS**

Since the categories remain latent until there is an imbalance the system can be regarded as of variable dimension number, since any weighted combination of the categories can be utilised, as of variable dimension type—and the variables which determine the utilised assemblage are compensated against the human operator's performance characteristics.

Thus it does not matter greatly what divisions are made when establishing the categories—though in practice we usually select any obvious ones which arise on account of a particular job. The divisions need not be symmetrical and in certain special cases the maximum or latent maximum number is not necessarily defined.

This is the case in some of the derived continuous systems which will be considered in the next section.

The means of representation in the display is not critical.

One need not, for instance, have four signal lights arranged in groups of four in a 64 light array, in order to represent the four binary category form of the 16 item system which has been discussed. An equally good method is to programme the machine structure so that on making a particular X-ARRAY selection the corresponding Y-ARRAY selection is gradually revealed. Thus, on making his selection in the X-ARRAY, the human operator is presented with 16 lights on a Y-ARRAY display board. As time goes on sets of three lights are obliterated—corresponding to the various categories A, B, C, D at instants determined by S(A), S(B), S(C), S(D)—and eventually only the one correct item remains. Thus, if he waits for a specification which is complete, the human operator is penalised. He may, if his state of knowledge or his willingness to take a risk is adequate, respond before specification is complete.

In this, the background theory is again implicit, though unnecessary for the practical justification of the device. Briefly, one conceives a decision process going on in the human operator's brain—certain stages of which are aided by his recollections. The object of the co-ordinator is to code the assistance he receives—as determined by S(A), S(B), S(C), S(D), so that it fits his state of knowledge and helps him where he finds difficulty—but not otherwise. Stated baldly the theory is not adequate—but it is possible to show that a weighted combination of any selected set of categories may function approximately as any set of categories which the human operator may have selected in his conceptual notion of the job—and it is not assumed that he does in fact select the arbitrary dichotomisation which has been imposed upon the display information.

Further, instead of determining an explicit probability of occurrence or an exposure interval, the display may be intensity modulated or
the information channels subjected to "noise" dependent upon the value of T(D), T(J), etc. etc., and S(A), S(B), etc. etc. Since the variables are compensated these forms of coding appear—as might be expected—quite satisfactory and equivalent to the more justifiable coding by relative duration or likelihood.

In practice, it is possible to impose a valuable modification upon the system by biasing the various categories. This is equivalent to introducing "degrees of error" or "degrees of success". For instance, it may be decided upon mechanical or other grounds concerned only with the part played by the skill under real life circumstances, that errors of one sort are more important than those of another. This scale of importance can be imposed at the marking mechanism as a bias which results, in effect, in the extraction of a difference signal—between the a priori estimate of importance and the human operator’s estimate of importance—for each contingency. The difference signals then contribute towards the averages and determine the state of the system.

The scale of importance, moreover, may be derived during the course of a performance as a function of the progressive state of a controlled system of a priori determined characteristics.

If, for instance, the control and the display are intended to represent the control of an aeroplane the result of the control up to a given instant may be computed as in a flight simulator and represented as the present state of the aeroplane. (The co-ordinator is determining the contingencies with which the human operator has to deal). This state may be "marked" against a criterion of mechanical stability of the "aeroplane" and the result employed as a feedback to the co-ordinator in mind that the distinction between learning situations and real performance is one of degree only, so far as these tactical situations are concerned, we envisage the use of the co-ordinators as devices which code the representation of many channels of information—as from meters etc. etc.—into a complex parameter display. They could thus be used as aids to performance in very complex control jobs where the present technique of using an a priori determined coding is inadequate.

The aeroplane example really shows how the system can be used to teach the functional characteristics of an assemblage—the aeroplane. In this sense the co-ordinated system enjoys an entirely general applicability. It has been found possible, empirically, to extend the same latitude which was noted for the display representation to the actual control variables—and for much the same reason. The response time measure, which has some foundation on Dr. Hick’s law, may apparently be replaced by measures of lever movement or other control operations which are relevant to a job. Thus some of the potential applications can be realised in practice—and the tactical situation for which the human operator is to be trained can be anything from a logical or managerial problem to a mechanical skill.

Finally, there is a class of system which has already been touched upon in connection with mental testing, in which we desire to establish a particular state of the system—or state of the human operator. Here, a co-ordinator may be used to catalyse the achievement of the desired state—and often, to render it more explicit. If some variable—say a stress promoting variable like "noise"—is applied to a system set up to simulate a particular job then the human operator will experience greater difficulty. Now if, in the case of a stress promoting variable, we make value of this variable at any instant inversely proportional to \( \theta \) a potent hypnotic relationship is set up which leads—rather dramatically—to a stress situation. (The results, as a matter of fact, can be really alarming).

Though more difficult to set up in practice much the same kind of thing occurs if some motivation variable is made proportional to the changing value of \( \theta \)—it acts as a realistic kind of score variable—. Here the situation is not one of stress but rather of pleasure. The situation is probably analogous to a game or a skill which we ordinarily enjoy doing. It seems possible, by using a co-ordinator in this manner, to create such a situation with certainty.

Clearly, a slight extension of this principle allows one to use a co-ordinated system for the comparison of the stress creating or the motivation creating effects of several different variables, in a very objective manner. It may, as already mentioned, be used to compare the susceptibility of different human operators to a variable of known potency. We have not, as yet, investigated these attributes of the system except in a qualitative manner but there is reason to believe that physiological variables (such as the integrated electromyogram from the frontalis muscle—some index of attentiveness—or the integral of the "a" rhythm "component" of the E.E.G. which has been used previously as an index of the narcosis of a subject) might be employed as the input to the co-ordinator. Again there is the possibility of using physiological variables (rapidly acting drugs, for instance), in place of a display. The idea is not so bizarre as it might seem at first sight—an ordinary servomechanism to control anaesthetic level as a function of the integrated E.E.G. is quite well known—and there may be, here, a very large field of clinical use for the co-ordinators especially in the treatment of mental patients.
CONTINUOUS VARIABLE CO-ORDINATORS
Since the human operator quantizes information when he perceives it, there is no hard and fast distinction between the discrete selection jobs already considered and situations which involve continuous display variables (and, or control variables). The electrical methods may differ considerably, however, and it will be worthwhile to exemplify this by one technique which has been adopted.

The technique is applied to a pursuit task (which can be arranged in one or more dimensions) and in which a human operator provided with a velocity control that determines the locus of a pointer—the VEHICLE—is required to follow the course of another pointer—the TARGET—.

Consider the case when the TARGET has no prefixed course.

In this case the TARGET strategies will be entirely determined by the co-ordinator. All other cases may be derived from this by application of a set of constraints—to determine a most probable target course—and then translation of these constraints by means of instructions from the co-ordinator.

Let the pure strategies of the target be:—

s.1. (1) Move left, if the vehicle moves right, right, if left.

s.2. (2) Move right, if the vehicle moves right, left, if left.

Also, for the vehicle—which is controlled by the human operator—there are the pure strategies:

f.1. (1) Move left, if the target moves right, right, if left.

f.2. (2) Move right, if the target moves right, left, if left.

Let any weighted combination of these pure strategies be available and all such mixed strategies be physically represented as degrees of either co-operative or competitive motion.

Conveniently this system can be set up using two motors which are servo controlled and which operate two sets of Y potentiometers, say Y(1), (2), etc., and Y(1), (2), etc. The potentiometers Y(1), Y(1) have applied across them, initially, a fixed potential which is used as a reference potential for a positional servo-mechanism. Then any situation at time t can be set up as two zeroing loci which correspond to the outcome points of playing two pure or mixed strategies, one from s.1....s.2, the other from f.1....

f.2. The pure strategies will correspond with the ends of the two tracks, respectively. The potentiometers X(2), Y(2), form a sensory bridge device whereby a variable θ derived at time t, is resolved into its s.1, s.2, f.1, f.2, components. The value of θ is then averaged with respect to these components. Call the average values V(s1), V(s2), V(f1), V(f2) and cause the potentiometer X(1) to have maintained across it, instead of a fixed potential, a potential V(s1)—V(s2), whilst the potentiometer Y(1) has a potential V(f1)—V(f2) maintained across it. Consider, then, a further servo-mechanism which equates the position of the target and the vehicle using as a reference scale the now abrupt scales on X(1) and Y(1). The motion of the target will now be as required if we make the correction rate at any instant, instead of become θ.u.

The variable θ is conveniently derived from two further potentiometers X(3), Y(3), across which is applied an alternating potential at some suitable carrier frequency—say about 500 c.p.—. The output is taken in this case from between the two moving arms on the potentiometers and its rectified and averaged value will be the average value of the target to vehicle deviation modulating, thus, by definition—θ—.

Whilst θ, in the system described is distributed about only four pure strategy points—i.e., the signal is applied to the moving arms of only two potentiometers and resolved into only four components—the procedure can be extended to any desired number of variables.

Finally consider two further potentiometers X(4), Y(4), which provide a potential that represents the position of the target and the vehicle in the display. Their moving arms may, for instance, be taken to deflection plates on cathode ray tubes or to meters which are deflected proportionally to the motor movements. Suppose that the potential across these potentiometers is constant then the display representation will be on a constant scale with respect to the actual motion. If, however, the potential across them is dependent upon θ the display scale or representation scale will increase—and thus deviations will become more readly discernible as the average deviation increases and less as it decreases.

Systems of this type have been used successfully and since the continuous physical variables present a more realistic job are very suitable for building up stress situations and for the similar procedures outlined in the previous section.

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Fig. 4.

Fig. 5.
Fig. 6.
Fig. 1.

$\text{DS}_1$

$\text{DS}_2$

$\text{SB}_1$

$\text{RS}_1$
Fig. 3.

Voltage

$\theta$

$P_i$

$P_{i+1}$

$\Delta t_i$

$\Delta t_{i+1}$

$V_{li}$

$V_{SM}$

$\sim \delta t_i$

$\sim \delta t_{i+1}$
Fig. 20.
Fig. 20.

Potential $V$ vs. Time $t$

- $V_{SC(i)}$
- $V_{ER(i)}$
- $V_{SC(i+1)}$
- $V_{ER(i+1)}$
- $S_{TC(i)}$
- $S_{TC(i+1)}$
- $S_{TR(i+1)}$

Time intervals:
- $t_{10}$
- $t_{11}$
- $t_{14}$
- $t_{15}$
- $t_{16}$
- $t_{20}$
- $t_{18}$
- $t_{21}$
- $t_{19}$
Fig. 21.
Fig. 31.
Fig. 35

Fig. 36.