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13 ABSTRACT

Research is summarized on models that describe the learning of a structured skill and on simulations of populations of automata that become more complex as they develop. Applicability and limitations on a simple learning model based on terms of continuous, information=like measures are discussed. The model considers the contribution from learning of the i-th skill to learning of the j-th. Limitations arise for the description of learning of higher-order concepts. The relevance of statistical and homeostatic approaches to the description of learning and adaptation is considered; each is viewed as contributing to the characterization of a real-life population of organisms. The simulation model shows that individual automata do not learn on their own but in cooperating groups. The elaborate population that is postulated shows stability over a larger range of cost parameter values in an unconstrained environment than in a constrained environment. A gregarious automaton is described that has a sensory system (sensitivity to density of population) and a memory system; significance is associated with properties that remain invariant or exhibit regular and correlated transformation. Two appendixes are included that consist of preliminary drafts of two chapters of a manuscript on "The Cybernetics of Living Systems" and are entitled "Cybernetic Models and Control Systems" and "Fabric and Organization of Memory."
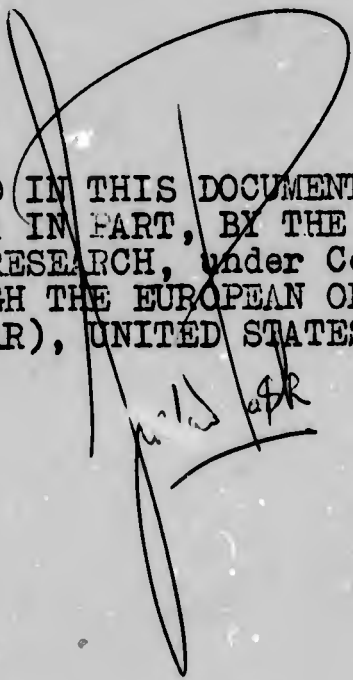
ANNUAL SUMMARY REPORT NO.3.

Research on Cybernetic
Investigation of Learning and Perception.

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Research on Cybernetic
Investigation of Learning and Perception

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15th February,1966.

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Introduction.

The work carried out during the year can be
conveniently classified under four headings
of which a pair have alredy featured in the
Administrative Reports No.8 and No.9 These
headings are:

(1)   Approximate mathematical models for
adaptively stabilised man machine interaction
(and analysis of data obtained from experimental
systems).

(2)   Final experiments with the existing form of
automaton population computer programme.

(3)   Discussion and formulation of a novel
class of programmes (to comprehend salient features
of the automaton population and the algorithmic
programmes).

(4)   Development of the basic Cybernetic Learning
Model to include processes such as Imprinting and
Maturation or their mechanical analogues.

The work under (1) has been carried out by
G.L.Mallen and I and, so far, has led to a
single publication describing a linear
approximation model which is shown to be
Lyapunov stable and in accord with the
experimental data. So far as (2) is concerned,
T.R.McKinnon Wood and I are chiefly responsible.
For the discussions involved in (3) we had the
benefit of Dr. Bjørn Hoijer's participation. Dr.
Hoijer visited the laboratory for a couple of
months in the summer; Mallen, McKinnon Wood and
I also participated. Item (4) is my own effort;
but currently the imprinting model is being
simulated and some preliminary data should be
available fairly soon.

Part 1. Analysis of the Cybernetic Learning Model.

Section (3) of Annual Summary Report No. 2.
Contract AF.61(052)640 describes an investigation
of some macroscopic properties of the basic
learning model. Administrative Report No. 7.
reports an experiment concerned with the adaptive
instruction of a perceptual discrimination skill
with eight subskills. Briefly, this experiment
involves an 8 x 8 display of squares, each of which
can be back illuminated. The track of an object is
displayed by illuminating, in succession, a sequence
of squares whilst groups of squares are cyclically
illuminated to provide a "random" background. The
skill consists in identifying and intercepting the
displayed trajectories as soon as possible after their
commencement. The difficulty of discriminating a
trajectory is varied by changing the intensity of
the random light pattern. An Adaptive Control Mechanism
(A.C.M.); selects trajectories from a class of
$N(n) = 1,2....8$ members at the nth. trial. The (A.C.M.),
adjusts the difficulty levels n , of the trajectories,
so that the subject's proficiency ρ remains constant
at a value ρ_0 predetermined by the experimenter.
Thus, if ρ_i is the subject's proficiency with the ith.
trajectory, at some stage in the instruction, then
the (A.C.M.) attempts to make $\rho_i - \rho_0 = 0$. The (A.C.M.)
also changes the membership of $N(n)$ - from which it
selects trajectories to present to the subject - according
to the following rule:-

$$\Delta N(n) = +1 \quad \text{if} \quad \delta\rho^+ > \delta\rho^- \quad \text{unless } N(n)=8 \text{ when } \Delta N(n)=0$$
$$\Delta N(n) = 0 \quad \text{if} \quad \delta\rho^+ = \delta\rho^-$$
$$\Delta N(n) = -1 \quad \text{if} \quad \delta\rho^+ < \delta\rho^- \quad \text{unless } N(n)=1 \text{ when } \Delta N(n)=0$$

Where $\delta\rho^+$ and $\delta\rho^-$ are the estimated values of $\partial\rho/\partial t$ (i.e.
rate of learning) for $N(n)$ and $N(n)-1$ respectively.

The results of the experiments with this arrangement
suggest certain conservation principles which were
discussed in Administrative Report No. 7.
These principles lead to a couple of analytic procedures,
namely:-

(1)   We may regard the coupled man/machine system as Liapunov stable.

(2)   We may regard the subsystems concerned with the η_i adaptive stabilisation of the subskills as quasi-independent components in the sense that compared to the relaxation time of the 'N' adjustment system, any one of these subsystems has a short relaxation time.   Hence the entire system can be partitioned.

A Mathematical Model for the Learning of a Structured Skill.

This work is fully reported in a paper by Pask and Mallen[1].   It is a mathematical description of the basic system behaviour when a subject learns a structured skill under adaptively controlled conditions.   It may also be argued that the model exhibits features which are common to more general cases of learning.   According to the familiar cybernetic learning model, as expounded in Annual Summary Report No.2. and elsewhere[2] the acquisition of a subskill is correlated with the development (in the subject) of an organisation that realises and embodies the subject's codes for this subskill. In the mathematical model presented here, the changes that occur when the subject learns under adaptively controlled conditions, are represented by the changes in a pair of information measures, namely H and I. Where H is the subject's uncertainty and I is the subject's maximum possible uncertainty and is determined by the experimental environment.

We envisage, in the first instance, that our model describes the acquisition of a single subskill and that the experimental environment has the following general features.

A subject is presented with a sequence of problem stimuli at a steady rate through-out a sampling interval Δt.   The sequence has an intrinsic uncertainty I associated with it. At the end of the sampling interval an adaptive control mechanism evaluates the subject's responses, and uses this information, according to some control rule, to adjust the content of the next sequence of problem

stimuli. If the problem stimuli represent components of a structured skill then the ACM can control and even optimise subject learning. Experiments conducted along these lines were reported in Annual Summary Report No.2.

Subject Assumptions.

Certain assumptions are made about the conduct of the subject in the experiment.

(1) We assume that the subject attends to the field of attention determined by the experimenter and interacts within the experimental environment "according to the rules of the game".

(2) We assume that the subject prefers to achieve goal satisfying responses rather than responses that do not satisfy the accepted goals.

Accepting these axioms, the following statements can be made regarding the abilities and behaviour of the subject.

(1) The subject has an upper and lower limit to his rate of mentation; if he is presented with material outside these limits he is unable to cope with it. We can express this condition in our descriptive model by stating that for learning to occur, the subject's uncertainty H, must at all times be such that

$$H_{max} > H \gg H_{min}$$

Where H_{max} and H_{min} are the maximum and minimum uncertainties that the subject is able to cope with.

(2) Learning will occur (i.e. $\frac{\partial H}{\partial t} < 0$) if

$$H_{max} > H \gg H_{min}.$$

(3) We assume that for all trials prior to reaching criterion performance (in a subskill)

$$\frac{dH}{dT} > 0 \text{ if } H_{max} > H \gg H_{min}$$

(4) We assume that the subject acts as a self organising system in the sense of von Foerster, i.e. the rate of change of behavioural redundancy is positive.

The model that we now present for a single subskill is the simplest that accounts for these conditions.

The Model.

For learning to occur, we know that, $H_{max} > H > H_{min}$.
Let H_O represent the subject's uncertainty at the

beginning of a trial. Then for learning to occur in that trial,

$$H_{max} > H_O > H_{min}.$$

We assume that the subject's learning rate ($-\frac{dH}{dt}$),

is proportional to :-
(1) A subject's characteristic parameter, k.
(2) The ammount by which his initial uncertainty H_O

exceeds H_{min}, i.e. ($H_O - H_{min}$).

(3) His remaining uncertainty H. Combining these, we may write:-

$$\frac{dH}{dt} = -k (H_O - H_{min}) H \qquad \text{Hence}$$

$$H = H_O \exp(-k(H_O - H_{min})t) \quad \ldots (1)$$

It is reasonable to assume that $\frac{\Delta H}{\Delta I} = $ constant.

This simply implies that the subject's uncertainty is related, in a linear fashion, to the intrinsic uncertainty of the experimental environment. For simplicity of description we assume:-

$$\Delta H = \Delta I \quad \ldots (2)$$

Next, we express the general form of the control action taken by the adaptive control mechanism. The general rule for a single subskill can be written as follows:-

$$I_{n \Delta t} = I_{(n-1) \Delta t} + \alpha \Delta I \quad \text{if } H_{n \Delta t} > H_{(n-1) \Delta t} \ldots (3a)$$

$$I_{n \Delta t} = I_{(n-1) \Delta t} - \beta \Delta I \quad \text{if } H_{n \Delta t} < H_{(n-1) \Delta t} \ldots (3b)$$

$I_{n \Delta t}$ is the value of I at the n-th trial, (trial length is Δt.
$H_{n \Delta t}$ is the value of H at the n-th trial, **before** control action is taken.
α and β are control parameters.

Considering now the behaviour of this basic model.
At t = 0 let $I = H_{to} = H_{min}$
then one trial later,
$H_{to + \Delta t} = H_{to}$, from (1)

And the control action to be taken is determined by (3a); that is,
$I_{to + \Delta t} = I_{to} + \alpha \Delta I.$

and, $H_{to + \Delta t}$ is increased to $H_{to} + \alpha \Delta I.$

During the period Δt to $2\Delta t$ $H_o > H_{min}$ and learning can and does occur. The subject's uncertainty at the end of this period is

$$H_{to+2\Delta t} = H_o(t_o + \Delta t)\ exp(-k \propto \Delta I \Delta t)$$

The decrease in H due to learning in that trial is $-\Delta H_{(to+\Delta t)} = H_o(t_o + \Delta t)(1-exp(-k\ H_o(t_o + \Delta t) - H_{min})$,

and in general the reduction in H in trial t is

$$-\Delta H_{(t)} = H_{o(t)}(1-exp(-k(H_{o(t)} - H_{min})\Delta t) \ldots\ldots(4)$$

We can see that $\Delta H(t)$ increases as t increases. At a time t_1, say, a point will be reached when $\Delta H_{(t_1)}$ is exactly equal to the increase in I, namely ΔI introduced by the A.C.M. For times after t_1 the initial uncertainty at the commencement of each trial (i.e. $H_{o(t)}$) will be $H_{o(t_1)}$. This will continue to be the case until $I = I_{max}$ at time $t = t_2$.

If the terminal criterion for a subskill is that $I_{T \Delta t} = I_{max}$ (T = no. of trials to reach criterion performance) and $H_{o(T \Delta t)} = H_{min}$. Then the time taken to reach this terminal condition will be $T \Delta t = t_2 + t_d$.

Where t_d = time required for H to decay from $H_{o(t_2)}$ to H_{min} at constant $I = I_{max}$. From (1) this time is

$$t_d = \frac{\log H_{o(t_2)} - \log H_{min}}{k(H_{o(t_2)} - H_{min})}$$

Thus, for a specific $H_{o(t_2)}$, t_d is dependent only on subject parameters and so is constant. Hence, $T \Delta t$ is minimised if $t_2 - t_1$ is minimised. $t_2 - t_1$ will be minimum when $H_{o(t_1)}$ is maximised and from (4) we see that this occurs when $H_{o(t_1)} = H_{max}$.

Then $\Delta H_{o(t_1)op} = \Delta I_{op} = H_{max}\left[1-exp\left(-k(H_{max} - H_{min})\Delta t\right)\right] . (5).$

ΔI_{op} is the optimum value of the discrete "difficulty" increase to give maximum learning rate. At equilibrium (after t_1, when $\frac{dH}{dt}o(t) = 0$).

$$\frac{dI}{dt} = \frac{\alpha \Delta I}{\Delta t}$$

Now, taking the linear approximation to equation(1) :-

$$H = - k(H_o - H_{min})t.$$

$$\frac{dH}{dt} = -k(H_o - H_{min}).$$

we note that $\frac{dI}{dt} = -\frac{dH}{dt}$ at equilibrium

and since $\frac{dH_{o(t)}}{dt} = 0$ we may put

$$\frac{dH_{o(t)}}{dt} = \frac{dI}{dt} + \frac{dH}{dt} \quad \ldots\ldots\ldots\ldots(6)$$

i. e. $\quad \frac{dH_{o(t)}}{dt} = \frac{dI}{dt} - k(H_o - H_{min}) \quad \ldots\ldots(7)$

These equations describe the behaviour of the coupled subject/machine system. $\frac{dI}{dt}$ is determined by the

A.C.M control rule.

We can interpret equation (6) as follows:
If due to some external interference, the subject begins to learn more quickly at $H_{o(t)} = H_{max}$ then $\frac{dH}{dt}$ goes more negative, and hence $\frac{dH_o}{dt}$ goes negative.
This is recognised by the A.C.M. which then increases $\frac{dI}{dt}$ to compensate. For a single subskill the A.C.M.
achieves this by changing α , the control parameter.

Extension of the Model.

So far the model has been described in terms of the continuous, information-like measures I and H. These are not easily measured during the learning process, but it is argued that they can be replaced in the relevant equations, by the sampled state variables, difficulty η_i and proficiency ρ_i.
In particular we can substitute

$$\Delta \rho \text{ for } - \frac{dH}{dt} \text{ and } \Delta \eta \text{ for } \frac{dI}{dt}$$

The model describes the processes that take place in the dynamic man/machine system when a single subskill alone is being learnt. In order to

extend the description to include the case when several subskills are rehearsed jointly, we must consider the cases of positive transfer of training and conditional interference among the various subskills. The single subskill model is characterised by the time constant Δt of the trial period or sampling interval. The A.C.M. takes control action at the end of periods of this length. In the multiple subskill case, or the case of a structured skill, control action for a particular subskill may be much delayed, since the time between one rehearsal and the next, may be relatively long. Thus the control mechanism must have a much longer time constant. The subsystem parameters change very slowly compared to the subsystem time constants Δt and so, approximately, we may regard the subsystems as separable, and if the complete system is stable, in dynamic equilibrium.

Positive Transfer of Training.

Suppose there are 'm' subskills and that we can attach 'a priori', values a, b....... to the interactions among them. That is we are given an interaction matrix

$$Z = (Q_{ij}) \text{ where } Q_{ij} = 0 \; ; \; i = j$$
$$Q_{ij} > 0 \; ; \; i \neq j.$$

The elements of this matrix indicate the amount by which the achieved state I_i of the i-th subskill aids learning rate in the j-th subskill. Consider the case when m = 2.

$$Z = \begin{bmatrix} 0 & a \\ b & 0 \end{bmatrix} \quad a, b, > 0.$$

Let us assume the subject has been brought to equilibrium, by the A.C.M, on each of the subskills individually before joint rehearsal takes place. Let t_1 be the earliest time at which both subskills are at equilibrium with $H_0 = H_{max}$. Let t_2 be the earliest time at which $I_i = (I_{max})_i$ for i = 1, 2.

Then from equation (7) we get two coupled equations specifying the new dynamic conditions for the equilibrium of the two subsystems. These are

$$\frac{dI_1}{dt} = k_1 ((H_{max})_1 - H_{min}) + b\, I_2 \ldots\ldots\ldots\ldots(8a).$$

$$\frac{dI_2}{dt} = k_2 ((H_{max})_2 - H_{min}) + a\, I_1 \ldots\ldots\ldots(8b).$$

now t_2 is determined by the lowest average $\frac{dI_1}{dt}$

and it is evident under the joint rehearsal conditions that this is minimised if $\frac{dI_1}{dt} = \frac{dI_2}{dt}$,

assuming that $k_1 = k_2$ and $(H_{max})_1 = (H_{max})_2$.

If we wish to maximise the expected rate of learning we may use the control policy indicated by this result. The A.C.M. can achieve this control by altering the microscopic difficulty levels ($\alpha\, \Delta I_1$), and ($\alpha\, \Delta I)_2$ of the two subskills or by varying the relative number of times each subskill is rehearsed.

The above analysis uses a linear approximation and it becomes inapplicable at the point, which is realised in real learning, at which the subject is using a higher order concept. When he has acquired this higher order concept the two subskills are treated as a whole and interaction between the two steps.

The case of conditional interference can be treated in a similar manner. The same rule optimising learning rate applies. Again, the linear approximation breaks down when the subject acquires a higher order concept.

Stability of the Coupled System.

Returning to the question of stability as exhibited by the coupled man/machine system. It is not altogether surprising that the coupled system shows features of stability since it is the purpose of an Adaptive Teaching Mechanism to make adjustments in the teaching environment to compensate for the changes that occur as a consequence of the subject's learning.

We will show below that it is possible to apply Lyapunov's criteria for dynamic stability to the coupled system. We can obtain a Lyapunov function for the system in terms of the behavioural redundancy R, of the subject. This will enable us to assert that a condition for stability is that the subject be able to act as a self-organizing system.

According to Lyapunov's theorem, any dynamic system with state variables z_i is stable if V is a function of these variables such that:-

(1) $\quad 0 > dV/dt. = \sum_i dz_i/dt \cdot \partial V/\partial z_i$

(2) $\quad V > 0.$

The state variables of the coupled man/machine system are the $2n$ values of ρ_i and η_i. Since, on the average, $\rho_i = \rho_0$ for all "i" (due to A.C.M. activity), we can state that $d\rho/dt = 0$. Then, the first Lyapunov stability condition (for the coupled system) becomes:-

$$0 > dV/dt. = \sum_i d\eta_i/dt \cdot \partial V/\partial \eta_i.$$

We argue that there is a function of η_i, and hence of I, which has the properties of a Lyapunov function for the system. Let this function be f(I), then we require that:-

(1) $\quad 0 > df(I)/dt.$

(2) $\quad f(I) > 0.$

Choose $f(I) = H/I = 1-R$ where R is the behavioural redundancy. Then:-

$$df(I)/dt. = 1/I.dH/dt. - H/I^2.dI/dt.$$

Now, when the coupled system is in equilibrium we have shown that $dH/dt = 0$. Thus:-

$$df(I)/dt. = - H/I^2.dI/dt.$$
Hence
$$0 > df(I)/dt. \quad \text{iff} \quad dI/dt > 0.$$

Thus the system is stable if, and only if, $dI/dt > 0$. In subject assumption 4, we assumed that, for learning to occur, the subject acts as a self-organizing system i.e. that $dR/dt > 0$ where $R = 1-H/I$. This condition implies that $dI/dt > 0$. Hence, the condition for $f(I) = 1-R$ to be a Lyapunov function is the condition that the subject be a self-organizing system.

References:

(1)   Pask G. and Mallen G.L. - The Method
of Adaptively Controlled Psychological
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(2).   Pask G., - Man as a system that needs to
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Part 2. Automaton Models and Simulated Populations.

(1). Programme Development.

In Administrative Report Number 9, we presented
fairly detailed records (automaton distributions
at moves 5,10,25,55, and 100), for a couple of
simulations that differed only insofar as in (I)
there were environment constraints intended to
favour the complex types "x" and "+" whilst in
(II) these constraints were deleted. The constraints
prohibited simple automata(those of types "-" and "1")
access to certain nodes which were thus exclusively
the feeding ground for complex automata.

It turned out that the complex automata were
dramatically dominant in (I) and in (II). In each
case the simple automata became extinct as might be
expected.   The rate of extinction was rather
greater in (I) than in (II) and the steady state
population number of complex automata is greater
in(I) than in (II).

This sort of dominance does, of course, depend
upon an initially diffuse distribution of automata
(the main experimental condition for Administrative
Report Number 9). Entirely different patterns (in
which the simple types of automata are relatively
more numerous) can develop from compactly structured
initial distributions, for example, the populations
in Graph 1.I and in Graph 1.II, of the induction
experiments described in Annual Summary Report
Number 2.   However, there is a sense in which a
"simple dominance" is metastable; transitions
" 1 or - +   or X" are permitted but the converse
transitions "t or x⨯ol or - " are not. the
induction effects produced in the experiments of
Annual Summary Report Number 2, all depend, in
one way or another upon this effect; similarly,
of course, biological induction depends upon the
metastability of equipotential cells which, in
this case, is due to the probability of differentiation
and the improbabilityand usually pathological
occurrence of dedifferentiation.

To ensure that the complex dominance effect in
(I) and in (II) is not an accident, these simulations
have been continued for a further sequence of 100
moves (making 200 moves in all of which the first
100 have already been reported). The results
appear in Graph.1. and in Graph 2 of the present
Report.

We now consider reducing the dominance of
these complex types of automata by selectively
increasing the cost of structural maintenance
for all of "x" or "+",and decreasing it for "-" or"1".

It is fairly easy to find a value of the
structural maintenance cost parameter (the amount
of food in the stomach of an automaton that must
be expended, each move, to maintain the automaton
body at a given age level) which renders the steady
state population instable and which will render it
extinct because automata that are able to reproduce
fail to make the encounters that are a prerequisite
for reproduction before they decay. The determination
of this cost value is shown in Graph 3, for the
environment with constraints and in Graph 4, for
the environment without constraints. The fact
that the critical value is higher in Graph 3
than in Graph 4 is due to the "filtering" effect
of the environment constraints which tends to
separate "x" from "+" into different habitats
as well as favouring "x" and "+" against the
"-" and "1" (the separation of habitats will,
on average, provide the automata with more food).

Now we insert a more than normal but slightly
less than critical value of the cost value into
the initial conditions of a simulation (so that
it acts upon the "x" and "+" automata before the
"-" and "1" automata have become extinct). In
this condition the maintenance of the "x" and "+"
population numbers depends jointly upon the
encounter of viable "x" or "+" and the encounter
of combinations of viable simple automata, namely
generative encounters of the type "-" with "1"
into "x" or "+". Insofar as the complex population
is marginally stable on its own it depends upon
generative encounters between simple automata.
Insofar as the larger than normal maintenance
cost value reduces the number of complex automata
at a given instant, the simple automata are
able to survive.The dependency, cited above,
renders the population of simple automata somewhat
analagous to a food supply to the complex automata
and so the complex automaton population can be
stable if and only if it allows its food supply
to survive by limiting its rate of reproduction.

In view of these comments the data in Graph 5,
for the constrained environment and in Graph 6, for

The unconstrained environment is not altogether surprising. As the value of the cost of maintenance parameter is increased from Graph 5 to Graph 6 for (I) and from Graph 7 to Graph 8 for (II) an oscillatory interaction develops between the simple automata and the complex automata. The form of oscillation is more evident in Graph 9 where the "x" and "+" automata are lumped together as complex types and the "-" and "1" are lumped together as simple types (for the constrained environment) and in Graph 10 (where the same procedure is adopted for the unconstrained environment). It resembles the Volterra like predator prey interactions that have been modelled in a statistical fashion by Kerner (1), and there is every reason to believe that the underlying process is some primitive form of the predator prey interactions he and others have considered in real life populations. As the cost of maintenance value is further increased the oscillation frequency increases (and predictably, since it is a non linear system) their amplitude also increases. Rather suddenly the amplitude of the oscillation becomes so great that one of the negative excursions reaches 0 for the simple automata. Since (by definition) the complex automaton population is instable alone at this value of the cost parameter and since there are no simple automata left, the entire system decays.

There is no explicit rule embodied in the programme that allows the automaton population to restrict its rate of reproduction. Yet it is evident that a restriction is applied, for otherwise the oscillatory behaviour would be, at the most, of ephemeral occurrence. In fact, this oscillatory behaviour persists over a considerable range of values of the cost parameter.

(2) Implicit Mechanisms

The mechanism involved is of some interest because the commentators on Kerner's work (1), often appear to regard his statistical conclusions as contrary to the point of view adopted by Wynne Edwards (2) in his discussion of homeostatic mechanisms for the control of population numbers. In fact there is no necessary disparity between the statistical and the homeostatic point of view in this matter, and the present simulation, primitive though it is when compared with a real life population, serves as a vehicle for the unifying argument that will be briefly presented.

According to Wynne Edwards (2) thesis (which was mentioned in Annual Summary Report 2) the local population in a given habitat either inherits or develops conventional constraints which act as a homeostatic mechanism for maintaining the number of members of the population near to an optimum value determined by the food available from this habitat. The sensory mechanism is usually a ritualised Epidictic display, for example, the ritual singing of male territorial birds and their habit of flying around their territory. Such a display allows any individual to glean and to compare information regarding the fruitfulness of the habitat and its number of occupants. The operation that is performed by the homeostatic control system is a limitation of the rate of reproduction or alternatively an operation that leads some members of the population to emigrate into another habitat. (Several, rather varied, mechanisms have been cited as responsible). The decision regarding which organisms shall be prevented from reproducing or induced to emigrate is made by an hierarchical ordering of the members of the population which is analagous to, and for some species may be identical with, the familiar peck ordering of fowls. Something akin to an hierarchical ordering is built into the present simulation due to the manner in which automata with a high value of stomach content are processed before those with a lower stomach content. However, a similar ordering is built into any population wherein the members differ in vitality or speed of response (which is true of any realistic population) and where vitality or speed of response confers some advantage upon the organism concerned (this advantage may, of course, be overlaid by a conventional ordering). But the simulation contains no conventions that are analagous to the Epidictic display or mechanisms analagous to a variation in reproduction rate.. Wynne Edwards refers to the gamut of sensory activities involved in the Epidictic display and the subsequent decision regarding which organisms shall be inhibited as "symbolic competition"(which is really a cooperative process)and the crucial issue is emphasised by the comment that our simulation programme makes no explicit provision for the cooperative process of "symbolic competition"(apart from the food procedence mentioned a moment ago)

In contrast, the idea of statistical interaction
lacks any cooperative feature. The predator prey
interaction is wholly competitive in character! As
the predators eat up the prey, fewer predators are
able to live in the habitat, hence the number of prey
can increase and consequently more predators may,
after some delay, be accommodated. If what amount
to "weak interactions" between predators are
subsumed by a "statistical mechanics" it is shown
that the situation can lead to an oscillatory
dynamic equilibrium; rather than the crass instability
predictable on the basis of a deterministic approach.

Mathematically, this system is impeccable. From
a practical point of view, however, we may profitably
make a closer examination of the population of
predators, and also of the weak interactions. For,
on the one hand, it is evident that a homeostatic
system would be an advantage if it existed. On the
other hand, it is evident that almost any conceivable
realised population will embody constraints and
inertial terms that could provide an implicit
homeostatic mechanism even in the complete
absence of any manifest or explicit or predetermined
arrangement. Such an implicit mechanism is readily
adumbrated by weak interaction and in some cases
exerts the required smoothing effect.

Our simulation, for example, provides
an implicit homeostatic mechanism. The automata
cannot learn on their own but cooperating groups of
automata most certainly can learn. There is plenty
of evidence that organised collections of automata
act as sensory devices that detect the food
concentration and possibly the automaton density
in the neighbourhood of a cooperative group of
automata. If, for example, the motile "x" automata
are deleted from the replicating cooperative group
of automata shown in DIAGRAM 8 of Annual Summary
Report 2, the entire structure decays. It is likely
that these automata have a sensory function with
reference to the group and in less elaborate cases
than DIAGRAM 8. such a function is perfectly evident.
Similarly, even though there is no explicit mechanism
for adjusting the rate of reproduction, there are many
cooperative interactions that allow an aggregate of
individuals to prevent the reproduction of an individual
member of this aggregate or a particular type of member.
These microscopic modes of interaction have been
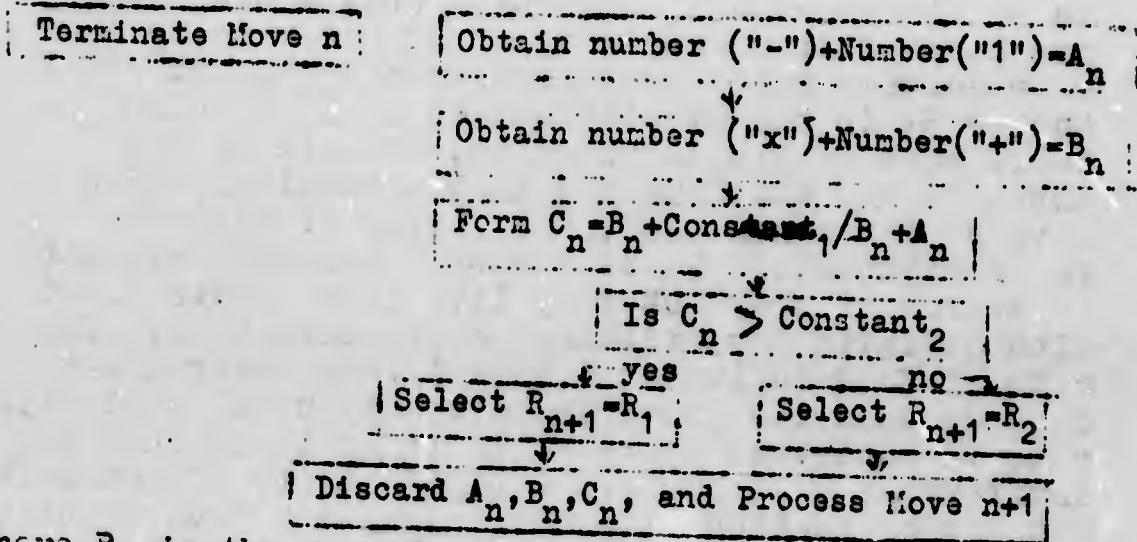adequately reviewed in previous publications.(3)(4).

It is difficult, and it may be impossible, to hold a particular implicit mechanism as responsible for the manifest control of predator numbers(the homeostatic system is almost certainly a distributed control system). However, it can be argued that a greater number of microscopic features are available in some conditions than in others, for example, that the unconstrained environment provides a greater diversity of potential implicit mechanisms (whether or not these are in fact used) than the constrained environment. In this connection, it is worth commenting that the elaborate population is stable over a larger range of cost parameter values in the unconstrained environment than it is in the constrained environment

The existence of implicit mechanisms able to form an implicit homeostatic system is a mechanical consequence of modelling, in a detailed fashion, the sort of organisation that is imaged at a macroscopic level by the competitive mathematical structure. These implicit mechanisms entail microscopic cooperation, often perhaps the mode of cooperation called symbolic competition. Hence, there is no hard and fast demarcation between a population that does and does not satisfy the paradigm of social homeostasis, although a ritualistic or conventional framework can be detected when this homeostasis is explicitly manifest. Since these comments are true for a rather crude model like the present simulation, they are presumably applicable in the case of any physical realistion, such as a real life population of organisms, where the constraints imposed by the physical fabric are more stringent and the inertial properties of this fabric are more elaborate. Thus, far from arguing that either thesis of mutualism is mistaken, I maintain that there is a continuum of which each thesis is one extreme case. In reality, the dynamics of mutualism are to be described by some point on the continuum. The only criticism is operational. Whilst the homeostatic mechanism remains implicit it may often be impossible to distinguish, according to operational criteria, whether or not it exists.

(3). Explicit Mechanisms.

It is possible to introduce explicit homeostatic mechanisms for the control of the number of automata

in the population at a macroscopic or at a microscopic level. The macroscopic control is mediated by the experimenter, but it could be embodied in an additional subroutine for the programme. The particular mechanism that has been adopted is not ideal and its form is chiefly determined by what is and is not an accessible part of the programme. It is easy, in practice, to obtain a print out of the number of simple automata "-" and "1", and the number of elaborate types "x" and "+". Further it is easy to modify the reproduction rules from move to move. Hence, the explicit homeostatic mechanism is merely:

| Terminate Move n |

| Obtain number ("-")+Number("1")=A_n |

| Obtain number ("x")+Number("+")=B_n |

| Form $C_n = B_n + \text{Constant}_1 / B_n + A_n$ |

| Is $C_n >$ Constant$_2$ |

yes   no

| Select $R_{n+1} = R_1$ | | Select $R_{n+1} = R_2$ |

| Discard A_n, B_n, C_n, and Process Move n+1 |

Where R_n is the reproduction rule to be used in processing the automata at the n-th move and where R_1 is the reproduction rule used in the present simulation, namely;

$R_1 = $ -o- = 75% -, 25% 1; lol = 75% 1, 25% -;

-ol = lo - = 50% "x", 50% "+" XoX = 100% X; + o += 100% +;

and X o + = X.o + = 50% x, 50% +;

and R_2 is the reproduction rule

$R_2 = $ -o- = 75% -, 25% 1; l o l = 75% 1, 25%; - o l = l o - = 50% x, 50% +; x o x = Nothing.

The effect of employing this macroscopic control system is exhibited in Diagram 11 and Diagram 12.

Explicit social homeostasis can also be
introduced at a microscopic level to yield a
distributed control system. The microscopic
mechanism is a rule that is built into all or some
of the automata and which, if suitably chosen,
acts as a form of social constraint (the automata
are designed to accept a limitation in the interest
of the group even though it may be contrary to
their own immediate welfare). Experiments with
microscopic mechanisms have been performed with
the earlier simulations, briefly mentioned in
Administrative Report Number 5 that contained
automata having 8 possible motions and imaged
as ✳ in the usual convention (the ✳ automata
are reached from simple types of automata by the
reproduction rules in Administrative Report
Number 5; in the simulations we shall discuss
there were no simple automata, and all of the
automata had the form ✳; in the simulations we
have so far considered, the ✳ type of automaton
is prohibited). These 8 motion automata are not
in search of prey but they live in an environment
with definite "overfishing" characteristics. The
rate of food influx at a node in the environment
depends upon its previous occupancy until a limiting
rate is achieved. Until this limit is reached the
environment will support a high density of automata.
But any collection of nodes is readily "overpopulated"
for beyond this limit such a high density of automata
cannot be supported. The population has "overfished"
the environment and it cannot survive unless it
is able to detect an approach to this critical
value before the value is reached and to adjust
its density. The fact that populations such as those
imaged in Graph 13 and Graph 14 (for population
number) and Graph 15 and Graph 16 (for the
corresponding food average) were, in fact, stable
is further evidence in favour of implicit mechanisms
of social homeostasis, for without it overpopulation
could hardly have been avoided in at least some
regions (of course, overpopulation did occur, in
many simulations).

Amongst several types of ✳ automata used in
these experiments one was "gregarious". The i-th
"gregarious" automaton contained an adaptive
parameter assuming the value of P_{in} at the n-th move.

It was equipped with a sensory arrangement for
determining the density of automata (rather than the
level of food) at the nodes to which it could move and
at the n-th trial, moved to whichever node had a
density of automata nearest to P_{in}. This sort of
automaton also had a "memory" system wherein it
could record the average increment of stomach
food whilst P_i was being increased by +1 for each
move, say $Z_{in}+$ and the average value of this
increment whilst P_i was being decreased by -1 for
each move, say $Z_{in}-$. It adjusted the value of P_i
by making

$$\Delta P_{in} = +1 \text{ if } Z_{in}^+ > Z_{in}^-$$
$$= 1 \text{ if } Z_{in}^- > Z_{in}^+$$

this "adaptation" smoothed out the density
distribution and stabilised some types of
population, but it was liable, as we have already
commented to an inherent instability that stems from
the fact that aggregations of automata with high
mean P_i values reproduce rapidly when they come across
a favourable part of the environment but are unable
to disperse when the food is depleted (they need a
mechanism like the phase mechanism for locust
emigration, but the programme does not provide it).

The gregarious automata were next developed
into a form that used the automaton density data
and the adaptively controlled value of P_{in} to
adjust the critical stomach food level at which
reproduction occurs, if there is a suitable encounter
with another automaton (the motions of these automata
were determined, as in the case of other non-gregarious
automata, by the food levels at all accessible nodes.
They move to the maximum food level available).

This arrangement is certainly an explicit
homeostatic mechanism and its efficacity at the level
of the population, rather than the individual
automata, is indicated by comparison of the "normal"
and the "homeostatic" curves in Graph 17 and in
Graph 18. The perturbation applied to induce
instability is a sudden, experimenter controlled
decrease in the food level at all of the nodes in
the environment. It is evident that the "homeostatic"

population is far more tolerant of this perturbation than the "normal" population from which it differs by the adjunction of the explicit control over rate of individual reproduction. This comparison is not exact because rather a long interval is needed (about 25 moves) for the P_{in} to assume

representative values. However, the effect exhibited is dramatic and similar effects can be produced repeatably in different populations (there is a mass of partly analysed print out that supports this point on inspection).

(4)   Social Norms.

There are many ways in which features of a developing population can be usefully described.   In Annual Summary Report 1, for example, we presented detailed data about the motions of individual automata.   It would have been possible to compute the correlations of motions and it might, in some conditions, be worthwhile.   Less detailed information is provided by density distributions and move by move plots of population number or plots of the average numbers of different types of automata.

Amongst the more interesting sorts of data, is a curve representing the numbers of individual automata that possess a particular property.   A couple of these curves are shown in Graph 19 and Graph 20.   If these distributions are invarient over a reasonable number of moves or if they show regular and correlated transformations they are often more revealing than an account of the motions executed by the automata.

In sociological studies, for example, stable distributions of this sort (made with reference to the number of individual organisms having a sociologically cogent attribute value) are called social norms. Arguing conversely (and no longer restricting our attention to social attributes) the motion characteristics of automata in the environment constitute a very specialised and not necessarily very interesting set of norms.   Indeed, suitable automata need not move in any such environment as a plane of nodes. They might equally "move" in a space of properties and the character of their motion might equally well be described by norms

or number distributions made with reference to
any or all of these properties. This is the type
of description and the type of automaton which is
considered in Part 3 of the present report. The
automata have an "abstract environment" which is,
however, more readily identified with interesting
facets of reality than a special plane of nodes.

(5). <u>Main Results.</u>

The present type of simulation has served a number
of purposes and has been used to test several
hypothesis. In some respects the picture it
provides, though readily conceived at a superficial
level,is cumbersome and of limited applicability.
Hence, although the programmes will be preserved and
may occasionally be used,it is not expedient to
carry out further experimental studies in this
framework. The picture remains, however, an
admirable vehicle for demonstration.

In fact, the chief merit of such a simulation
lies in the opportunity it affords for investigating
<u>mechanisms</u>. The macroscopic characteristics of
populations are often mathematically tractable and the
mathematical or statistical model is obviously
preferable (in the macroscopic case) when it is
available. There would thus be no real point in
trying to validate macroscopic hypothesis within
this framework (there may, of course, be some
exceptions to this comment) and the mechanistic
hypotheses that <u>can</u> be tested are greatly restricted
by the form of the environment and the interpretation
of events as "motions" in a "plane". We shall
indicate the main achievements,so far, and proceed
to some radical innovations.

(I) The microscopic behaviour of automata ina
potentially cooperative environment has been fully
investigated. The initial experiments were rather
crude hand simulations, carried out informally by
the author. These have been checked and in most
respects confirmed by a number of careful hand
simulations performed under this contract. The
microscopic behaviour of motion, simple interaction,
reproduction and the cooperative actions of
cooperative groups of automata have been checked
on an initial computer programme (designed in accord
with the hand simulation) and described in the
Annual Summary Report No.1.

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(II)   Cooperative groups were shown to replicate as in Annual Summary Report 2.

(III)   Their members were shown to conditionally differentiate. In other words a persistent division of labour has been demonstrated.

(IV)   The stability and cooperative interaction of various types of <u>adaptive</u> automata have been examined. Broadly, an adaptive automaton is able to introduce a form of variation akin to the variation between individuals who have learned from a different background of experience..

(V)   Generative reproduction rules, of the type considered in Administrative Report 5, have been simulated. The later generative simulations deleted type ✳ to avoid the convergence of X and + to a single type.

(VI)   A study of induction with 4 type populations of automata is described in Annual Summary Report 2, and serves to distinguish several mechanisms for induction.

(VII)   Using 4 type populations and a rather simplified environment in which only the main features of the food distribution are preserved (but in which the "payoff" function governing the interaction between the automata is still "superadditive", so that cooperation is still advantageous) it has been possible to consider the effect of constraints that favourthe "elaborate" types of automata "x" and "+". These selective constraints are a generalisation of the idea of a "filter" for automata previously mooted in connection with the informal hand simulations. The flow chart for the modified programme embodying the generative rules and the simplified environment - as DIAGRAM 1 - is attached (since it has not appeared in previous reports).

The effect of the generalised "filter" constraint is described in Administrative Report Number 9 and in the present report.

(VIII)   In the present report we consider a predator prey like interaction wherein, by increasing the cost of maintenance parameter value for the "x" and the "+" automata these elaborate types of automata act as predators in respect to the simple automata of types "−" and "1" that act as their prey.

(IX)   Implicit mechanisms and explicit mechanisms
for population number control or "social homeostasis"
have been discussed and exhibited. The "implicit"
mechanisms exist in all of the simulations. A
macroscopic explicit mechanism has been described
and its effects have been observed in conjunction
with the "simple" environment programme. This
explicit mechanism was shown to stabilise a viable
population of automata and to render it "viable" in
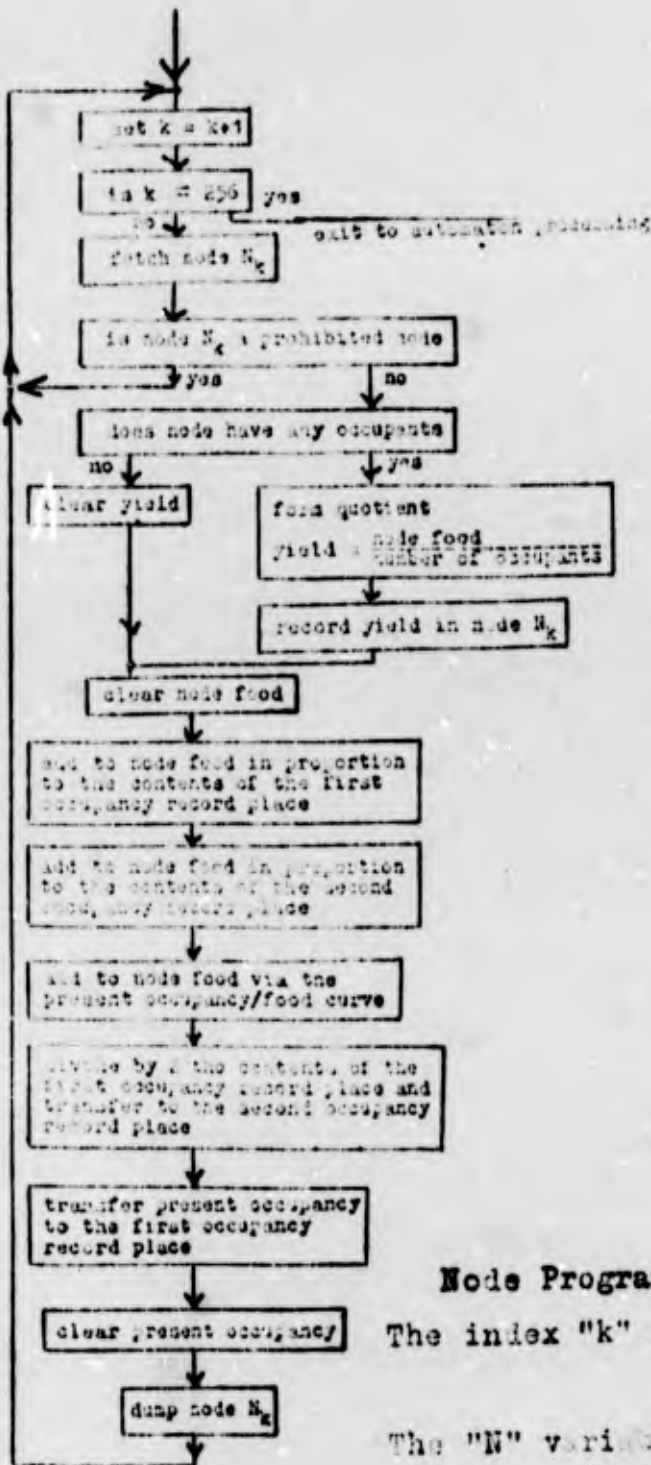conditions that proved inadequate in the absence of
this mechanism.

(X)   Experiments using a microscopic (and distributed)
mechanism for social homeostasis have been performed
with a modified type of gregarious automaton. Although
the data has recently been extracted from the print
out and presented in the present report, the experiments
(which involve the original environment) were carried
out more than a year ago.

        These results have been obtained using a couple
of essentially different computer programmes, written
by R.J. Feldmann for the I.C.T.1202 computing machine,
in machine language. Several modifications of each
basic programme have been used. The first programme
is outlined in Annual Summary Report Number 1 and
replicates the hand simulations that are described
in that report.   The other programme is outlined
in the attached flow chart in DIAGRAM 1.   Mr. Feldmann
was also responsible for the idea of a gregarious
automaton and since leaving this organisation has
conducted several "automaton like" simulations
(the details of his present work can be obtained
from him at the University of Bonn.   But, very
broadly, I understand that he is trying to apply
concepts of the sort used in the present study,
within a chiefly biological framework, as a model for
particle interactions or at any rate descriptions
of particle interactions, in physics).

        Although the results we have reported have been
presented at various meetings, they have not yet
been published (apart from an account of the informal
hand simulations and some descriptions of the field).
A couple of papers, one chiefly concerned with the
induction experiments and the other with the mechanisms
for social homeostasis, are being prepared.   These

papers may be published in "Kybernetik" or
possibly submitted to the "Bulletin of Mathematical
Biophysics". A bald statement of the experimental
results will appear in the Proceedings of the 4th
Congress of the International Association of Cybernetics
to complement the description[5] which has recently
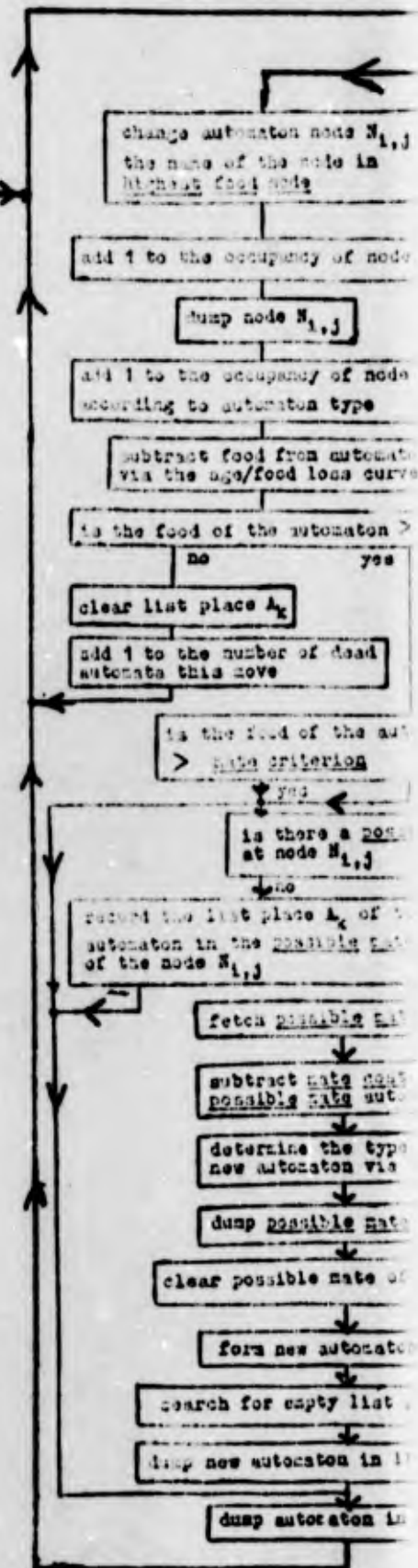appeared in the proceedings of the 3rd Congress,
held in 1961.

Later,it is intended to examine the already
existing print out in greater detail and to publish
a commentary upon the more subtle features of the
system.

Node Programme:

The index "k" runs between 0 and 255.
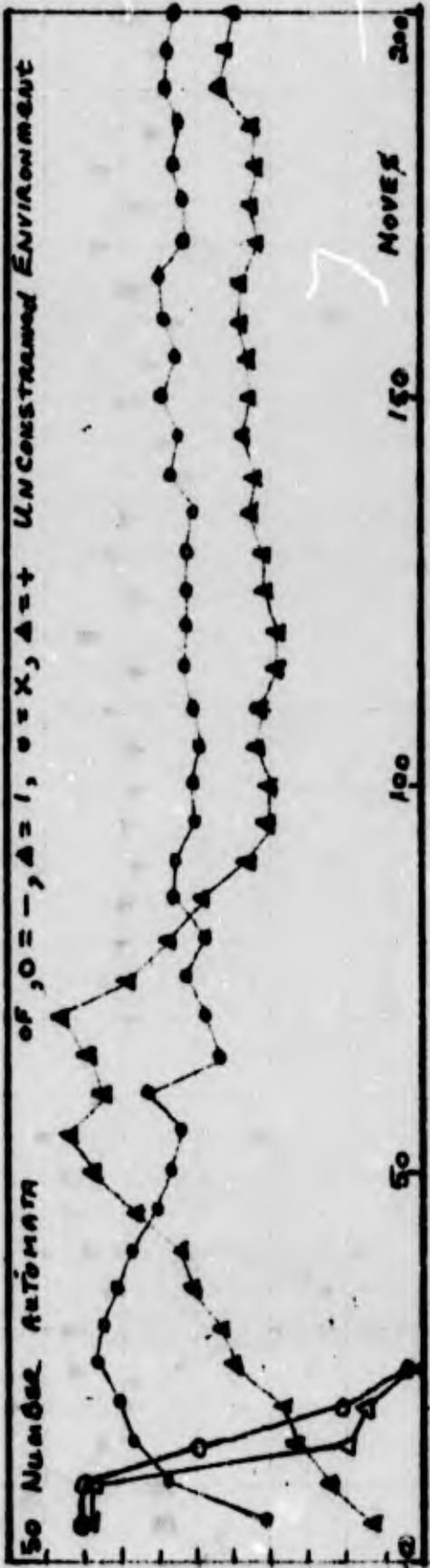
The "N" variable is the node variable

set k = k+1

is k = 256 — yes → exit to automaton processing

no

fetch node N_k

is node N_k a prohibited node — yes / no

does node have any occupants — no / yes

clear yield

form quotient

$$yield = \frac{node\ food}{number\ of\ occupants}$$

record yield in node N_k

clear node food

add to node food in proportion to the contents of the first occupancy record place

add to node food in proportion to the contents of the second occupancy record place

add to node food via the present occupancy/food curve

divide by 2 the contents of the first occupancy record place and transfer to the second occupancy record place

transfer present occupancy to the first occupancy record place

clear present occupancy

dump node N_k

A

Automaton Programme:

The index "k" runs betw...
The "A" variable is the...
the automaton resides.
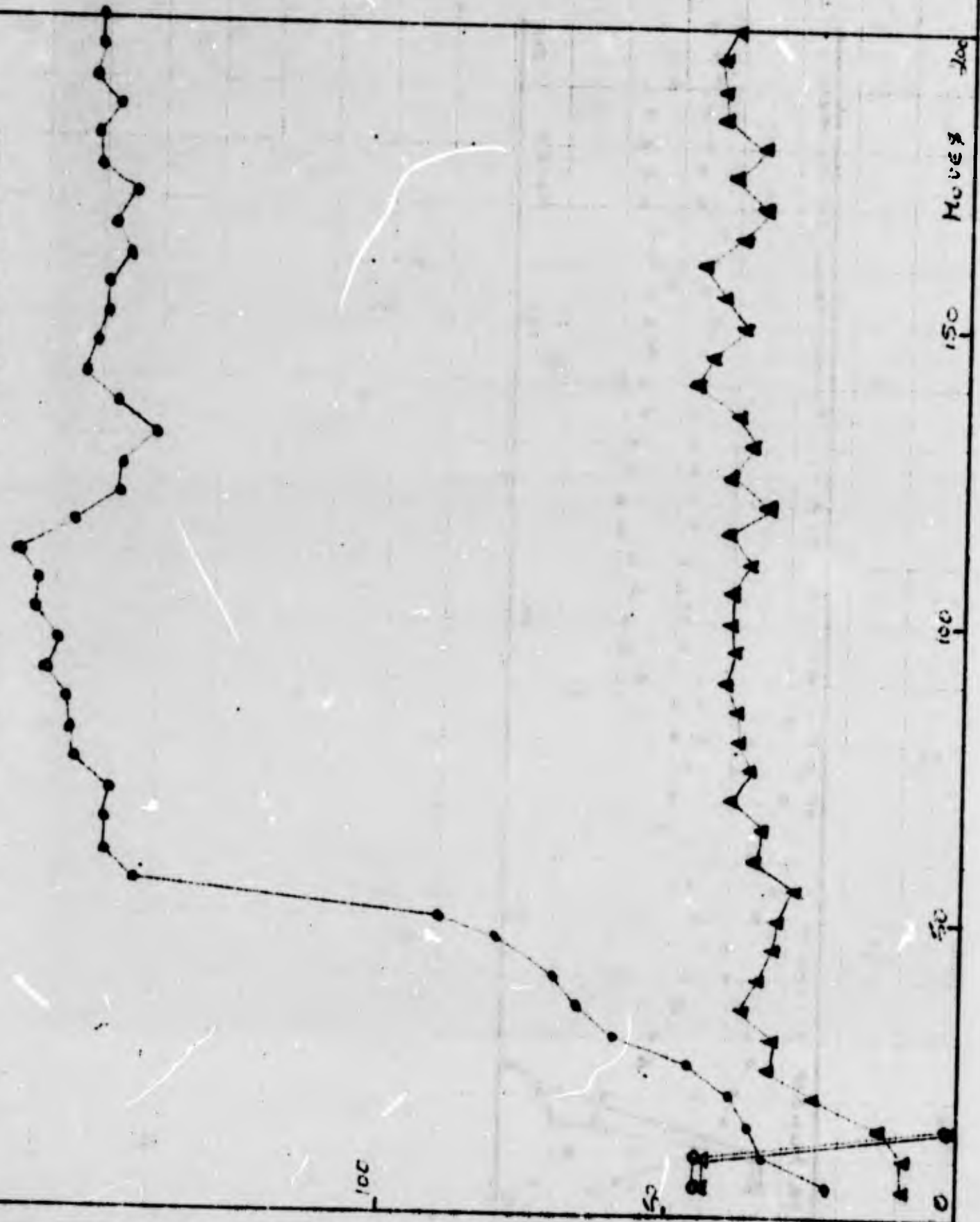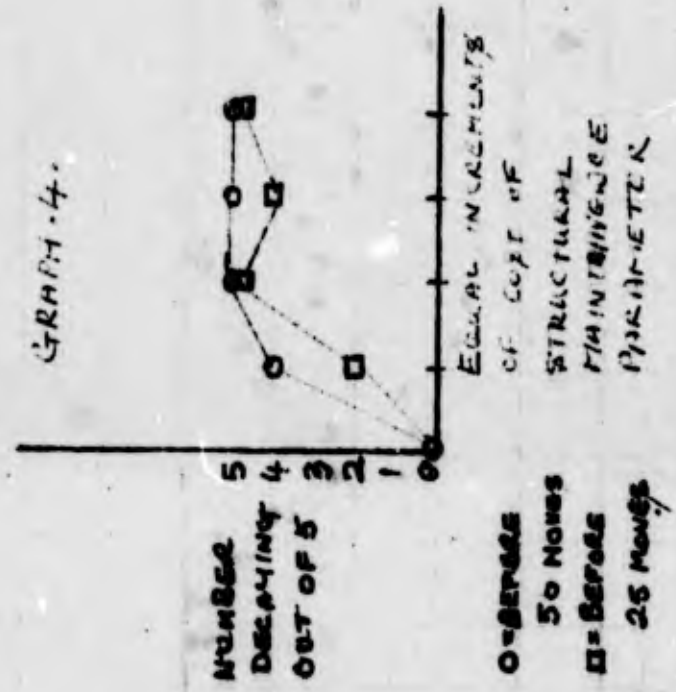The node variable in the
$N_{i,j}$ i-th row, j-th c...

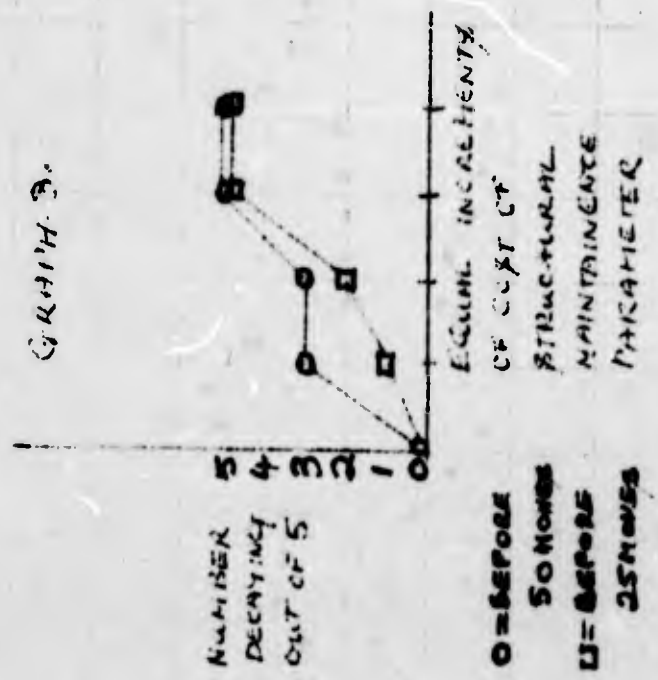change automaton node $N_{i,j}$
the name of the node in
highest food node

add 1 to the occupancy of node

dump node $N_{i,j}$

add 1 to the occupancy of node
according to automaton type

subtract food from automaton
via the age/food loss curve

is the food of the automaton > — no / yes

clear list place A_k

add 1 to the number of dead
automata this move

is the food of the aut...
> mate criterion — yes

is there a pos...
at node $N_{i,j}$ — no

record the list place A_k of
automaton in the possible mate
of the node $N_{i,j}$

fetch possible mate

subtract mate food...
possible mate aut...

determine the type
new automaton via

dump possible mate

clear possible mate a...

form new automaton

search for empty list

dump new automaton in...

dump automaton in

DIAGRAM 1.

Flowchart boxes (left column, top to bottom):

- change automaton node $N_{i,j}$ to the name of the node in highest food node
- add 1 to the occupancy of node $N_{i,j}$
- dump node $N_{i,j}$
- add 1 to the occupancy of node $N_{i,j}$ according to automaton type
- subtract food from automaton via the age/food loss curve
- is the food of the automaton > 0   no / yes
- clear list place A_k
- add 1 to the number of dead automata this move
- is the food of the automaton > mate criterion   yes / no
- is there a possible mate at node $N_{i,j}$ no / yes
- record the list place A_k of the automaton in the possible mate of the node $N_{i,j}$
- fetch possible mate automaton
- subtract mate cost from the possible mate automaton
- determine the type of the new automaton via table A
- dump possible mate automaton
- clear possible mate of node $N_{i,j}$
- form new automaton
- search for empty list place A_j
- dump new automaton in list place A_j
- dump automaton in A_k

Flowchart boxes (right column, top to bottom):

- set k = k+1
- is k = 256   no / yes → exit to print results
- fetch contents of list place A_k
- is list place A_k occupied   no / yes
- add 1 to automaton age
- fetch into highest food node the node $N_{i,j}$ at which the automaton resides
- add to the automaton the food yield of the node $N_{i,j}$
- is the automaton % or + or ¦ type   yes / no

block ¦:
- is i-1 ≥ 0
- fetch node $N_{i-1,j}$
- if the food of node $N_{i-1,j}$ > the food of the highest food node
- transfer node $N_{i-1,j}$ to the highest food node

block ¦ (dashed)

- is the automaton % or + or — type   yes / no

block ←

block →

- is the automaton % or x type   yes / no

block ﹨

block ╱

block ⟋

block ╲

Automaton Programme:

The index "k" runs between 0 and 255.
The "A" variable is the name of the storage location in which the automaton resides.
The node variable in the automaton program is doubly indexed
$N_{i,j}$ i-th row, j-th column, where i and j run between 0 and 15.

GRAPH 1.

50 Number Automata of, $O = -$, $\triangle = 1$, $\bullet = X$, $\blacktriangle = +$ Unconstrained Environment

50   100   150   200

MOVES

GRAPH 2.

NUMBER OF MATCHES, O = —, Δ = 1, □ = X, ▲ = +   Constituent Environment

HOVER

GRAPH 3.

NUMBER
DECAYING
OUT OF 5

5
4
3
2
1
0

EQUAL INCREMENTS
OF COST OF
STRUCTURAL
MAINTENANCE
PARAMETER

O = BEFORE
50 HOURS

□ = BEFORE
25 HOURS

GRAPH 4.

NUMBER
DECAYING
OUT OF 5

5
4
3
2
1
0

EQUAL INCREMENTS
OF COST OF
STRUCTURAL
MAINTENANCE
PARAMETER

O = BEFORE
50 HOURS

□ = BEFORE
25 HOURS

GRAPH. 5.

Number Automata   O = -   Δ = 1   Constrained Environment

Number Automata   ● = X   ▲ = +   Constrained Environment

GRAPH. 6.

GRAPH-7.

GRAPH. 8.

GRAPH·9.

Automaton Number $c = x \frac{or}{} + \square = -\frac{or}{} 1$ Constrained Environment

GRAPH·10.

Automaton Number $c = x \frac{or}{} + \square = -\frac{or}{} 1$ Unconstrained Environment

GRAPH·11·

AS IN ⑨ w³
TO MOVE 100

STABILISATION
INTRODUCED
AT "C" BETWEEN 4 AND V

NUMBER OF O = X OR +
□ = - OR I

MOVES

GRAPH·12·

AS IN ⑩ w³
TO MOVE 100

STABILISATION
INTRODUCED
AT "C" BETWEEN 4 AND V

NUMBER OF O = X OR +
□ = - OR I

MOVES

Number Automata — GRAPH·13.

Food Available — GRAPH·14.

Number Automata — GRAPH·15

Food Available — GRAPH·16.

Number Automata

Food Available

Number Automata

Food Available

GRAPH. 17.

Level of food
influx Reduced
by approximately
50% at
point - - - - -

GRAPH. 18

Level of food
influx reduced
by approximately
50% at
point - - - - -

GRAPH 19.

Sequence of histograms
showing the percentage
of automata that are
associated with different
values of P_i

Move 20

Move 40

Move 60

Move 80
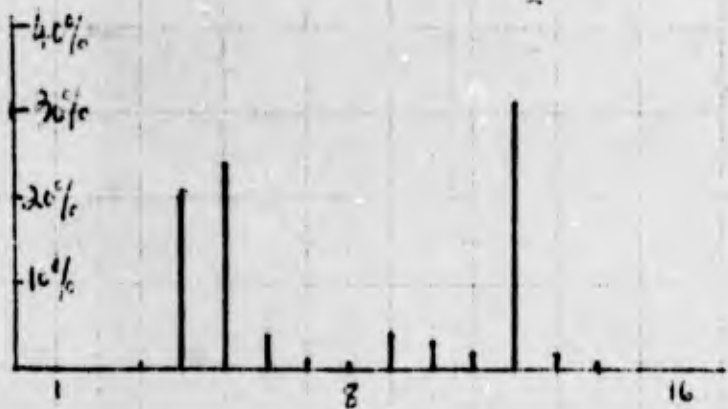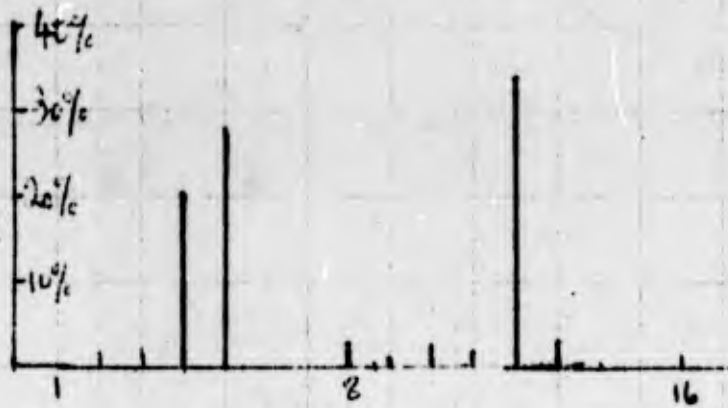
Move 100
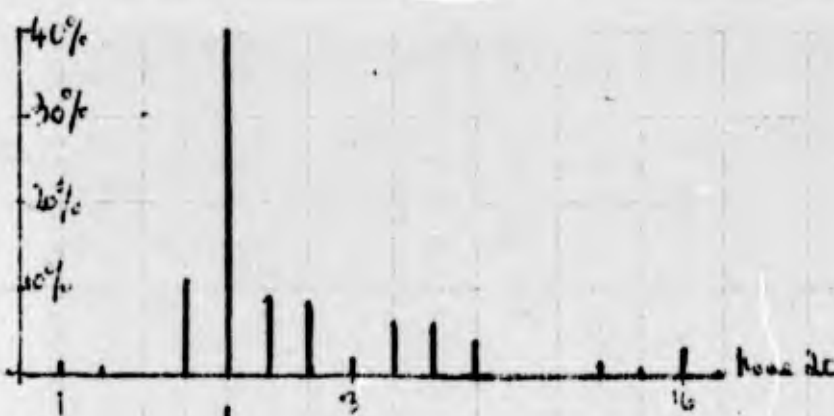
GRAPH 20

Sequence of histograms showing the percentage of automata with different values of relative horizontal and vertical motion.

The appearance of β in addition to α is correlated with the appearance of another cooperating group of automata.
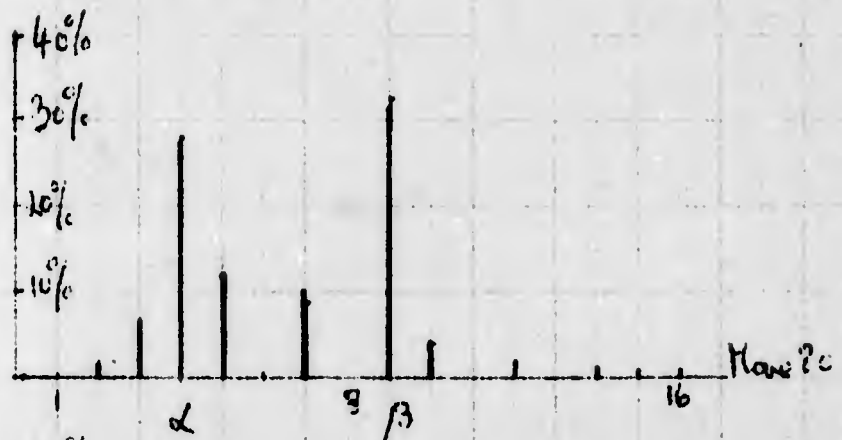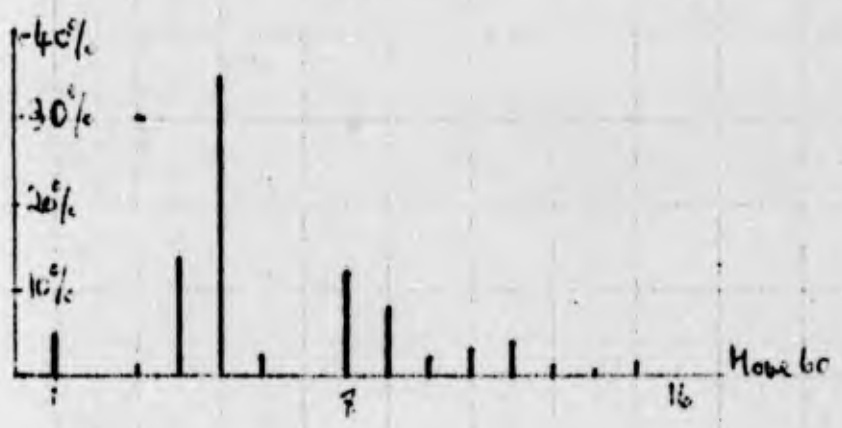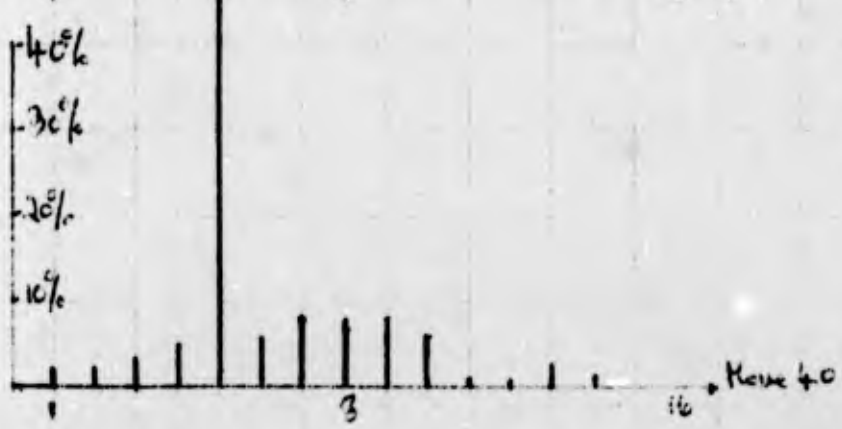
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Discussion of criteria for designing additional programmes.

In the abstract we aim to simulate a cycle of activity of the form indicated below. It may be variously identified as "learning" or the development of an embryo or the development and evolution of a social structure. This "cycle" is

(1)   Variation, producing a variety of potentially novel forms.

(2)   Differentiation, through a selective process, to produce some stable and distinct entities realising a subset of these forms.

(3)   Dispersion of and discrimination between these stable entities.

(4)   Cooperative interaction between these entities to produce higher levels of organisation, so that variation can provide potentially novel forms of a higher order in an hierarchy of control and organisation.

Depending upon the chosen identification of the Cybernetic Model the variation in (1) may be "Mutation of a genetic code" or "the effect of differing experience", the differentiation in (2) may be biological differentiation, the application of an available analogy relationship, the realisation of a code, imprinting, or the stable division of labour in society; the dispersion in (3) may amount to adaptation, discrimination, the movement apart of cells from different tissues, or localisation. Finally, the cooperative interaction in (4) may amount to evocation in the embryo of a novel structure by the juxtaposition of previously separate tissues, the production of a novel analogical relationship, or the acquisition of a conceptual structure.

The cycle indicated is entirely consonant with the initial statement of the "evolutionary system" model that is contained in publications such as (3), (4), and (5). The innovations needed in order to bring matters up to date are chiefly a realaxation of the constraints upon the environment in which the

"entities" become dispersed and through which
they interact and a separation between the codes
for individual entities that develop the "forms"
of the previous paragraph) and the codes for the
"higher order" entities that (as in the previous
paragraph) are produced by their interaction.

We have already commented upon the
environmental restrictions. It is proposed to
remedy this defect by reducing the environment
to a payoff (analagous to food) a communication
network (determining the neighbourhood of automata
or entities in the simulation) and, a communication
cost defined as a function of proximity in this
network.

So far as the codes are concerned some further
discussion is necessary. In the present simulations
we have embedded rules that allow the individual
automata to become more elaborate as they develop,
for example, that allow pairs of "-" and "l" to form
the "x" and "+" types of automata. In this particular
case the production of an "x" type or an "+" type of
automaton is explicitly an unfolding and realisation
of the basic code for an * type of automaton. Hence,
the event is distinct from the production of a code
of the sort that occurs when a cooperative group of
automata develops as a stable system, is replicated,
and persists. The cooperative group also has a code
although it is not explicitly stated in the programme.

In the first place, we intend to automatically
produce or (in degenerate cases) to explicitly embed
the codes for higher order structures and to separate
the code for the original and automaton like entities
(from their realisation) so that this code has the
status of a set of instructions that are carried by
the automaton. The automatic production of higher
order codes presents a chiefly technical problem.
It appears to be practicably solvable in several
ways but no solution has so far been selected.

The codes of the individual automaton are to
be progressively modified as a function of the
parentage, age, and experience of the automaton.
The parentage determines the potentially available
codes. The age leads to a decrease in the "competence"
(in the biological sense of this term) of the automaton
(the number of codes that can be realised is decreased
with increasing age). The experience of the automaton or
within the biological nomenclature,the"field" effect of
neighbouring automata, acts upon the codes that are
competent at the particular instant when an experienced

event takes place. This leads to a more elaborate individual automaton than those used in the present simulation and as a practical issue to populations of fewer automata. So far as the elaboration is concerned the form of an automaton is a subroutine in the programme that is elaborate enough to specify the learning process associated with a single subskill of a structured skill and the first flow chart for this individual, shown in DIAGRAM 2, has been designed with this identification in mind. Hence, the increased elaboration has the effect of allowing for something comprehensive enough to embody the previous algorithmic learning model as the code for an individual automaton (the adjunction of the mechanistic model to produce a realised entity or automaton is exhibited, in a slightly degenerate form, by DIAGRAM 2).

Obviously the (necessarily reduced) numbers of automata will present some difficulties. It seems likely, however, that we can compensate for an inadequate size of population by introducing statistical variables that represent the rather loosely coupled effect of an aggregate of the other members of an imaginary large automaton population. Once again there are some technical problems and apart from the case in which the simulation is identified with the learning process in a student who is acquiring the subskills of a structured skill these problems have not been solved. The solution used in this case may be universally applicable. It is presented in the paper " Man as a system that needs to learn" that is cited in Part 4 of this report and is being embodied in the programme of which the flow chart above represents a single subroutine. This programme is being written for the 1301 computing machine at Brighton and, in a specialised form, in Sweden also.
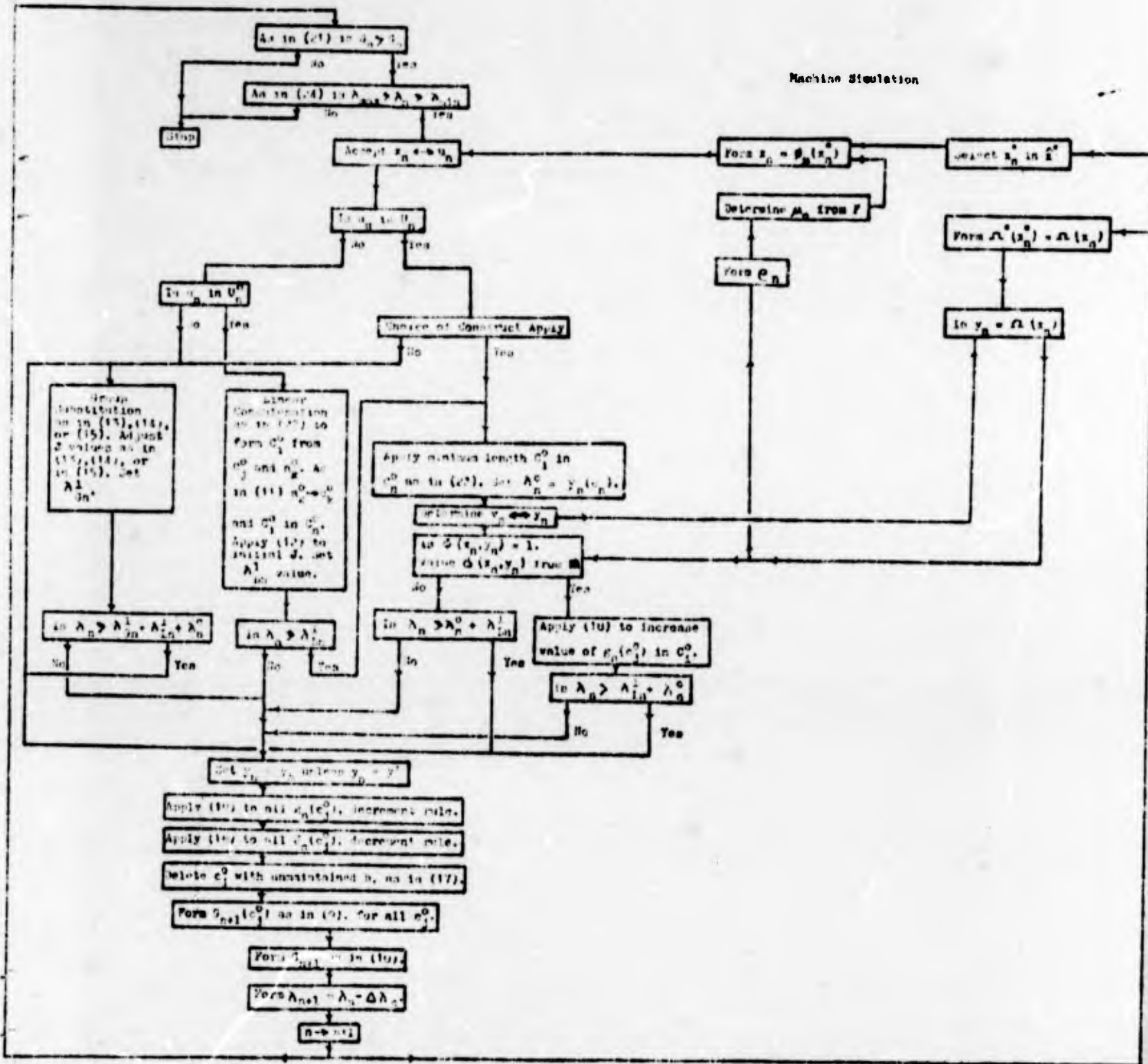
DIAGRAM 2.

SYMBOLS USED IN THE FLOW DIAGRAM OF THE COMPUTER PROGRAMME.

U_n — A set of intelligible problems.

u_n — An intelligible problem.

U_n^c — A set of understandable problems.

$u_n^{c'}$ — An understandable problem.

U^* — A set of similar and unsimplified problems.

u^* — An unsimplified problem.

x_n — A stimulus (which may be simplified).

x_n^* — An unsimplified stimulus.

$\hat{x}^*$ — An arbitary sequence of x^*.

v_n — A solution .

v^+ — A correct solution.

y_n — A responce state.

y^+ — A correct responce state.

Ω — A solution mapping from u_n to v^+.

Ω^* — A solution mapping from u^* to v^+.

$\emptyset_{\lambda_i}$ — A simplification procedure of degree λ_i .

$\zeta(x_n y_n)$ — Knowledge of results signal; $(x_n, y_n) = 1$ if $y = y^+$ and 0 if not.

ρ — Proficiency.

a_k^o — A code unit.

A^o — A string of code units.

c_i^o — An embodied code unit.

C_n^o — A string of embodied code units.

Symbols for flow diagram (cont.).

b^o — Minimal subsystem of mentarion.

λ^o_n — Number of operations used in L^o application.

λ^1_{Ln} — Number of operations used in Linear Concatenation (L^1 applications).

λ^1_{Gn} — Number of operations used in Group Substitutions (L^1 applications).

$\lambda_{max.}$ — Maximum number of performable operations in time Δt.

$\lambda_{min.}$ — Minimum number of performable operations in time Δt.

$\Delta\lambda$ — Change in $\lambda_{max.}$ and $\lambda_{min.}$.

$g_n(c^o_j)$ — "Activation" of c^o_j .

$J_n(c^o_j)$ — "Concentration" of c^o_j .

$G_n(c^o_j)$ — $g_n(c^o_j) - J_n(c^o_j)$.

G_n — $\sum G_n(c^o_j)$.

G_o — Limiting value of G_n .

The subscript 'n' refers to the nth. trial.

Part 4.

Further Development of the Cybernetic Learning Model.

Since Annual Summary Report Number 1, the concepts underlying the basic learning model have been considerably extended and attempts have been made to identify the abstract Cybernetic structure with physical systems. So far as its psychological identification is concerned the argument is set out in "Man as a System that needs to learn" (this paper has been modified to bring it up to date, it is, at last, genuinely in press, and a Xerox copy of the final manuscript has been provided for the file). A partly psychological and partly "data processing" identification, also up to date, is available in "Some Comments on the organisation of Men, Machines, and Concepts" which appeared in "Education for Information Science", Edited by Heilprin, Markusson, and Goodman, Spartan Press and MacMillan 1965(reprints of this paper are also in the file).

Finally, I have attempted to produce a form of this model devoid of ordinary symbolism; in other words, with mathematical symbolism replaced by a graphical convention. This graphical form is adequate for several biological or ethological identifications of the model and, in particular, for an account of the conjoined maturation and learning process called "imprinting". This development of the model appears in a book that is being written (by the present author) called "The Cybernetics of Living Systems". Since some innovations are involved and since the "imprinting" model seems novel enough to deserve simulation (it is certainly amenable to simulation) Chapter II and Chapter IV of "The Cybernetics of Living Systems", which contain the relevant material are attached to the present report as appendices. Although the content of Chapter II and Chapter IV is unlikely to be changed, these appendices should not be regarded as the final manuscript. In several places the style needs to be improved before publication, but the basic ideas are presented.

APPENDIX I

CHAPTER II
Cybernetic Models and Control Systems.

Control Systems.

Chemical plants and factories are controlled by automatic
devices which are designed to maintain the goal of satisfactory
operation.   Aeroplanes are flown by automatic pilots that
respond to haphazard perturbations of the vehicle and satisfy
the goal of keeping it on a proscribed course.   The temperature
in a building if often adjusted by a control mechanism that
senses the room temperature, compares it with a standard
value and turns the heating on or off as an operation that
achieves the goal of maintaining the room temperature value
nearly equal to the standard.

Nature is teeming with control systems.   Large scale control
systems maintain the character of the Biomes (such as "Coniferous
Forest" or "Desert" or "Grassland") given the basic resources
of air, sunlight, water, minerals and space in which to grow.
The action of these ecological control systems can be observed
in the microcosm of an aquarium that is freshly innoculated with
pond water.   After several days, the aquarium attains a dynamic
equilibrium condition.   The plants, animals and bacteria live in
balanced numbers; the animals use the oxygen produced by the
plants, (which aerates the water) one species uses another for
food and waste products, in non-toxic concentrations, are
reutilised and transformed.   The whole thing is driven, through
photosynthesis, by sunlight.   We can show that it is a control
system by artificially disturbing the balance when, within limits,
the balance is automatically rectified or by changing the basic
conditions of illumination or size when a different dynamic equil-
ibrium is achieved.   Hence, the entire system is stable for it
achieves the goal of maintaining a balanced population in the
presence of arbitary disturbances.   Further, it is ultrastable,
(in the sense of Ashby) because, when the basic conditions are
modified, it achieves another goal which is compatible with membership
in the class of all viable aquaria.

Distributed Control Systems.

Unlike the majority of mechanical control systems, an aquarium is a __distributed__ control system. It would be difficult to identify and localise the part which senses a deviation from the goal condition or the part that operates (like the heating apparatus in room temperature control) to approximate the goal. The difficulties over localisation are exacerbated by the complexity of the system; it is a mesh of control rather than a single control system. There are the metabolic control systems of the individual organisms, the control systems that maintain the concentration of various products in the water by changing the secretion and ingestion of the population as a whole, and many others all of which interact with one another. But it will often be impossible to put a finger on the components of a single control system in this mesh, even if it is isolated. The functions of different parts are carried out upon different occasions by different physical elements. Further, on any one occasion, a functionally distinct action or computation may be carried out in many different places. Hence, we say that the control system is distributed (or that the functionally distinct entities making it up are distributed).

Distribution of control is neither confined to natural systems nor is it true that all natural control systems are of this form. There is, for example, one class of error resistant automata that is functionally distributed. These automata are networks with the property of automatically compensating for arbitary changes in structure(that, in the absence of a special design, would introduce error into the overall computation). These automata have been considered in detail by Cowan and Winograd; their design entails the recoding of an original network which is able to carry out a computation C without error(using components that each do a specific job) into a further network in which C is computed by components that may do several jobs. Some mechanical and some natural systems are of this sort, for example, some parts of a mammalian brain.

Some are distributed without the special virtue of error resilience. Other natural systems, including many of the control systems in a brain or in animal behaviour, are perfectly localised.

Basic Organisation.

Whether or not its parts are localised, the __organisation__ of a control system is well defined. It is built up from the __functional__ entities in DIAGRAM 8. namely,

(1)   A bounded domain representing properties of the environment or of the system itself, upon which the system operates and in respect to which it aims for a goal.

(2)   A sensory or recognition device able to determine states of this domain, a goal specification, and a comparator that determines the value of a "distance" or "deviation" from the goal (the extent to which the present condition of the domain is unsatisfactory and must be modified).

(3)   A source of variation. In the simplest control systems (such as temperature controllers and positional servomechanisms) the variation occurs in the domain; the room temperature fluctuates or the position of the motor shaft changes haphazardly.   In other cases there is an inbuilt source of variation which, in the absence of any change in the domain, perturbs it by making trials or performing experiments. We shall call these active control systems and some systems, for reasons we shall discuss later, are necessarily active. The locus of the variation becomes a matter of definition when the system is distributed; the source of variation needed to keep an aquarium going may be in the environment or in the control system as we please, for the domain is not well localised.

(4)   A decision rule that stipulates, for any deviation from the goal, what sort of operation shall be performed in order to approximate the goal. The decision rule usually belongs to the familiar class of "negative feedback" rules; the system annuls deviation from the goal by operating to a degree that is the inverse of the deviation or "feedback" signal.

(5)   An operation that acts upon the domain to achieve and preserve the goal state. The diversity of operations is as great as the diversity of domains; turning on a heating apparatus, changing the concentration of a metabolite, moving a muscle and, for an interesting class of systems that have a collection of individual organisms as their domain, changing the rate of growth of these organisms or their rate of reproduction. The crucial points are (I) that the operation shall be throttled back by the instruction received from the decision rule (in the absence of which the muscle may move a large load or the reproduction rate may be gigantic) and (II) that only an energetically or numerically small change of instruction from the decision rule is sufficient to produce an energetically or numerically large change in the operation. Properties (I) and (II) yield the essential condition that there is an amplification in the control loop from sensor to effector or, in a slightly esoteric usage of the term a power gain.

Artificial and Biological Control Systems.

Probably the most cogent distinction between man-made and natural control systems is that, in the former case, the goal is specified by a designer, whereas in the latter, it is discovered by an experimenter. Neat as it sounds, the distinction is no more than a useful generalisation; some man-made control systems (such as the evolutionary simulations in Chapter VI, and various "learning" and "intelligent" artifacts) do <u>not</u> have any well defined goal; conversely, the experimenter often uses a design that constrains the natural system and partially determines its goal.

Although the goal of a control system at a given instant is fixed, it need not represent a static condition. It may, for example, stipulate a constancy of rate, (in which case the <u>state</u> of the system is not constant, by definition), or it may prescribe a restriction upon the changes that occur without in any way, deterring change; the dynamic equilibrium of an aquarium is an illustrative case; the maintenance of a constant number of individuals in a population wherein some members decay is another.

Stability.

The control system is stable if it can achieve its goal. Now stability is an important but deceptively simple concept. Strictly it is defined with respect to a given class of disturbances or perturbations, with respect to a particular state description (a model in which certain properties of the system and certain operations are deemed relevant and used as descriptive coordinates) and often with respect to a particular class of laws (such as the class for which all changes in state can be described by linear equations). Control engineers can usually make enough assumptions to justify fairly strong stability statements and there is a collection of more or less stringent "stability criteria" which allow them to inspect certain properties of a system and to determine without setting it in motion, whether or not it will be stable. Most of these "stability criteria" are inapplicable in biology because the basic assumptions cannot be justified. Some of them can be applied to special cases (like the control of voluntary movement and the Mantid control system in Chapter III, and those (such as the Lyapunov criterion) which do not depend upon linearity assumptions can be used more generally.

In the absence of formal criteria it is still possible to say something about the capabilities of a stable control system. It must be able to compensate for any admissible deviation from the goal; it must be able to act more rapidly than the environmental fluctuations that perturb its domain) it must be able to operate in an appropriate fashion. The most comprehensive formulation is given

by Ashby in his law of "Requisite Variety".   If we know
the possible operations of the control system (any one
of which may constitute a long sequence or strategy of
actions, it is unambiguiously stated) these can be used
to label the columns of a table; knowing the possible
perturbations of the domain, these can label the rows
of this table; the entries (or row and column inter-
sections) are possible <u>outcomes.</u>   The goal of the
system is satisfied by a collection of one or more
of these outcomes. Ashby points out that a control
system is only able to achieve its goal and thus to
be stable if the possible variety of the actions
(or columns) is at least as great as the possible
variety of the perturbations (or rows) in this
tabulation and this is its <u>requisite</u> variety.

Composition Rules for Control Systems.

The control system in DIAGRAM 8, is the basic unit
in a Cybernetic Model and it can be combined to
yield the <u>reducible</u> structures shown in DIAGRAM 9 and
DIAGRAM 10. Since these structures <u>are</u> reducible they
are also Cybernetic Models.

DIAGRAM 9, is a parallel combination of systems
<u>a</u>,<u>b</u>, and <u>c</u>.   These systems are coupled in a specific
fashion that does not entail the modification of their
goals, and they interact. Most of the control systems
in an aquarium are coupled like this.   Alternatively,
<u>a</u>,<u>b</u>, and <u>c</u>, could represent separate automata
communicating by signs.

DIAGRAM 10, is a sequential concatenation of
control systems or an operation sequence(of the
operations carried out by the control systems).
As Brissey points out, this structure is characteristic
of the motor and "conative" functions of an organism
(whilst the parallel combination is characteristic of
sensory and cognitive functions. We shall also come
across operation sequences in many behavioural
organisations.

At the motor level the control systems A,B, and
C, might concern lowering and taking body weight on
the right foot, raising the left foot and bringing
it forward.   The operation sequence (A,B,C) images
a crude sort of walking movement. In any operation
sequence (walking or not) we call the goals of A,B,C,
<u>subgoals</u> and engage B when A's subgoal has been achieved

and C when B's subgoal has been achieved. An
engagement of A thus realises the walking movement
(providing that the contingent subgoals are
achieved) which is the goal of the entire operation
sequence. Now A or B or C in isolation are largely
irrelevant to walking; C is mechanically impossible
without B; and the engagement of A,B, and C, in an
improper order is usually absurd. Thus the improper
ordering A,C,B, will land an organism flat on the
floor.

Codes for Control Systems.

If we have an alphabet of signs for objects and
operations then this organisation of (A,B,C) which
expresses the contingent dependence of the several
control systems and leads to the satisfaction of the
"walking movement" goal, may be stated as a code
expression such as "Achieve Subgoal A, go to B and
achieve subgoal B, go to C and achieve subgoal C".
This code does not stipulate how the subgoals should
be achieved or what physical operators realise the
operations prescribed by the code. It specifies,
in each case, some operation and this in turn, a
class of operators. Hence the code (or the class
of codes we consider) is the explicit statement of
a goal(and the implicit statement of its constituent
subgoals) in a given sign system or language. The
code, in fact, is a programme like a computor
programme, wherein the constituent codes for A,B,
and C are subroutines. In deference to the fact
that codes such as the code for A,B,C represent
control systems, Miller, Gallanter, and Pribram
have called them TOTE or "Test, operate, Test,
exit" units (the "exit" specifying the address for
a further subroutine of the same sort). The operation
sequence is a physical realisation of a TOTE unit
sequence (each operation being replaced by a specific
operator).

The embodiment of a code prescribes something
or describes something; it can accept instructions,
such as "realise the operations that are prescribed,
as operators", it can also issue instructions, such
as "consider the next code sequence"; hence, the
embodiment of a code, its written form, must have
certain properties. There must be an alphabet
of signs able to denote objects or other signs and
there must be rules for the association of signs and
the denotation of associated groups of signs. Finally,
there must be an interpretation mechanism whereby sign
sequences are converted into actions or further signs.

Various physically stable structures serve as signs
and are used to embody codes, for example, chemical
molecules and parts of the nervous system.

The Control of Control Systems.

The construction of FIAGRAM 11 (I), is an hierarchy
involving the control of control. It is obtained by
replacing the domain of any control system (the higher
level or L^1 system) by the collection of goals
available to an L^0 or lower level control system(so
that the L^1 controller acts to change the goal of
an L^0 controller and receives feedback information
regarding the achievement of these goals).

If, as in DIAGRAM 11 (II) the L^1 control system
is embodied in a physical system but the L^0 control
system is not, then the L^1 control system exerts certain
constraints upon the L^0 control systems that may
subsequently be embodied; in particular, it determines
their possible goals. However, no L^0 system exists,
In deference to this fact, we adopt the symbolism in
DIAGRAM 11 (II) and comment that the constraints
exerted by the L^1 system upon the putative L^0 system
are identically an L^0 code for this control system.
It is entirely possible, if the system is realised
in a fabric with malleable or inertial characteristics,
that these constraints persist after the L^1 control
system has been active or even after it has decayed.
In this case we adopt the symbolism in DIAGRAM 11(III)
which is equivalently an assertion that the code for
an L^0 control system is written in an alphabet of L^0
signs.

The control of control is alternatively
represented in terms of selection. The necessary
construction is obtained by replacing the L^1 operation
of L^0 goal variation by an L^1 operation of selecting
an L^0 control system(able to aim for only a single
goal)from a collection of alternative L^1 control
systems and it appears in DIAGRAM 12 (I). As
indicated by DIAGRAM 12 (II) the selective action
of an L^1 control system determines an L^0 code and
if the L^1 control system of DIAGRAM 12 (II) decays
(although its selective constraints persist in a stable
fashion) this is an L^0 code written in an L^0 sign
system as suggested by DIAGRAM 12 (III).

The selective construction for representing the
control of control, is particularly useful in
connection with the genesis of operation sequences.
Amongst the most common L^O operation sequence codes
are programmes, produced by an L^1 control system,
that specify the order in which certain operations
must be performed without determining in detail
what operations shall be performed. Such a code
is indicated by DIAGRAM 13 (I); it is identical
with the specification of Z and the domain and
ordering of the boxes labelled as A,B, and C; the exact
contents of A,B.C, the operations to be performed,
are not yet determined because the specifications of
the subgoals "A","B", and C only determines a class
of control systems.   Hence A may be legally
substituted by A_1 or A_2, B by B_1 or B_2 and C only
by C_0 (hence,C is determined, which is exceptional)
to yield the operation sequence in DIAGRAM 13 (II).
The legality of any substitution is merely a matter
of whether or not it satisfies the Lo code and any
other constraints that may be imposed.

At this stage (A,B, and C have not been
substituted) an instruction to achieve the goal Z
is ineffective. But it may (and commonly it does)
provide an input to a further L^1 control system,M,
that is able to select substituent operations within
the L^O code constraints often also imposing constraints
of its own.   The system M need not be the L^1 system
that erected the initial L^O operation sequence code
and usually it is not. Further, in some important
cases, the substitution process depends upon externally
provided L^1 signals and upon L^O signals that are dealt
with by any L^O systems that have already been
constructed as a result of partial substitution.
(In any case, as Brissey also points out, the
construction of a sequential process entails some
'parallel' data).

The genesis of an operation sequence is readily
generalised to yield parallel combinations of control
systems and thus amounts to a general model for learning
in the non-trivial sense of building up control systems.
To obtain the learning model we have invoked a malleable
or inertial fabric,(or the concept of adaptibility) but
the control hierarchy is reducible to control systems
(embodied in such a fabric) and consequently this model
for learning is a reducible Cybernetic Model..

To complete the picture we comment that in
experimental situations the L^0 signals which act
upon the learning process are <u>stimuli</u> and that the
L^1 signals are "reinforcements" or "rewards"(where
applicable, instructions also).

If the adaptible fabric has the physical
characteristics required for a sign system
(according to our previous account) then the
codes we have considered may be written or
embodied in this fabric. Given such an embodiment
the concept of a level of control or of an
organisation, the hierarchy $L^0, L^1 \ldots \ldots$, is open
to an equivalent linguistic definition. These
levels of organisation are distinct domains of
expressions in the sign system; L^1 is the domain
of expressions that describe or prescribe L^0
expressions and L^0 is the domain of expressions that
denote reality hence, if the sign system is a
language, a level of control is simply a level of
discourse in this language.

Systems that are and are not immutable structures.

Any localised machine (mathematically, any finite automaton) must decay due to haphazard abrasion of its structure. So far as man made machines are concerned, we accept and neglect this fact. Until they wear out, their fabric as well as their organisation is regarded as immutable. The same sort of decay affects the localised living organism. Its fabric is obviously subject to the inroads of age and of predation. But the actual rate of breakdown of its constituents is very high indeed. An organism could never achieve its normal age (indeed it could never be born) without special arrangements for reconstructing the physical embodiment of its organisation. The components of an organism are in continual flux. Even in the higher animals the materials forming many of the organs are replaced completely every few weeks and, in some cases, every few days.

To exemplify the permanence of an organisation within a labile fabric we shall consider the control systems of a cell, where the flux of material is rapid and obvious. Although the organisation of a cell is complex it has recently become rather well known because of several important and lucidly described advances in molecular biology. A study of this complex organisation also provides an especially straightforward illustration of the difference between (and the reality of) levels of organisation and control such as L^1 and L^0; it will be evident that these are levels of coding (for the L^1 and L^0 alphabets of signs and the forms of the corresponding expressions are unambiguously defined); and we shall thus demonstrate the plausibility of a later contention that L^1 and L^0 are languages, or alternatively that they are levels of discourse in a rather comprehensive single language.

The Cellular Control System.

The lowest level control systems in the cell are organised enzymes* or sequences of enzymes. The organisation of these catalysts may or may not entail spatial distribution on a membrane (it does, for example, in the case of the respiratory chain mechanism in the mitochondria). In any case, the essential organisation is a chemical specifity wherein the product of a catalysed reaction is used as a feedback signal to inhibit at least one of the enzymes catalysing this reaction. It was once believed that inhibition depended chiefly upon substrate competition (in other words, that the product molecules competed with the substrate for the active catalytic site on the enzyme). Some inhibitory systems do work in this way, for example, Oxalacetate ions inhibit succinic dehydrogenase in the Krebbs cycle of DIAGRAM 15. On the other hand, many enzyme molecules are "allosteric". They have more than one "active" site. One site is

*Biological catalysts made of protein.

occupied by the substrate molecules, the other is occupied by a specific molecule that alters the configuration and activity of the enzyme. It may act as an activator or as an inhibitor, for example, L Isoleucine inhibits the action of L Threonine Deaminase which is an enzyme rather a long way back in the reaction chain that gives rise to L Isoleucine. The important point about allosteric interactions is that the several specific inhibitors and activators are <u>signals</u> in a communication system and need bear no immediate relation to the substrate or the product of the reaction that is modified. Hence, cooperative effects are able to form parallel and sequential combinations of control systems and these cooperative interactions bind the metabolic control systems into a coherent organisation (this <u>level</u> of organisation will be denoted as L^C, and the metabolic control systems will be called L^O control systems).

Enzymes are proteins(molecules principally made up from long sequences of amino-acids). There are 20 alternative amino-acids and since their pattern determines a protein they form an alphabet of 20 letters in which the L^C code for a protein is written as a long sequence. Now proteins decay and must be replaced by a manufacturing process. Enzymes and other proteins are manufactured at structures in the cell called ribosomes, which also participate in the process of decoding genetically specified information that gives instructions for assembling amino-acids into protein molecules.

The system concerned is shown in DIAGRAM 14. The genetic code which specifies the cellular organisation is embodied in a substance,D.N.A. which makes up the chromosomes in the nucleus of a cell. The D.N.A. is made from chains of airly small molecules called nucleotide bases (thamine,adenine, cytosine and guanine,labelled as T.A.C.G), that are held together by sugar molecules and are associated with proteins called "histones". At this level of organisation, which we denote as L^1, the instruction for taking up and assembling a single amino-acid appears as a triple selected from T.A.C and G. so that a complete protein is represented by a string of triples. Any D.N.A. strand specifies many proteins,which are thus specified in an L^1 code as words in a four letter alphabet. We comment that D.N.A.strands exist(in the cells of nearly all organisms) in pairs and that the pairing is orderly; if strand I contains C at a given position, Strand II contains G, if I contains G then II contains C, if I contains T then II contains A and if I contains A then II contains T; hence the strands are complimentary.

Now the decoding system which interprets L^1 instructions in terms of the L^O specification of enzyme proteins involves the fact that one D.N.A.strand can form a complimentary strand of a substance called "Messenger" R.N.A. Like D.N.A. the strand of R.N.A. is made up from four bases; A.C.G. as in

D.N.A. and uracil U, in place of T, but in R.N.A. the bases are held together by a different sort of sugar.

The production of an informationally homologous and complimentary strand of messenger R.N.A. is effected by a polymerising enzyme, but it is controlled by a number of distinct L^1 control systems. In a multicellular organism the cells are differentiated; only some of the genetic code can be copied. They are also restrained by hormones which, possibly acting through the histone proteins, allow or disallow the production of R.N.A. from specific loci on the D.N.A. molecule. In addition there are L^1 control systems that are able to recognise L^0 signals. The underlying L^1 mechanism consists in the "structural" loci or "genes" on the D.N.A. that are able to produce messenger R.N.A. codes for a particular system of enzymes and another pair of loci, the "operator" gene that control the structural gene group and determines whether or not it <u>will</u> produce the messenger R.N.A. that it is <u>able</u> to produce and the "repressor" gene that manufactures a specific material the regulator, which acts (1) upon the operator gene, which it inhibits or disinhibits according to whether it is or is not activated, and (2) as an L^0 signal recognising device in the sense that it is specifically activated by some molecule that is either one substrate or one product of the enzyme system*. If the specific activating molecule activates the repressor and inhibits the operator to "switch off" enzyme production, the control system is called <u>repressible</u>; if the converse effect "switches on" enzyme production it is called <u>inductible</u>; in each case the effect may persist after the L^0 signal has appeared and is no longer present. (The underlying mechanism, at any rate for repressible systems, is often less elaborate insofar as the operator gene and the repressor gene are combined at a single locus).

The messenger R.N.A. that bears the L^1 code for an enzyme group is broken down fairly rapidly in the cell, chiefly by an enzyme, ribonuclease. Before this occurs the messenger R.N.A. passes on its L^1 code to a ribosome which translates it and interprets it as an L^0 code and which embodies this L^0 code in the protein molecules of the enzyme.

*<u>Footnote</u>. The inductible system that has been most thoroughly described is responsible for producing the enzymes, Permease and Galactosidase which are required for the assimilation and metabolism of lactose in the bacterium E Coli. This E Coli lactose system is induced by the L^0 signal "lactose" in the culture medium. The most thoroughly described repressible system manufactures the enzymes needed to synthesise Tryptophane and it is repressed by the specific L^0 signal of "Tryptophane" in the cellular environment.

The ribosomes are made from protein and a stable form of
R.N.A. ribosomal R.N.A. (which is also manufactured from a
D.N.A. code but which bears no message).   In the cell there
is another stable form of R.N.A.(again produced by D.N.A. but
bearing no L^1 message) which is called transfer R.N.A.   The
transfer R.N.A. exists in at least 20 specific forms corresponding
to the 20 different amino-acids that are used for the manufacture
of proteins and that embody the signs in the L^0 alphabet.   In the
cell, each of the amino-acids is attached by a specific enzyme to
a specific transfer R.N.A. through an energy bearing phosphate
linkage.   The Transfer R.N.A. amino-acid combinations are
assembled on a ribosome to form the L^0 coded strands of enzyme
proteins that are specified in the L^1 code by the messenger R.N.A;
the ribosome thus "translates" the L^1 code into an L^0 code, or it
"interprets" this code; further, it cooperates with an energetic
mechanism to embody the L^0 code as a specific protein.

The control of this interpretation process is mediated
at the point where informationally homologous messenger R.N.A.
is produced from a D.N.A. coded genetic locus.   This "between
level" control of an L^1 process by an L^0 process has already
been described (in terms of inductible and repressible systems)
and given a specific signal molecule for each L^0 control system,
it couples the L^1 control systems to the L^0 control systems to form
an hierarchical organisation as in DIAGRAM 14.

Reproductive Process.

Amongst other materials the metabolism of the cell produces
nucleotide bases and the remaining constituents of D.N.A.
Although the exact mechanism is not yet known, it is evident that
a signal is produced whenever either (1) The cooperative interaction
between the parts of the cell is impaired by decay or (2) the
multicellular organism needs more cells of the type concerned; in
the latter case the signal is hormonal. (In passing, it is useful
to compare (1) with the recycling signal in the Tsombega system
of Chapter VII and (2) with the signals in Capter VIII).   On
receipt of this signal the double strands of D.N.A. are replicated
using the materials provided by the metabolism and the genetic code
is thus freshly embodied in a copy of the original D.N.A.   After
D.N.A. copying the entire cell divides and the copied D.N.A. conveys
the genetic data to the daughter cell.

In principle the copy may be perfect; an organism acquires
potential immortality in a static world insofar as it has the
trick of using its own metabolism to reconstruct its own code in
a stable embodiment like D.N.A. and thus to reproduce.   However,
such an organism could not keep pace with a dynamic world; to do so,
it must be capable of variations (that are supplied in fact, by
genetic mutation) and it must be equipped with a "natural selection"
principle whereby those variants that fit the changes in this world
preferentially survive.

Energetic Metabolism.

The whole process depends upon a supply of energy which, in
animal cells, is mainly derived from the oxidation (or equivalently
the dehydrogenation) of foods such as sugars and fats. Now the
synthetic activities we have outlined (as well as the more
specialised cellular activities of actively maintaining an ionic
balance or, in muscle cells, of contracting) accept energy in
a common form and unit. The energy is accepted from a common
energy carrier, Adenosine Triphosphate (or A.T.P.) which donates
an energy rich phosphate linkage as the common unit and is thereby
converted into Anenosine Duphosphate or A.D.P.*(1)The basic
energetic requirement is thus to manufacture A.T.P. as the "charged"
form of energy carrier given A.D.P. as the "discharged" carrier
that has activated some reaction. To do so entails the provision
of a highly structured physical system that oxidised food in stages
that provide the right size of energy units. Most of the parts of
this system situated in the mitochondria of the cell as indicated
in DIAGRAM 15*(2). It thus appears legitimate to conceive the
primary function of the L^0 control systems as the construction and
maintenance of this __energetic__ machinery and the __synthetic__ machinery
(such as the ribosomal mechanisms supporting membranes and so on)
which it feeds.

Hence we arrive at a reciprocal correspondence that images
the crux of hierarchically organised control in systems that
(unlike most man made artifacts) are not immutable and must actively
maintain their characteristic patterns. The L^1 control systems
construct and maintain the embodiment of the L^0 control systems;
the L^0 control systems replicate, freshly embody and reproduce the
L^1 control systems. Finally, in an environment that changes and
calls for an adaptible collection of L^0 control systems, the variation
of this environment must be countered by a variation amongst the
L^1 control system codes. This variation isppovided by the "mutation
of genes" whereby the genetic code is modified in a manner that is
not directly correlated with changes in the environment.

*Footnote (1). This is a method for activating a chemical reaction
that is catalysed by some enzyme, there are some exceptions to this
statement, for example, some reactions accept from A.D.P. replacing
it by Adenosine Menophosphate.

**Footnote (2). Since the mechanism of energy transfer is peripheral
in our discussion, no description of the process is attempted.
However, DIAGRAM 15 offers a fairly up to date picture of the
mitochondrial organisation which will be intelligible to anyone
versed in the nomenclature of this field. At least it serves to
indicate the highly organised and physically structured pattern
of the L^0 control systems that are maintained against continual
abrasion and decay.

The Statistical Mechanics of the Cellular Control Process.

Any cell contains a vast number of control systems of the type
we have described, any one of which is conveniently represented
in the notation of DIAGRAM 16.   The problem of describing their
conjoint activity has recently been tackled by B.C. Goodwin and
his theoretical analysis is one of the outstanding achievements
in Biochemical Cybernetics (it gives rise to a "statistical
mechanics" of cellular interactions). We shall not deal with the
mathematical part of the model but will briefly indicate how the
model has been assembled since the analytic process is complimentary
to the linguistic approach we have adopted (in common with the
majority of authors who have modelled cellular reactions, we have
taken an L^1, L^0, distinction for granted.   Similarly Waddinton,
for example, makes a distinction on empirical grounds, between
the "epigenetic" level of control and the "metabolic" level of
control. Goodwin arrives at this hierarchical structure in a
different way.)

        The state description of the cell contains variables that
represent the concentrations of different reactants, a pair of
variables being needed to describe the state of each control
unit.   Under the influence of specific catalysis and given the
energy required, these concentration values are altered to generate
a trajectory of states of the cellular system(its state at any one
instant being represented as a point in a space of the descriptive
variables).   Now, on further scrutiny, it turns out that this state
description can be partitioned. This possibility arises because the
systems controlling the reactions have relaxation times that are not
continuously distributed (roughly a relaxation time is the interval
needed to regain equilibrial conditions after a unit disturbance).
Some systems have relaxation times which, in the cells of higher
organisms, are in the order of several hours; others have relaxation
times in the order of a few minutes, and there are few in between
values.   It happens that the systems with long relaxation times
often correspond to "epigenetic" systems concerned with the synthesis
of large molecules at an L^1 level of control; similarly the
"metabolic" systems at the L^0 level of control often have short
relaxation times. But even in the absence of this correlation,
it would still be possible to partition the variables in the state
description for, although these different types of systems interact,
the variables of the long relaxation time systems appear as fixed
parameters in the equations describing the activity of a short
relaxation time system and conversely, in dealing with the equation
for a long relaxation time system, it is possible to assume that all
of the short relaxation time systems that are associated with it can
reach dynamic equilibrium between one change of its state and another.
The distinction of levels in DIAGRAM 16, is thus based upon the
observation that the relaxation times of the cellular systems are
grouped rather than being continuously distributed and it is possible

to separate the essential variables of systems having different
relaxation times as subspaces of the space of descriptive variables
and to order those subspaces under logical inclusion. Thus the
subspace of the long relaxation time (as it happens , epigenetic)
system variables include the subspace of short relaxation time (as
it happens, metabolic) system variables. But, since the epigenetic
variables are parameters in the metabolic equations and the metabolic
variables are essentially stationary valued in the epigenetic system
equations the analysis of the epigenetic systems is not necessarily
more elaborate than that of the metabolic systems.

The control units in DIAGRAM 16, are plausible entities just
because of this separatability. It is evident that any control
unit is specified epigenetically but that it interacts in a not
very well determined fashion with a host of other control units
through the metabolic processes it controls. Since these
interactions are at the metabolic level we may regard them as weak
interactions to be specified, ultimately, in no more than a
statistical manner.

In addition, there are strong couplings between the control
units which, as suggested in DIAGRAM 16, are mediated by repressor
feedbacks to specific genetic loci. These interactions must be
stated explicitly and they will be viewed as deterministic in
character and will appear in the equations of activity of the control
units.

The equations of activity for any single control unit can be
deduced from some plausible assumptions about the biochemical
processes involved; so can the equations for certain strongly
coupled combinations of control units(some combinations are excluded
because the equations cannot be integrated; hence the exclusion
is a matter of mathematical convenience and it could be avoided
by using and possibly developing more elaborate mathematical
procedures). Goodwin shows that any control unit acts as a
restrained oscillator and that strongly interacting combinations
yield elaborate oscillatory behaviour with long term temporal
organisation.

The difficulties that beset an analysis of the behaviour of
the entire cellular system are (I) that although all of the control
units can be described within the same state description their
initial states are undetermined and (II) that the weak interactions
between the control units are not well defined.

To avoid the problems engendered by (I) and (II) Goodwin has

introduced a statistical mechanics* as in Chapter I. In place
of a single control unit we consider an ensemble of control units
which may either be conceived as an indefinitely large collection
of abstract replicas as in Chapter I, or as the large but finite
collection of physical systems in the cell. The states of the
ensemble are represented as points in the descriptive space and
the trajectories of the members of the ensemble are associated
with a constant, in time, of this motion, which(by analogy with
the statistical mechanics of gas molecules, rather than control
units) has the characteristics of energy. To avoid confusion
between the energy of molecules and the constant of the trajectories
of the ensemble of control units this quantity is called the
"Talandic Energy" of the ensemble. Although the "Talandic Energy"
is a constant for the entire ensemble, it is the commodity which
is exchanged, when there is coupling, between subsystems of the
ensemble.

Another important statistical parameter is a measure of the
excitation of the entire system or of a subsystem of control units
which (again by analogy with the statistical mechanics of gas
molecules) is a "temperature". This "Talandic Temperature"
determines the expected direction of exchange of "Talandic Energy".
It is also possible to show that the "Talandic Temperature"
represents a measure of the degree of non-linearity of the
oscillatory behaviour of the control units and to argue that the
maximum temporal organisation of such a system increases with its
"Talandic Temperature".

Footnote.

The prerequisites are (1) Statement of the differential equations for
single and strongly interacting combinations of control units and
their presentation in Hamiltonian form (2) Identification of a
suitable integral of the equations for an ensemble of control units
with the energy (3) Statement that the equations for an ensemble
satisfy Liouvilles theorem so that the density of neighbour points
about the state point of any representative member of the ensemble
is invariant (4) Derivation of class of averages over the ensemble
equivalent to time averages and assumption that all admissible
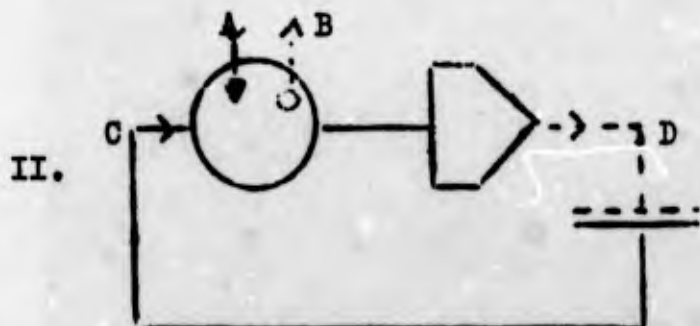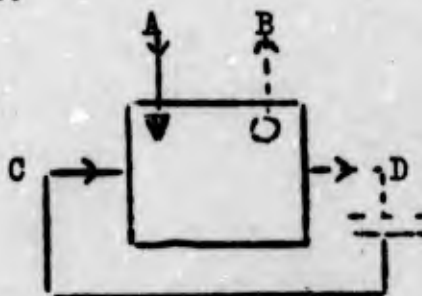initial states are equiprobable.

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ABREVIATES TO;   OR TO;

I.
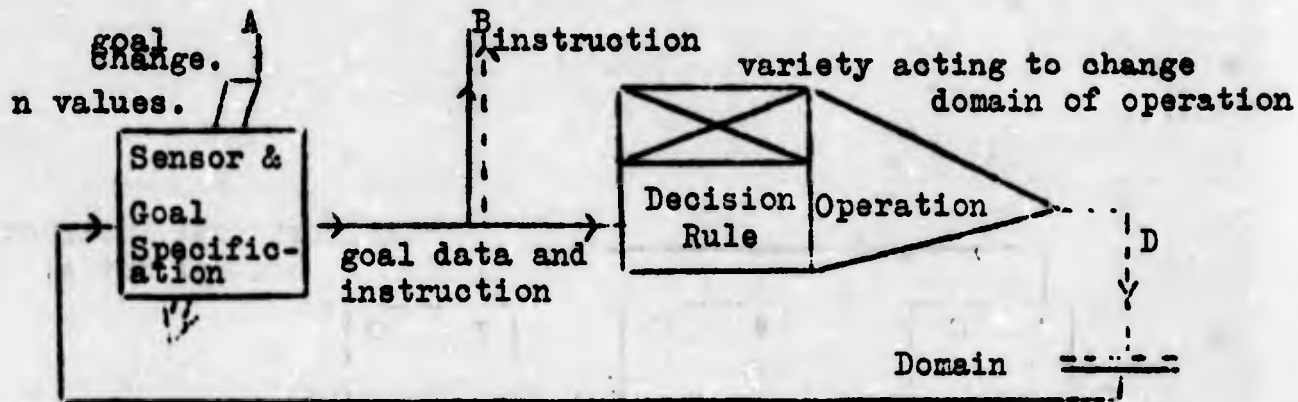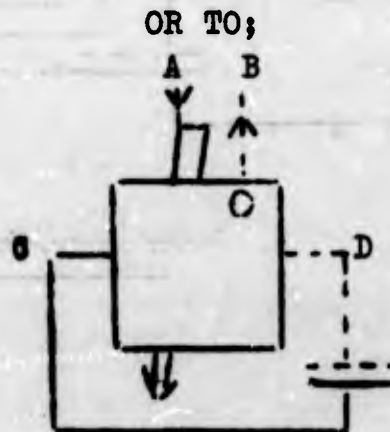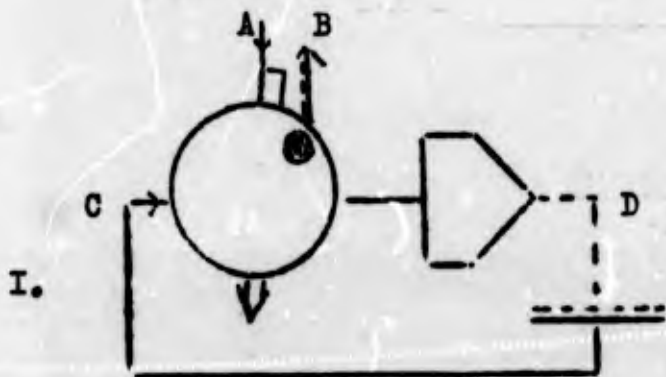
And if goal change instruction is "aim for" or " remain inactive"
only, this abreviates to;

II.   or to:

Notice that n of the II units are equivalent to one n goal
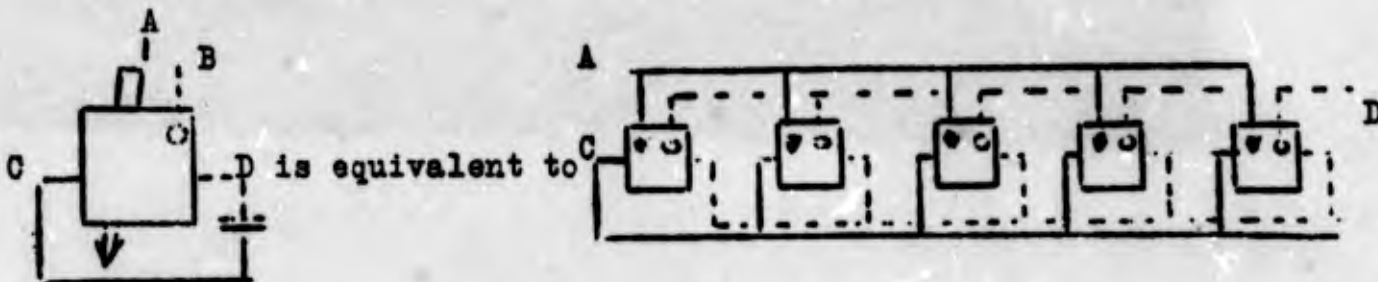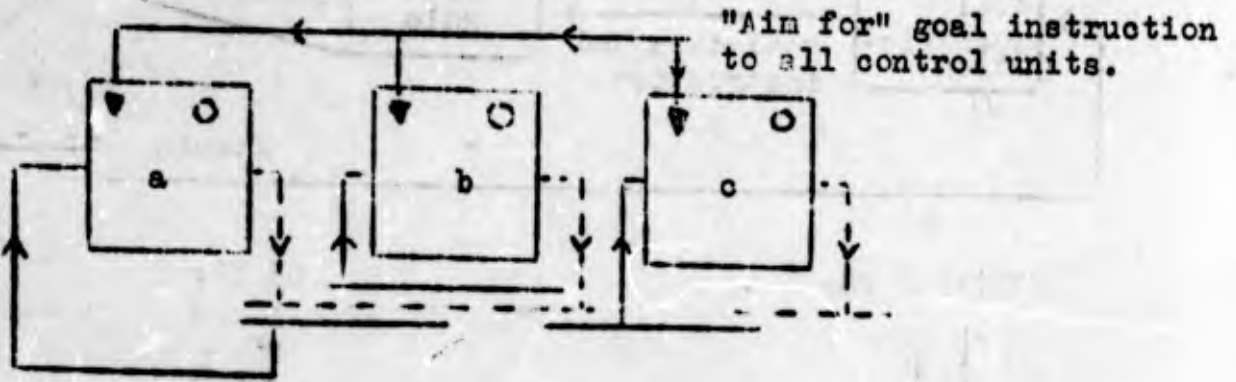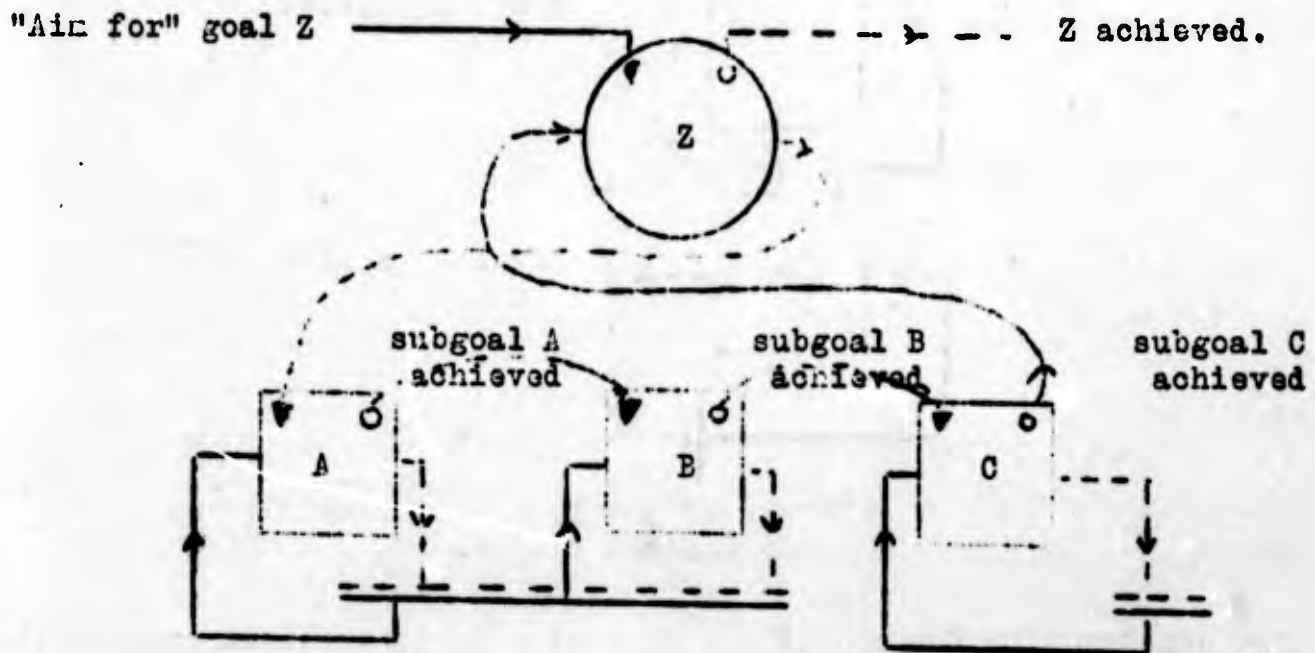alternative I unit. Thus for n = 5,

D is equivalent to

DIAGRAM 8. I, II,

"Aim for" goal instruction
to all control units.

**PARALLEL COMBINATION OF
CONTROL SYSTEMS.**

DIAGRAM 9.

"Aim for" goal Z → ─ ─ ─ → ─ ─ Z achieved.

Operation sequence A,B,C, with subgoals A,B, and C, and a goal Z.
Notice, (1) that domain of control units may be the same as in A and
B , or different as in the case of C, and (2) that the operation sequence
is the operation of control unit Z.

DIAGRAM 10.

I.

To L¯

Level L^1 system

Level L^0 system

Domain of environment or some
other control system.
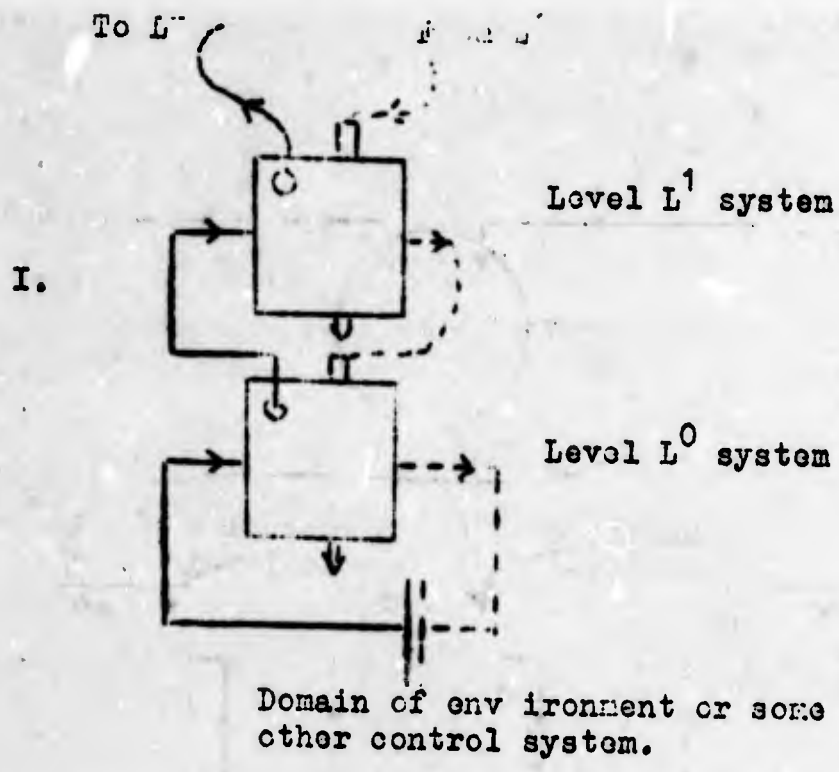
The construction for control of control and hierarchical organisation.
If L^1 control system _is_ embodied in a physical structure, but the L^0
system is _not_ embodied, then the constraints exerted upon subsequent

realisation or activity of an L^0 system, are an L^0 code for its L^0
goals. The existence of a code is represented by the symbolism:-

II.

L^1

L^0
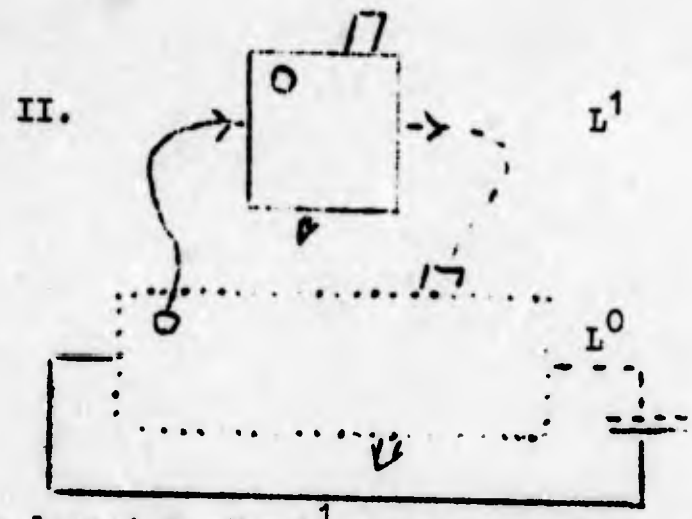
When as in learning, the L^1 system operates upon a malleable or plastic
fabric, the constraints may persist as a "written" code, even if the
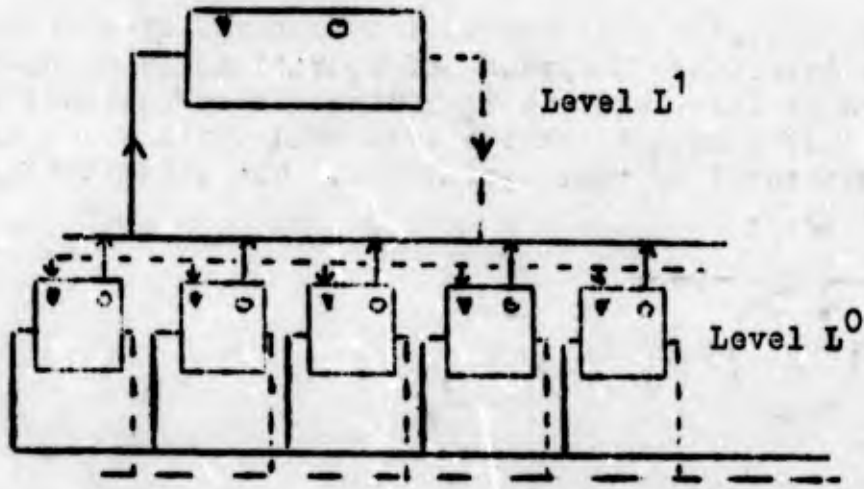L^1 "writing" system decays. In this case we use symbolism:-

III.
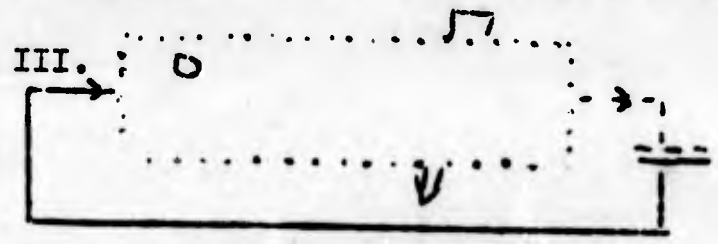
DIAGRAM 11. I, II, III.

I.

Level L^1

Level L^0

An alternative "control of control" symbolism in which the L^1 system selects amongst alternative L^0 control systems. If only one L^0 system is selected from a set of alternatives as determined by the L^1 source of variation, this set, due to the L^1 constraints, is an L^0 code which is conveniently represented as :-


II.

L^1

L^0
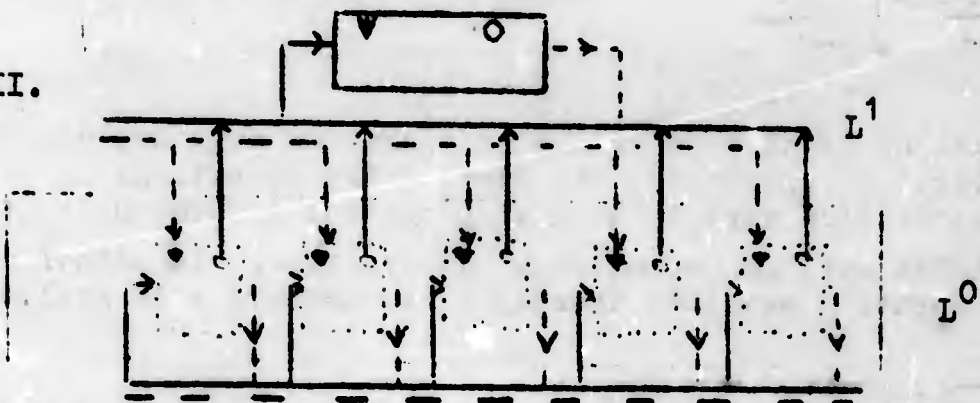
If in learning, the L^1 system imposes it's constraints by "writing" the L^0 code in some malleable or plastic fabric, then the "written" code persists after the L^1 system decays, as in :-

III.

DIAGRAM 12. I, II, III.

As a special case, the code constraints imposed by a highor order control
system, may determine the order of operations in an operation sequence
leaving more or less latitude regarding the operations, as indicated below
We comment that Z cannot achieve it's goal until the operation sequence
code is substituted by real operations. The substitution process is
carried out by M.

I.
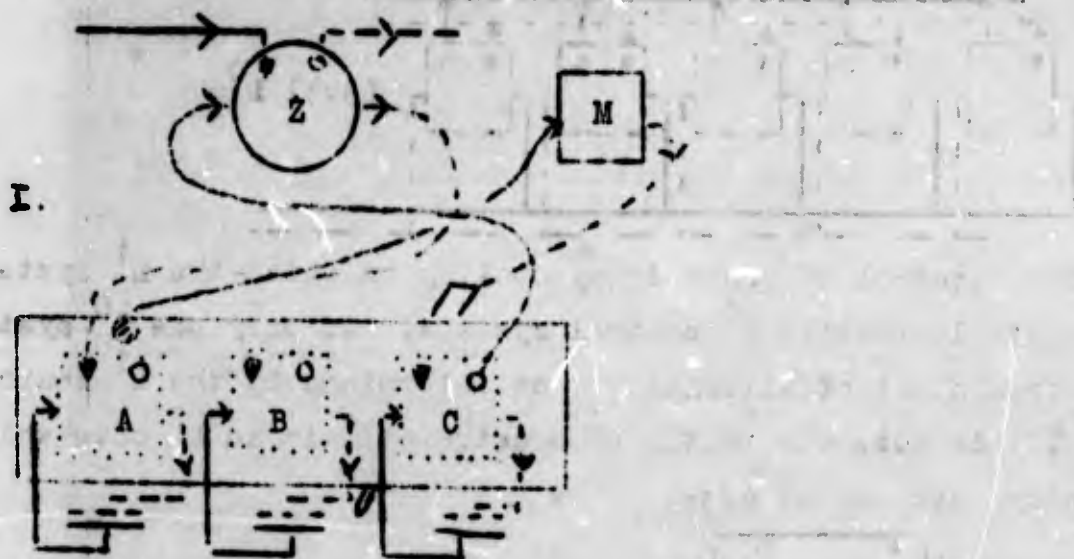
$$A = A_1 \text{ or } A_2 \qquad B = B_1 \text{ or } B_2 \qquad C = C_0$$

When the operations of this programme or operation sequence code are
physically relised as operators, the form of the operations is determined.
The actual substitution depends upon an L^1 control system, M, that selects
from the available set, and upon the L^0 interaction. In either case the
result is an operation sequence whereby Z can achieve it's goal.
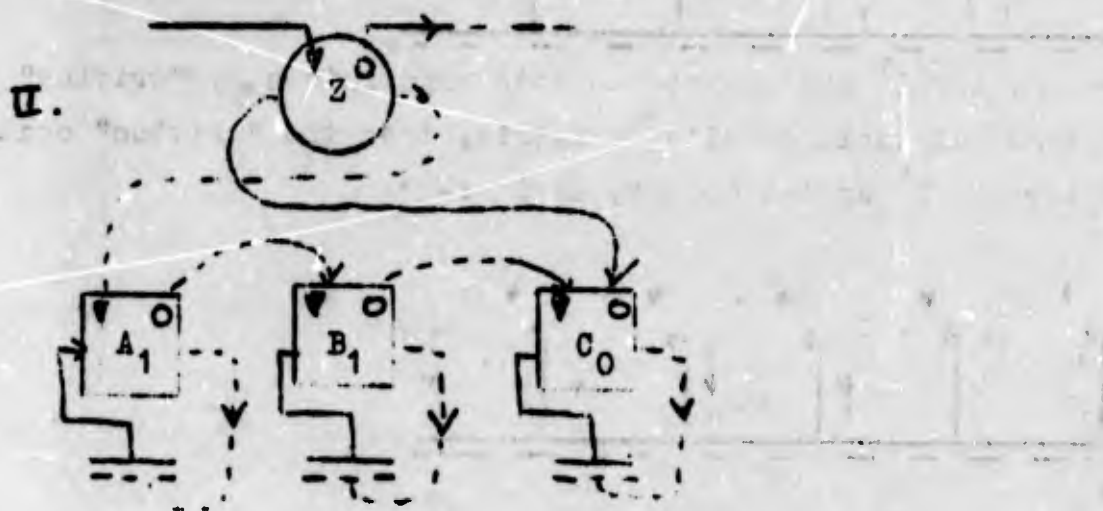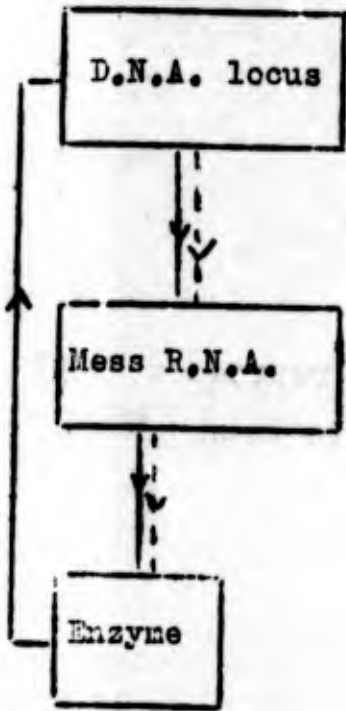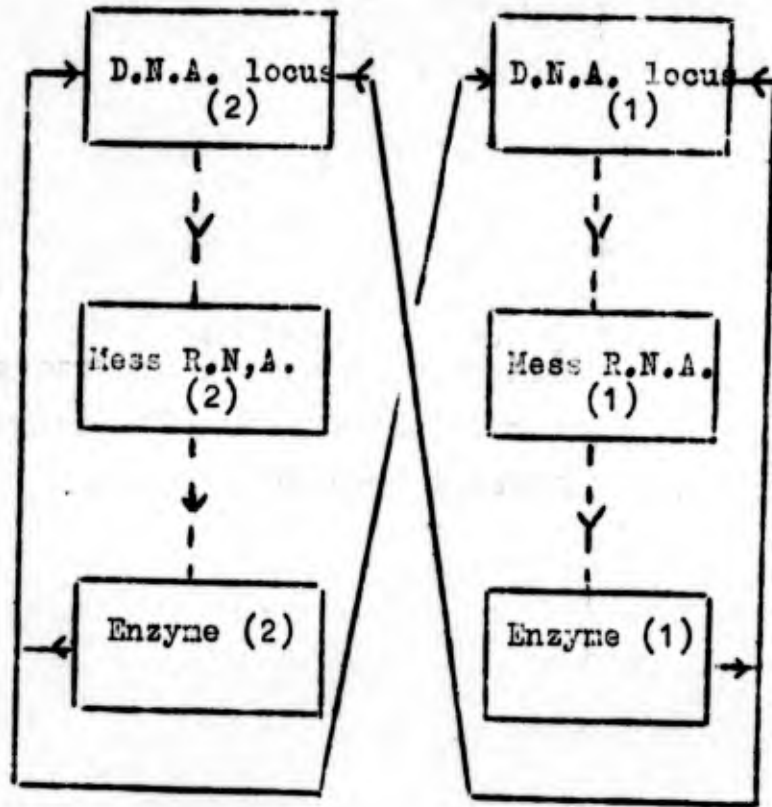

II.

DIAGRAM 13. I, II.

Diagrams 14 and 15 are too complicated to reproduce accurately on stencils. Therefore, they have been omitted from this report.
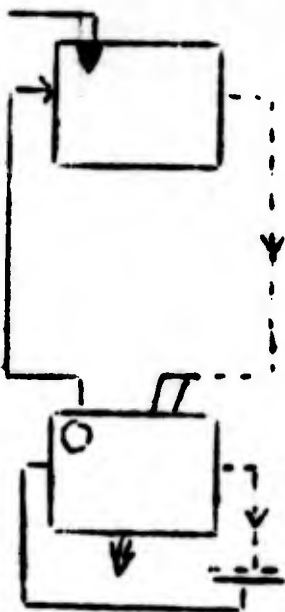
Single unit
Goodwins symbols

Strongly coupled pair
of units in Goodwins symbols

Single control unit
in present symbolism

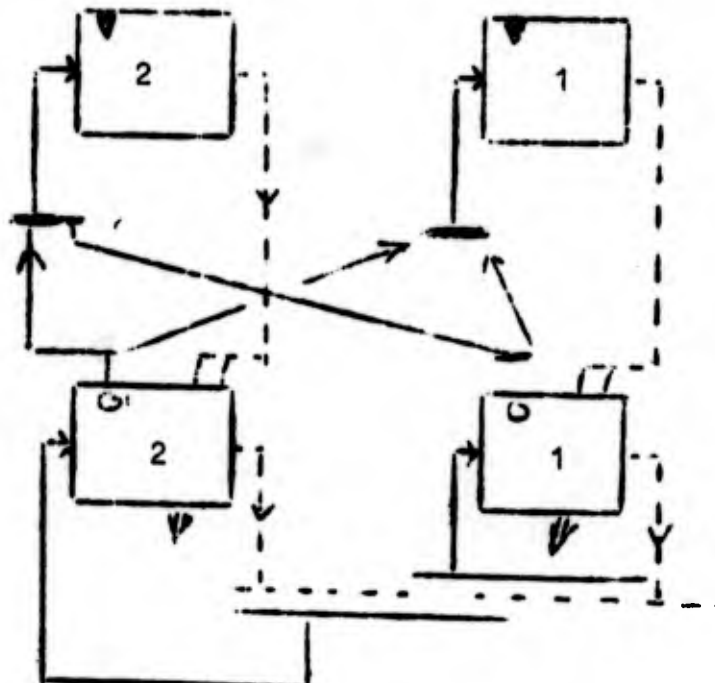Strongly coupled pair of control units
in present symbolism

DIAGRAM 16.

APPENDIX II

CHAPTER IV

Fabric and Organisation of Memory.

The Malleability of Animal Fabrics.

Although animals perform some wonderful feats of
learning and memory, it is prudent to reserve the
wonderment for the organisation of the process.
There is nothing very astonishing about the fact that
animals retain an impression or "trace" or "engram"
of their history for they are built from a malleable
fabric which is inherently capable of habituation
and adaptation, and as Ashby and Beer have pointed
out, so is the fabric of many natural systems. We
are so accustomed to machines, such as computers,
wherein the components have been designed to avoid
the effects of habituation and adaptation that the
ubiquity of these processes in nature is often
overlooked.   In fact, it is difficult to imagine
conditions in which a neurone, for example, would
not bear many persisting traces of its previous
stimulation and the real problem is to select a
relevant class of mechanisms of learning from an
unduly rich collection of possibilities.

Mechanisms of Malleability.

Four sorts of mechanisms have been widely discussed
as possible vehicles for the malleability in the
nervous systems of the higher animals.   These
mechanisms chiefly involve the neurones of the
brain but there is an impressive body of data
suggesting that the glial cells which support and
nourish the neurones also take part in memory processes.

(1)   If a loop of self excitable neurones is once
stimulated it will continue to reverberate and
the existence of this activity signifies its
previous stimulation. A suitable network of self
excitable circuits may be thrown into different
stable modes of activity by distinct stimuli and the
pattern characterising its prevalent mode signifies
the previous stimulation. Dynamic memory systems
of this type are "cleared" of all the retained
information if their electrical activity is interrupted
and because of this it is known that long term
memory is <u>not</u> dynamic though short term memory
(and the mechanism for placing data into long
term memory) almost certainly <u>is</u>.   Thus brain
freezing (which brings the electrical activity
of the brain to a standstill) has no effect upon
at least some long term memory, nor does the

administration of a disruptive electrical shock.
But either freezing or shock impairs the assimilation
of experience over an interval extending up to about
half an hour before the treatment and for some time
after it.

(2) If a neurone, i, is excited by signals arriving
at its j-th synapse it is plausible, on the grounds
of physical chemistry, to suppose that a change in
membrane properties takes place which signifies,
to the i-th neurone, the fact that it was once
excited by a signal at the j-th synapse. An older
and more extreme version of this hypothesis suggested
that activity dependent growth of nerve fibres
established or extended synaptic connections.
Whilst there is plenty of circumstancial evidence
in favour of at any rate the modern version of
this hypothesis, it is difficult to conceive an
experiment that would test or disprove it.

(3) The members of another class of hypothesis,
suppose that excitation of a neurone by a temporal
or spatial pattern of impulses P, gives rise to a
physio-chemical change in the cell membrane that is
peculiar to P, rather than the fibres that conveyed
P.   Once again, the hypothesis is almost certainly
true but it is difficult to disprove.

(4) A peculiarly stable type of P sensitive
memory has been proposed in connection with the
experimental work of Hyden and others. To be
definite we present a mechanism for memory
which goes considerably beyond the experimentally
verified field.   Suppose that a spatial or
temporal pattern of impulses P induces the
production of a specific messenger R.N.A. which
is used to synthesise a particular protein, p,
with the property that in contact with the pattern
P, protein p breaks down into substances that
excite the neurone.   Once that p has been produced
it remains available because a messenger R.N.A. is
available for its synthesis. Finally, we assume
that several messages, $P_1, P_2 \ldots\ldots\ldots P$ give rise
to several specific proteins $p_1, p_2 \ldots\ldots\ldots p$ and
that a given neurone develops a particular class
of proteins able to "recognise" a corresponding
class of patterns.

The chief evidence for this sort of memory
mechanism comes from experiments in which rats
learned to perform special skills, such as

balancing on a tight wire. In rats the learning
of a balancing skill depends upon cells in
Deiter's nucleus and it was found that nucleotide
base ratios in the R.N.A. from Deiter's nucleus
cells of rats that had learned to balance on a
tight wire differed very greatly from the normal
base ratio (or the ratio for rats that had been
simply suspended and rocked), hence suggesting
the learning controlled synthesis of an abnormal
R.N.A.   Similar results have been obtained for
other animals, but they are open to the criticism
that the base ratio analytic technique demands
separable cells and the acquisition of rather
special experimental skills.   Again, learning
can be inhibited, in certain conditions, if an
animal is treated with an antibiotic such as
Puramycin, that inhibits protein synthesis but
these results can be criticised because, apart
from learning, the treatment interferes with
other aspects of the metabolism.

It seems likely that all of the mechanisms
(1),(2),(3), and (4) are at work in normal learning.
Data must be consolidated in short term memory
by some dynamic process.   An appreciable delay
is involved in producing an R.N.A. molecule and
although reverberation patterns could hold the
information whilst the data in short term memory
is assimilated into long term memory it is likely
that an intermediate "plastic" change is involved.
Surpisingly small "plastic" changes of connectivity
are needed to stabilise a particular mode of
autonomous activity in a network such as DIAGRAM 25,
in the sense that once the i-th reverberation R_i
has induced certain changes of connectivity C_i,
the most probable pattern of reverberation becomes
R_i.   In other words, if the network characterised
by C_i is subsequently excited in a haphazard fashion
it will prove to reverberate in the i-th mode R_i.
Further, a system of this sort admits a type of
contingency which is needed in any learning system.
The changes in connectivity required to achieve
R_i in DIAGRAM 25, are only admitted if R_i, arises
from a goal approximating form of excitation of the
network.

The Location of Memory.

People ask "Where is the memory?" meaning, "Where is some item stored?" and they ask "Where is memory?" meaning, "Where is the memory organ?". It may be the case that neither enquiry is answerable, but in each case something can be said. The original picture of memory, as a sort of file index system with something like a cortical neurone registering a single item was reversed by experimental work, such as Lashley's that showed learning and memory in rats and other creatures to be unspecifically effected by large cortical ablations. The file index theories were replaced by dynamic memory theories in which items were registered by complex modes of activity. These notions have been rejected so far as long term memory is concerned although they plausibly apply to short term memory.

The present thinking on this subject is that long term memory is neither localised nor is it diffuse in the dynamic sense. To illustrate the point, consider a "phantom limb" (somebody with a painful and diseased arm has it amputated. Later, he feels the pain that used to exist, say in his fingers, even though the hand is missing. If so, he is said to have a "phantom limb" (which is a curiously tangible sort of memory). It is possible to remove the phantom limb by destroying a very precisely definable tract of nerve fibres that are responsible for signalling the pain (destruction of the tract can be achieved by a beam of ultrasonic sound or in other ways). The "phantom limb" disappears. Hence, the memory must be localised. But a few months later, the limb returns. Hence the original memory was evidently represented in some coded form, in another part of the nervous system and, in this sense, it was diffuse. The relearned "phantom limb" can again be exorcised by an operation that is entirely local. But a few months later it is relearned, so the relearned memory was also represented in some distant part of the nervous system.

Briefly, a memory has a specific operational locus, which is one of its representations. But it has many, and conceivably an indefinitely large number, of representations in the brain. There

is a great deal of evidence in favour of the view
that memory involves a continual relearning in
which whatever is relearned becomes differently
and more diffusely represented.   We comment that
an organisation of this type is identical with
an associative memory system in which data is
stored in terms of many tokens for its properties.
The datum "Aunt Amelia's sitting room" is stored,
for example, in terms of properties, such as being
rectangular, being a rectangular room, containing
an aspidestra plant and belonging to an irrascible
old lady.   For each property value there will be
a token or tag and "Aunt Amelia's sitting room"
is ultimately represented as a way of associating
its tokens.   As more items are stored in an
associative memory, more descriptive properties
are generated and insofar as these are relevant
to an existing item, this item becomes differently
represented due to the acquisition of novel tokens
that relate it to the novel descriptive properties.

The Items in Memory.

What "item" is remembered and relearned. The
evidence points very strongly to the proposition
that an organism remembers what to do about a
situation in order to achieve a goal; in other
words, the basic "item" is a control system code
which, depending upon the level of abstraction,
(or the level of the coded control system in an
hierarchy of control) is either an instruction
for doing something goal directed or a prescription
for building an operator that will do something
(or a prescription for a class of prescriptions
and so on).   Consequently, the descriptive
properties in a memory system should be either
properties of goal directed action or more
abstracted properties of properties of action,
and there are good reasons for supposing that they
are.

Aunt Amelia's aspidestra is recalled as that
into which, we might pour a glass of tonic wine
and Aunt Amelia's irrascible disposition is
recalled as that with which we argue to get our
own way. The case of the phantom limb appears
to contradict this hypothesis (it seems as though
a phantom limb is a "fact" or simply a "feeling").
But even here it is feasible to argue that the
feeling occurs because the organism has a memory
that makes it try to do something or to make a
compensation that cannot, in fact, be done or made

(which avoids the rather unfair repartee that a
phantom limb is a pathological memory anyhow).

In support of the contention is the fact that
the most basic sorts of learning, including
coordination skills and maintenance of posture,
are impaired or prevented if the subject is not
allowed to do what he normally would do or if the
motor feedback derived from these actions is
distorted or interrupted. On a slightly different
tack, all learning which has been examined
experimentally is associated with goal achievement.
In laboratory experiments of the type we shall
consider in Chapter V, the animal is rewarded by
the experimenter for doing whatever it should
learn to do and there is little doubt that the
creature learns how to achieve the goal of getting
a reward. The experimenter must, of course, find
out what the animal treats as a reward; this may
be something obvious, like food for a hungry
animal or it may be something that satisfies a
more subtle physiological requirement; indeed,
it may be any commodity that the animal has a
"drive" to get. From the tenor of our previous
discussion it will be evident that not all "drives"
are of the directly physiological type (subserving
a reduction in hunger or the provision of sexual
satisfaction). If the creature contains or
acquires any code or programme which prescribes
a goal, then there is a perfectly good symbolic
drive to achieve this goal(when the programme or
code is acquired as a result of previous learning
the reward suited to a symbolic drive is often
called a "secondary reinforcer", in contrast to
a "primary reinforcer" which acts as a reward for
a physiological drive). Symbolic drives, at any
rate those that are innate, can often be generalised.
Most of the higher animals have a generalised
curiosity drive, and Desmond Morris has emphasised
the "neophylic" or "novelty loving" propensity
of certain species. None of this is at all
surprising. We might predict that animals would
seek to explore their environment on the grounds
that they are active control systems; we might
expect to find higher animals exploring in the
hinterland between the unfamiliar and the positively
frightening. But these symbolic drives, however
predictable, are not physiological drives in the
classical sense. I am stressing the point because
all of the counter-examples to the present contention
namely all the exemplars of learning that is not

goal directed rest upon the absence of physic-
logical drive and rely upon the supposed absence
of any drive. The chief exemplars are latent
learning, copying, and imprinting. Of these
latent learning and copying almost certainly
represent delayed forms of imprinting which is
a process we shall consider in a moment.

Where is the Process?.

Is the organ of memory the brain(as we supposed
above) or something more than the brain or some
part of the brain? If we accept the view that
memory involves relearning, then there is no real
answer to this enquiry; certain sorts of relearning
depend upon the states of the organism and others
upon states of its environment (yet it would
hardly be reasonable to call the environment part
of the memory organ). It is perfectly reasonable
even so, to say that some cells in the organism
are specialised as malleable units. According to
most present day thinking, these are all neurones,
and the neurones specialised as malleable units
are scattered rather diffusely about the nervous
system. In some animals these cells have been
identified, for example, J.Z.Young has advanced a
scheme of the sort shown in DIAGRAM 26, to
explain how the octopus learns to advace or
retreat from a visual form. The specialised cells
in DIAGRAM 26, are the amarcrine cells in the
octopus opti. lobes.

Not surprisingly, if the "items" in a
memory are "codes" for control systems, the
organisation of memory appears to be identical
with the organisation of a goal directed hierarchical
control system. At the lowest level of
organisation a control system realised in
physically malleable fabric could adapt in favour
of its goal, so that if some environmental
condition is repeated it will subsequently select
an action that is goal approximating. Thereby
it acquires or improves its decision rule. If we
start with an active control system as in DIAGRAM 8,
then this adaptation becomes a primitive sort of
learning. The source of variation guarantees that

if the system is not perturbed by its environment
then it will act upon its environment (in a
fashion that is haphazardly selected within the
constraints imposed by its structure). Such a
device is imbued with the rudimentary auxiliary
goal of learning(in a rather inefficient, trial
making, way) about its surroundings.

The "control of control" construction yields
a higher level of organisation wherein the L^1
control systems learn about and operate upon
(according to DIAGRAM 11) or select and construct
(according to DIAGRAM 12) the L^0 control systems
in their domain. If the attitude controller of
DIAGRAM 21, is embodied in a malleable fabric
it "learns attitudes" and is, of course, a special
case of DIAGRAM 11. If each parameter value is
associated with a distinct L^0 control system,
then DIAGRAM 21, has the form of DIAGRAM 12.
Since all of these structures are reducible to
active control systems of the sort in DIAGRAM 8,
the learning process is also reducible.

When embodied in a malleable fabric "control
of control" is a non trivial sort of learning; an
hierarchical concatenation of trivially "learning
about learning". Since the process entails the
stable association of control systems, or the
codes for them, it is apt to call it "concept
building"; notably "concept building" in a
semantic universe of discourse is isomorphic with
the reciprocal process of cellular reproduction,
when the system is interpreted in Chapter II, in
a biochemical domain.

If "control of control" is iterated, the
resulting system is able to build an indefinitely
large hierarchy of concepts. Each level in this
hierarchy is concerned with a distinct collection
of signs and may be regarded not only as a distinct
level of discourse but as a distinct sign system
or internal language. Hence, the interpretation
of concepts, codes, or one level of expressions
in terms of another level(or in terms of the
system language) entails translation. If,as in
DIAGRAM 27, a pair of organisms A and B are
assumed to communicate concepts at level L^j then

they must each be equipped with an interpretative
mechanism that translates between L^j and their
system language.

Several Levels of Discourse.

There are a couple of outstanding and closely
related questions about learning and memory.
One question is "To what extent can a pair
of organisms A and B communicate concepts?".
This is really an issue of what interpretative
codes A and B jointly possess. The other
question is "To what extent does learning depend
upon the codes that are innately determined
(specified as part of the genetic instructions
of an organism)?". This will be dealt with
later.

If A and B are to communicate as suggested
in DIAGRAM 27, then they must be equipped with
arrangements for translation from the higher
conceptual levels into the system language.
Since the system language certainly accomodates
L^0 signs for data about the environment, this
may amount to providing an L^0 interpretation or
translation of expressions at any other level
of discourse (we could achieve L^1 communication
by establishing a direct connection between the
L^1 organisation in A's head and the L^1
organisation in B's head, using the L^1 data
codes.   But this would imply "getting into" A's
head and "getting into" B's head in a rather
literal fashion which is physically impracticable).

*Footnote. The distinction of levels in this
rigid way is not accidental. It stems from the
need, in a reducible model, to avoid any ambiguity
regarding the level of discourse to which statements
refer. A similar distinction is made, in a logical
context, between "logical types" and yields a "type
hierarchy" or its equivalent.

Do organisms need to communicate higher level concepts? It appears that they do. The teaching relation "A teaches B a skill" certainly entails L^1 discourse, for A must be aware of the goal to be satisfied by B, he must ostensively define this goal in L^0, provide exemplars of the stimuli that are dealt with in the skill (again L^0) and he must reinforce B if his responses are goal satisfying. The relation "A teaches B a skill" occurs very commonly in animal communities and is about the simplest case of higher level discourse. The offspring of ravens, for example, grow up in an elaborate social milieu which evidently, from Lorenz's account, involves a great deal of teaching on the part of the parents and other adults.

Do organisms have the necessary translation systems? They do, insofar as they are able to indulge in any higher level discourse. But there is plenty of evidence that the acquisition of these translation systems (usually by a teaching process) is something of a stumbling block and we shall argue that it imposes the chief restriction upon social evolution. In the absence of a translation mechanism a concept is isolated and cannot be shared.

Is there any way, apart from direct connection (which is impracticable) of establishing higher level discourse between A and B. The reply is "No", if stratification is retained and if, as a result of this, statements in the system language are unambiguous. The reply is "Yes", if the stratification is avoided by using a self referential system language that is able to describe and construct its own expressions. In particular, it is possible to specify the entire concept building process in a suitable self referential language and the stratification becomes unnecessary. The price to be paid is an irreducible ambiguity of reference Thus the expedient of discarding stratification is only open or organisms able to tolerate ambiguity or to give their own idiosyncratic interpretation to statements in the system language.

The consonance of Codes.

Let us now return to the question of which codes are innate. Any animal has some behaviour that

is innate, in the sense that just this behaviour would develop even in an odd and atypical environment. Most animals have some behaviour that is learned in the sense that an adaptation occurs, which is jointly consonant with its innate codes and the structural codes of its system language. Some of birdsong is innate (the recognition of certain sound coordinates and the use of certain muscular actions) but some of it is learned (the recognition of specific sound patterns and the refinements of singing). The same comment applies to most of sexual behaviour and to the selection of a habitat in which to live. The really notable point is that the behaviour of the animal ultimately fits the structural code of the system language and thus that there is a "consonance" between the genetic code of the animal and the linguistic code. In fact, the "consonance of codes" is a general biological principle and the sequential learning process that brings it about is of general importance. The consonance between the innate codes of the whole animal and the structural code of its language is due to a particular manifestation of this sequential learning process called "imprinting" which occurs in the first part of life.

Some Experiments on Imprinting.

Imprinting was first noticed by Spalding in 1872. The phenomenon was studied by several workers including Lorenz in the late 1920's and it has been intensively investigated by Tinbergen, Thorpe and others, so that a large body of data is available. Ideally, and as originally conceived by Lorenz the phenomenon of imprinting consists in the rapid and irreversible acquisition (without the satisfaction of any physiological drive) of an attachment or an aversion usually entailing the recognition of a releaser sign, which is, by definition, in the system language. Imprinting of a given type can only occur within a short "sensitive period" in the animal's life.

Typically the sign that is recognised is "Mother". In normal conditions the baby animal comes across its real mother within the "sensitive period" for maternal imprinting and, if so, it subsequently exhibits maternally directed behaviours like "following". But the sign for a mother is not innate, although the

need to have a "Mother"sign is innate. Hence, the
imprinting process can be"fooled". Many animals
can be imprinted to "follow" and to espouse rather
inappropriate objects, for example, ducklings that
are exposed to the experimenter in their sensitive
period will subsequently follow the experimenter;
Harlow's baby monkeys became maternally attached
to a cloth covered wire structure; by an unfortunate
accident a peacock was once led to regard a turtle
as its only possible mate(imprinting applies to
sexual as well as maternal attachments. In fact,
it applies to most signs and actions that are
important for survival or that are used in connection
with other animals of the same species).

In a recent survey of the field, Sluckin has
pointed out that imprinting does not usually have
this ideal character but merges into ordinary
learning by trial and reward. It is not so
immediate as used to be imagined and there is some
evidence that it may not be any more irreversible
than other learning. So far as drives are concerned,
the curiosity drive is presumably satisfied if it
exists. But in any case, the goals are perfectly
adequate symbolic goals that are achieved by the
fact of imprinting, as such. Finally, the work of
Guiton shows that in chicks, at any rate, the
sensitive period is more adequately conceived as
an ordering of sensititivities. The organism is
sensitive to Type A imprinting until A_1 is imprinted
and to type B imprinting until B_1 is imprinted.

Perhaps Sluckins main point is that imprinting
occurs within a framework (of perceptual attributes
and predetermined action patterns). Chicks, for
example, become imprinted to follow (as they would
their mother) after any moving dark or light object,
or even any flashing light. This, and a few other
features of a mother are salient properties to which
they attend and these perceptual attributes are
inherited. They are also, of course, consonant with
the system language indeed they determine its
universe of discourse. Whilst accepting this point
of view, we comment that the number of perceptual
attributes normally associated with the imprinted
figure may be very much larger than the number
encountered in the laboratory. In some respects,
the relatively simple figure of Harlow's cloth
covered wire structure did not act as a mother;

later in life the baby monkeys exhibited several
deficiencies. By hypothesis some of the relevant
perceptual attributes were missing from the maternal
figure in the experiment.

The Sequential Development of Consonance.

The consonance of codes developed through imprinting
involves a sequential control process which belongs
to a rather large class of similar processes, all
of which can be developed from the paradigm case
in DIAGRAM 13. As a first step in this development
we convert the substitution process, M, in DIAGRAM
13 into an operation sequence. This yields the
organisation of DIAGRAM 28 (I).

The best exemplor of this organisation is the
metamorphosis of insects; such as the familiar
transformation of an insect egg into the larval
form of caterpillar and the caterpillar into the
adult which is a butterfly or a moth. Within hours
after the insect egg begins to divide an initial
embryonic control system, R say, lays down the code
, for the adult form; this is embodied in
scattered groups of cells called imaginal buds. As
the larva develops (enlarging chiefly by undifferentiating
expansion of the existing cells and accommodating this
expansion by moulting), the imaginal buds remain dormant.
Now R also produces a substitution system, M, that
is embodied in the hormonal control mechanism in
DIAGRAM 29. The secretory cells in the brain
produce hormones of which one stimulates the secretion
of a further hormone P.G.H. from the insects
prothoracic gland,(as in DIAGRAM 29.   there is also
an inhibitory feedback of P.G.H. to the brain.
Similarly, a pair of bodies, the corpora allata
that are closely associated with the brain (and
are analagous in insects, to the pituitary gland)
secrete a juvenile hormone J.H. In the presence
of J.H. In the presence of J.H. the P.G.H. system
controls the cyclic changes of moulting, and the
imaginal buds remain inhibited. As the concentration
of the corpora allata's J.H. decreases* the pupating
insect larva becomes responsive to external stimuli
such as temperature which render the brain and the

*Footnote. Although the mechanism for the decrease in
J.H. concentration is not elucidated the process can be
reversed experimentally, for example, the insect can be
retained as a giant developing larva by injecting J.H.
or made to metamorphose prematurely by removing its
corpora allata.

P.G.H. system functionally equivalent to M.   A
sequential process occurs in which the imaginal buds
are activated and the code α is substituted stage
by stage.   Coincidentally, the larval cells are
dissolved and used to provide nourishment for the
α coded adult.

The next modification of the paradigm organisation
appears in DIAGRAM 28 (II). Now the initial process
R lays down a pair of codes α and β as well as M.
Although the substitutents for the α and β operations
are undetermined before M becomes active, R does
determine the interconnection of the domain of the
putative control system.

The best exemplar of this organisation is the
biological specifity of motor and sensory limb
innervation patterns which has been chiefly studied
in the embryos of amphibia. α is a central
representation of action patterns (such as the
walking movement) or of sensory patterns. β is
a peripheral representation of these patterns which
names the muscles and nerves involved (and is
probably a chemical coding). Rather late in embryonic
development M, which is the limb innervation system,
sequentially substitutes the operations in α and β
in a consonant fashion, and brings about the required
neural connections. The character of this process is
revealed by the fact that it can be experimentally
"fooled".   By ingenious surgery that alters the
peripheral "names" it is possible to induce a bizarre
α to β correspondences reflected in anomalous
structures such as amphibia that have futile movement
patterns or that scratch their backs when they are
tickled on their front.

Finally, consider DIAGRAM 30.   The codes α and
β and the substitution system M, are again laid down
by R, which is however, conceived as an evolutionary
rather than a genetic control system. β is the set
of constraints upon a system language, its syntax
and alphabet. α is a code for releasers and other
signs in an individual organism with the system
language β (so that, in a sense β could be specified
by an aggregation of the α codes characterising all
members of some local population).   The substitution
system M is the <u>imprinting</u> system.   Although M only
acts upon α we stipulate in DIAGRAM 30 that it receives
at least some external L^1 control signals (in other

words, at least some β signs can be interpreted
or recognised by the organism as instructions to
M). These signals have the form "thus L^o input
belongs to the class of mothers" which may amount
to no more than "the class of stimuli associated
with a flashing light". For imprinting, nothing
further is required. The imprinting of a given
element of α is restricted by the admissible β signs
in (unless, experimentally, we import some bizarre
object with the same name in the β universe of
discourse; say, the experimenter himself). The
process is sequential (B can only be imprinted after
A has been imprinted) the goals are internal and
symbolic goals; but notice that the organisation
would depict <u>reinforcement</u> learning rather than
imprinting if we had required an effective L^1
feedback of data. Indeed, there is a sense in
which the specifity obtainable by reinforcement
feedback is replaced, for imprinting by the
restriction of β .

To illustrate the point, DIAGRAM 31, is an
imaginary but plausible substitution plan. It is
assumed that α admits $A = A_1$ or A_2 or A_3 or A_4,
that $B = B_1$ or B_2 or B_3 or B_4 and $C = C_1$ or C_2.
The code β imposes the partially sequential dependencies
shown in DIAGRAM 31, which indicates the constraints
imposed upon the imprinting process by different
experience of β signs emitted by other organisms or
the environment.

The Production of Novel Organisations.

So far, we have presupposed the existence of higher levels
of organisation without specifying how they appear.
The omission is deliberate, for an adequate account
of the development of higher levels of organisation
entails the cooperative interactions which will be
discussed in Chapter VI. However, this is a logical
point to consider the essential part played by
<u>differentiation</u> in providing the entities that <u>do</u>
cooperate presupposing some vague idea of what
cooperation is, and leaving it vague until Chapter VI).
The imprinting process is one of the most important
types of differentiation (it might, alternatively, be
dubbed "symbolic" differentiation). A more elaborate
but also more tangible differentiation occurs amongst
the cells in a developing embryo, leading to the
production of coherent tissues like skin and brain and
kidney. Indeed cellular differentiation and imprinting

are isomorphic if we accept a view, most explicitly
stated by Flickinger, that the development of
"competence" in a cell is a sequential process.
Although rather little is known about the detailed
mechanism of cellular differentiation it is commonly
agreed that cells differentiate because of an
interaction between their "competence" and the embryonic
"field" in which they reside. The competence of a cell
(at a given instant) is the collection of genetic codes
or genetic loci that can be realised at that instant.
Initially, the cell is equipotential (in the sense
that any of its codes can be realised). It becomes
restricted, Flickinger suggests in a sequential
fashion, as certain genetic codes are blocked or
prohibited. If α in DIAGRAM 30 represents the
genetic code then M is analagous to this sequential
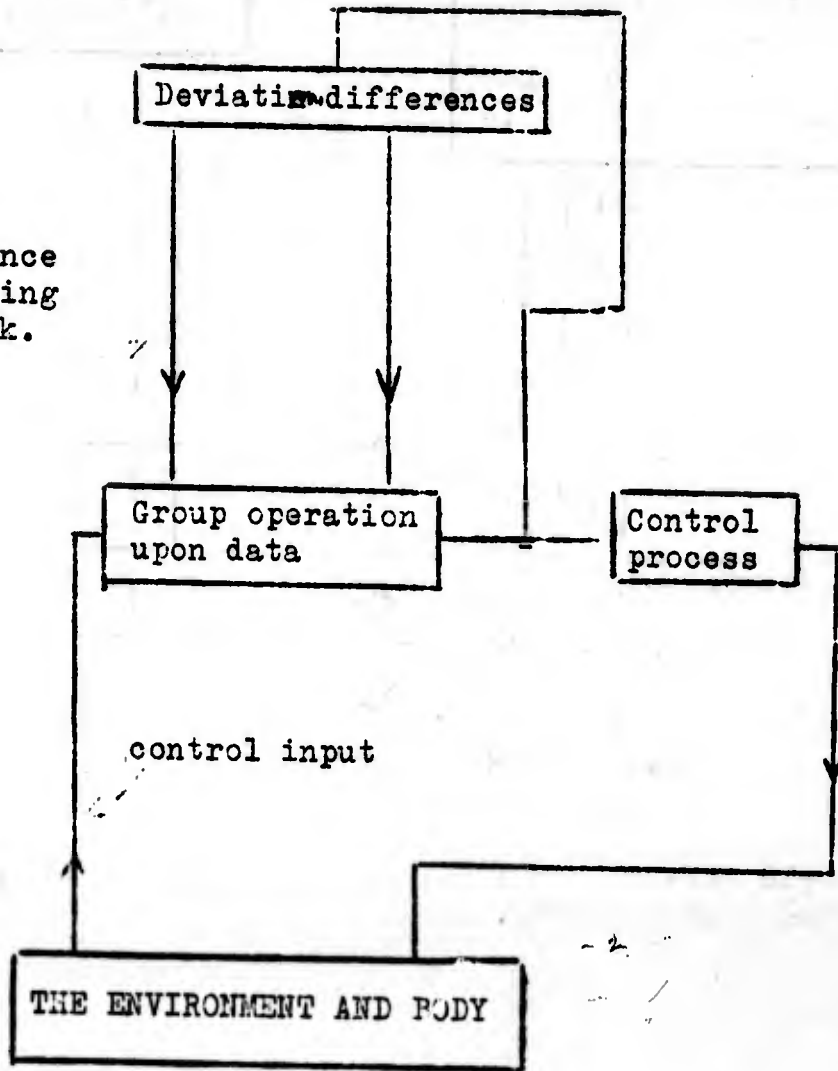process.

The embryonic field of a cell consists in the
influence exerted upon it by all neighbouring cells
in their immediate condition of competence. The L^0
discourse in DIAGRAM 30 is analagous to the β
restricted influence of other members of the local
population upon the individual organism, whilst the
L^1 discourse is strictly analagous to the effect
of inductive stimuli that influence M and induce
the substitution of code blocks. Since β is
derivable from a composition of the several α codes
there is an important sense in which the α and β
interaction cannot give rise to a "novel" form or to
essentially "higher" levels of organisation. It is
true that novel forms of differentiation could arise
from externally induced mutations. But the
discontinuities of genuine innovation cannot arise
from any internal process unless the differentiating
and developing system is constrained in some fashion
that would, in the absence of cooperation, merely separate
the parts (or place them in a competitive relationship,
for cooperation is the converse of competition).
For imprinting, the relevant constraints are social.
They entail the systems of convention and tradition
discussed in Chapter VII and Chapter VIII. In the
developing embryo they are occasionally more tangible
and depend upon the geometry that restricts growth
(if you have a ball of cells, for example, that grows
more rapidly at the top than at the bottom, then,
geometrically, this ball must invaginate). Genuine
novelty occurs when restrictions of this sort bring
separately differentation parts into informational
proximity and, in the case to be cited, into
physical proximity.

At a rather early stage in the development
of the embryo of amphibia it is possible to distinguish
a primitive or presumptive mesoderm (which arises
from the so called "grey crescent" of the egg).
Whilst the embryo is still a hollow ball it is
also possible to distinguish primitive ectoderm
(which is to be the outer layer when the ball
invaginates to produce a "gastrula" and which,
in the adult, gives rise to structures such as the
skin). These tissues develop separately until
the embryo"gastrulates". At this point the presumptive
mesoderm and the ectoderm come into physical contact
and the presumptive mesoderm induces the local
transformation of ectoderm into neural tissue.
In embryology such an occurrence is called"evocation".
It is perhaps the most explicit case of novelty
production and it exemplifies the type of evolutionary
process which, in the abstract, has the form

(1)   Variation to produce alternatives by differing
       experience or external mutation

(2)   Differentiation of specifically distinct
       structures

(3)   Separation of these structures and further
       differentiation.

(4)   Approximation of distinct and separately developed
       structures.

(5)   Cooperative interaction to form some novel
       organisation.

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Deviatim differences

Difference
minimising
feedback.

Group operation
upon data

Control
process

control input

THE ENVIRONMENT AND BODY

which, in the present idiom, becomes:-

Deviation
differences

Difference
minimisation

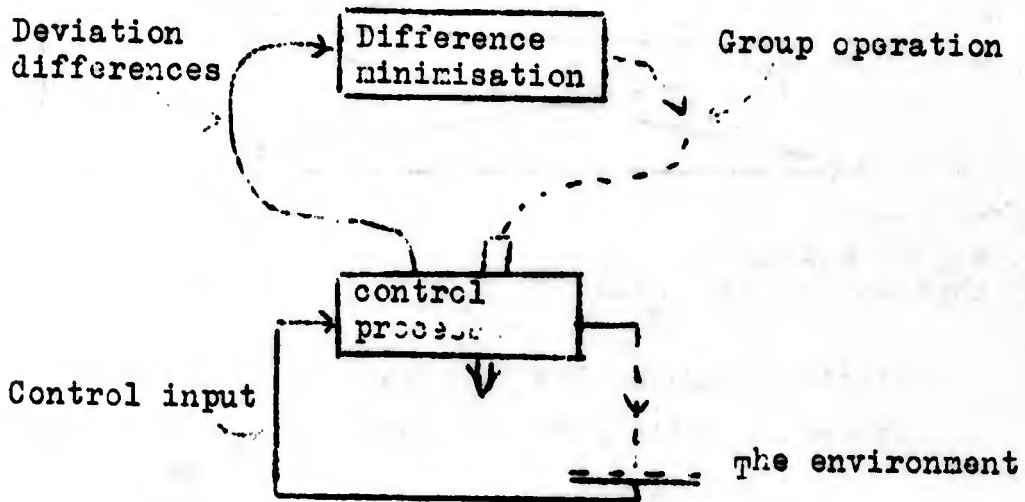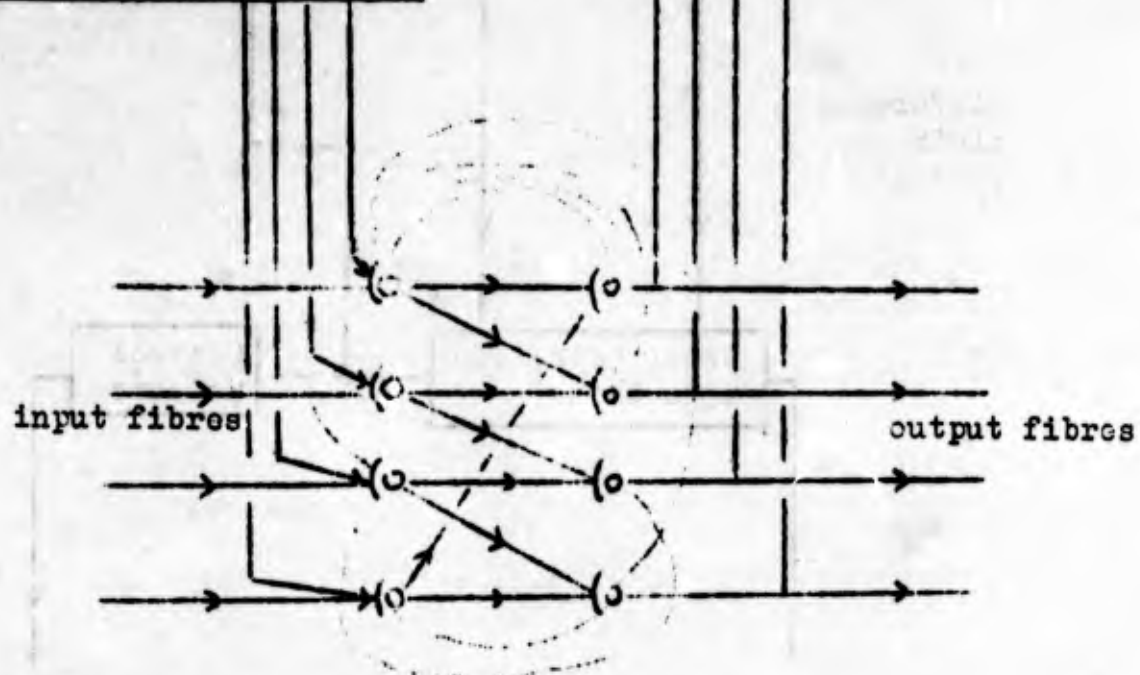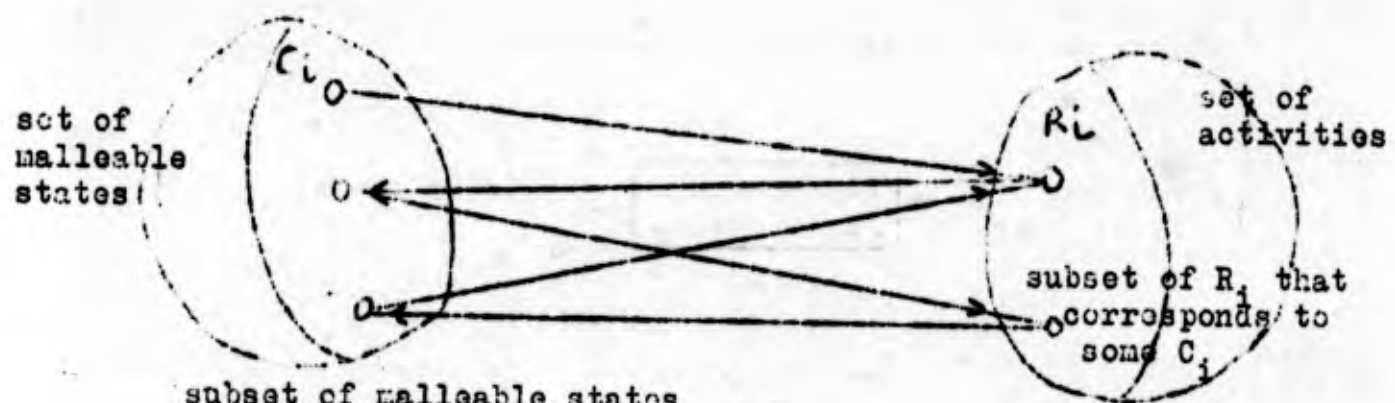Group operation

control
process

Control input

The environment

DIAGRAM 21

Reinforcement device allowing synaptic facilitation and thus change in C_i if R_i is acceptable, if R_i is acceptable,

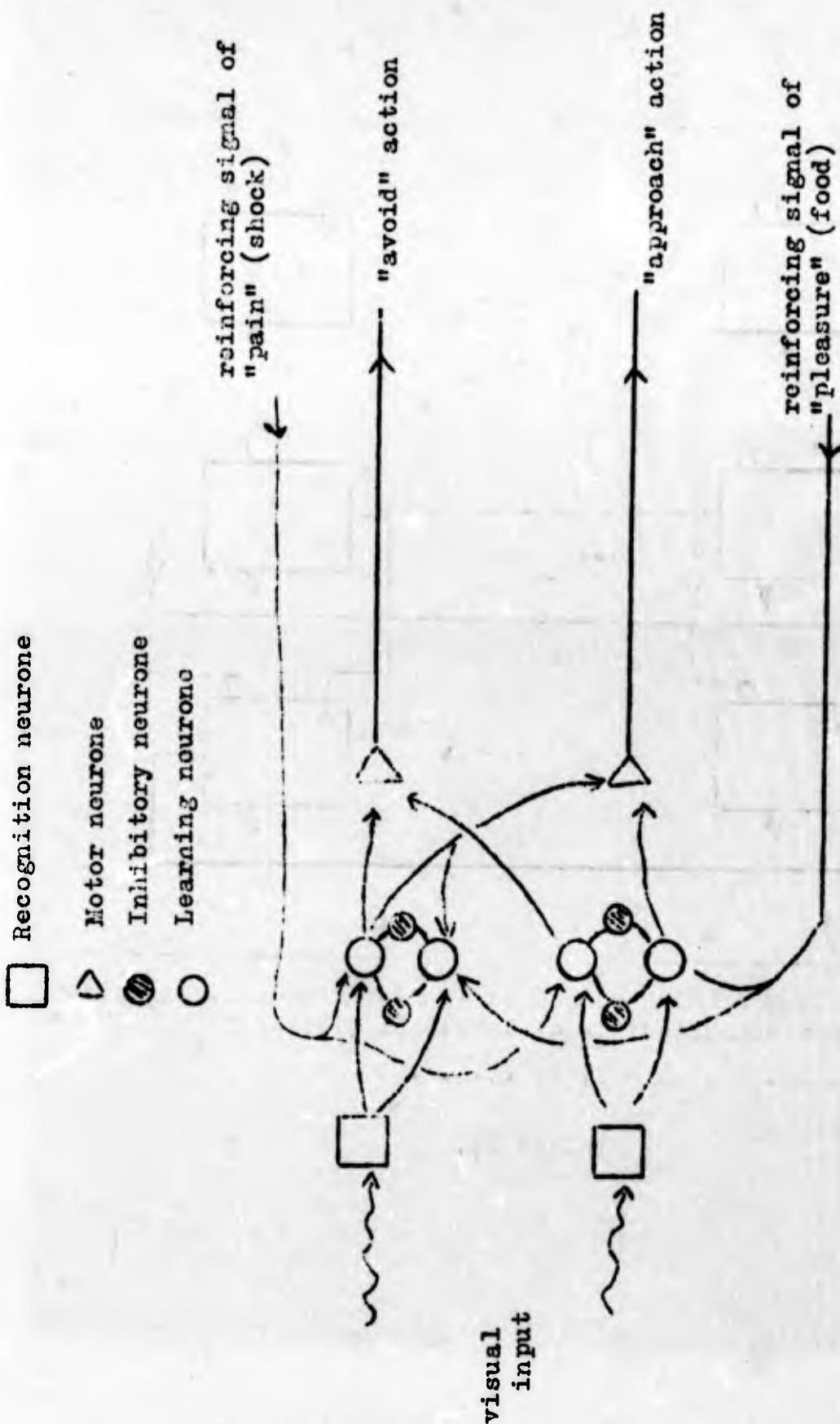Filter looking for acceptable R_i.

input fibres

output fibres

Simple malleable and reinforcible network with autonomous activity.

set of malleable states

C_i

set of activities

R_i

subset of R_i that corresponds to some C_i

subset of malleable states C_i that induce some activity R_i.

Relation between plastic states C_i of maleable network and it's modes of activity R_i.

DIAGRAM 25.

Recognition neurone

Motor neurone

Inhibitory neurone

Learning neurone

reinforcing signal of "pain" (shock)

"avoid" action

"approach" action

reinforcing signal of "pleasure" (food)

visual input

One of YOUNG'S proposed mechanisms for learning to avoid "pain", and to approach "pleasurable" visual stimuli.
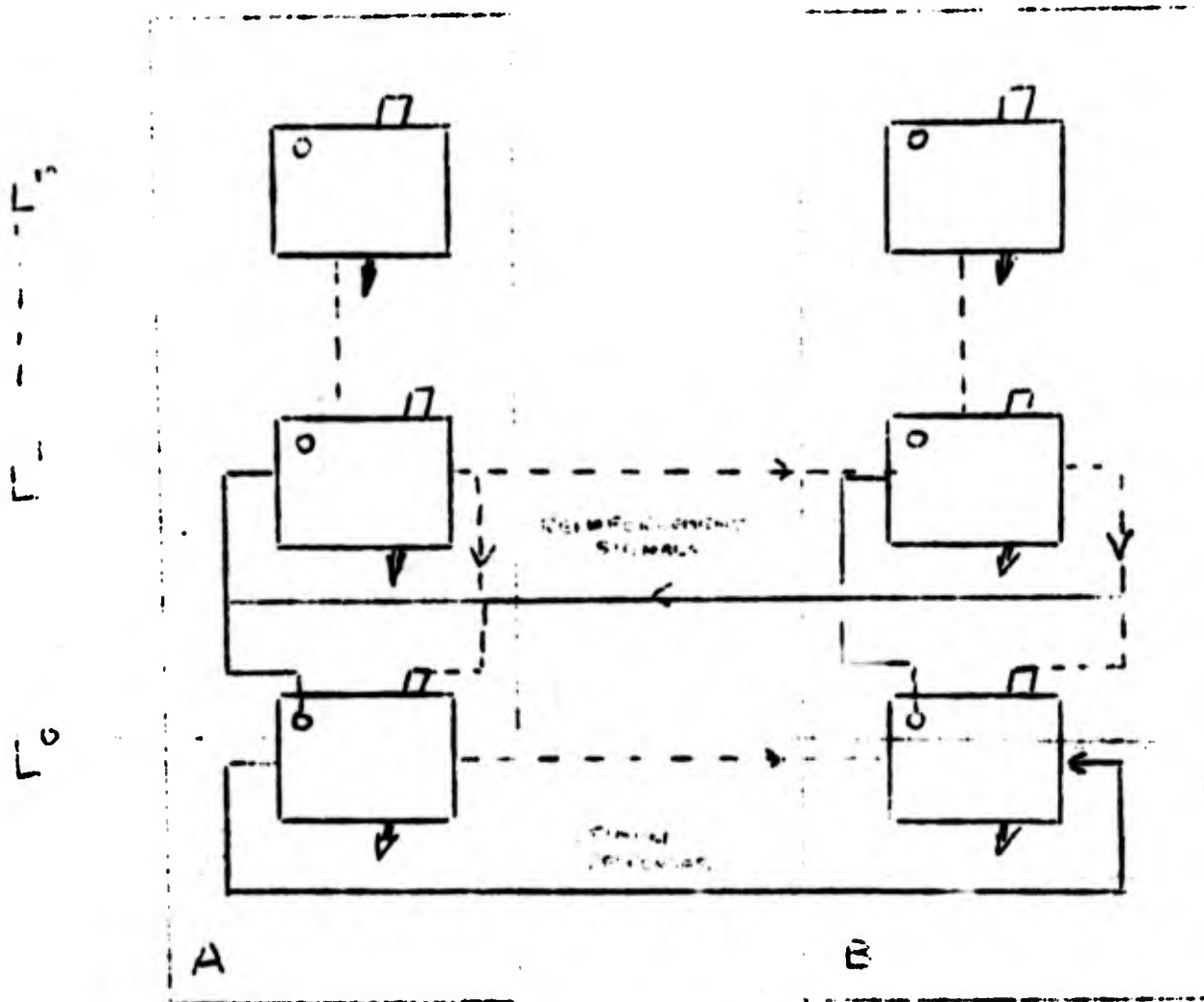
DIAGRAM 26.

Pair of organisms A and B conceived as hierarchically organised
control systems communicating at levels of discourse
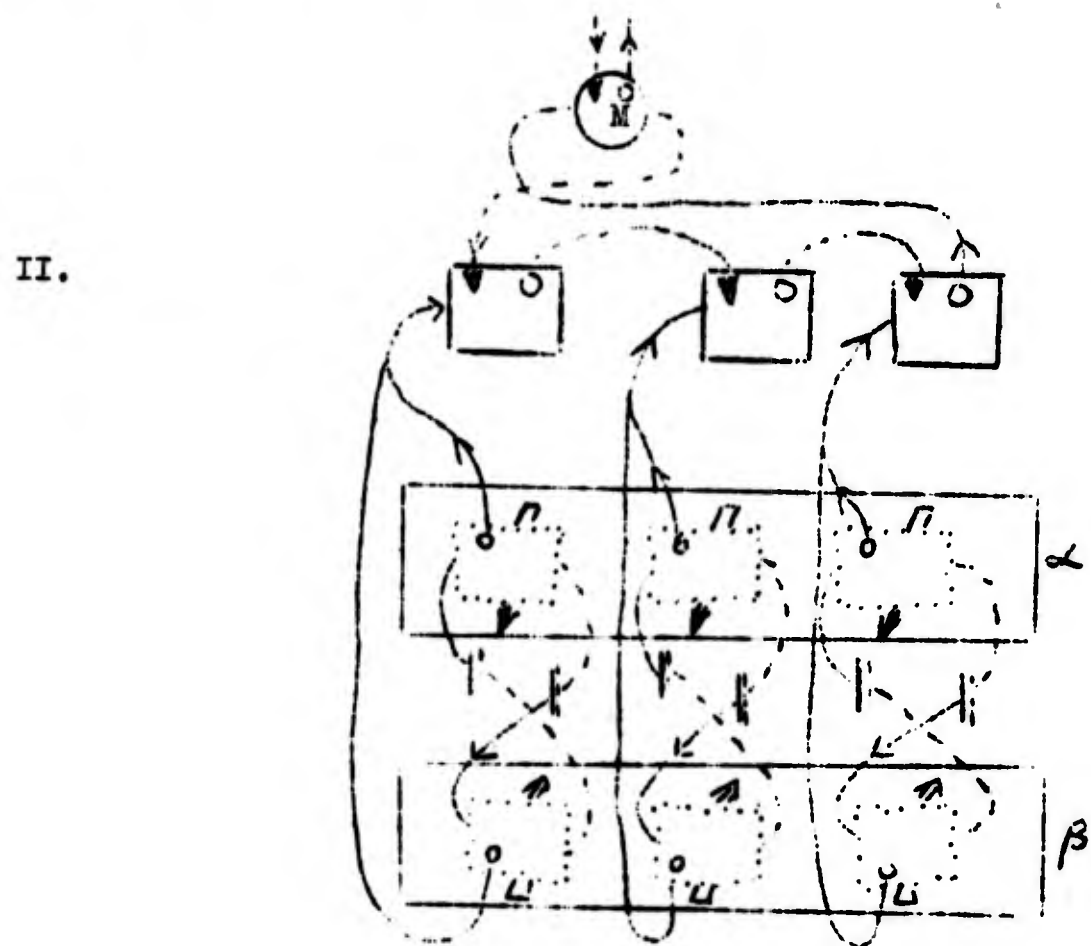$L^0, L^1 . . . . . . L^m, L = 0, 1, ...$

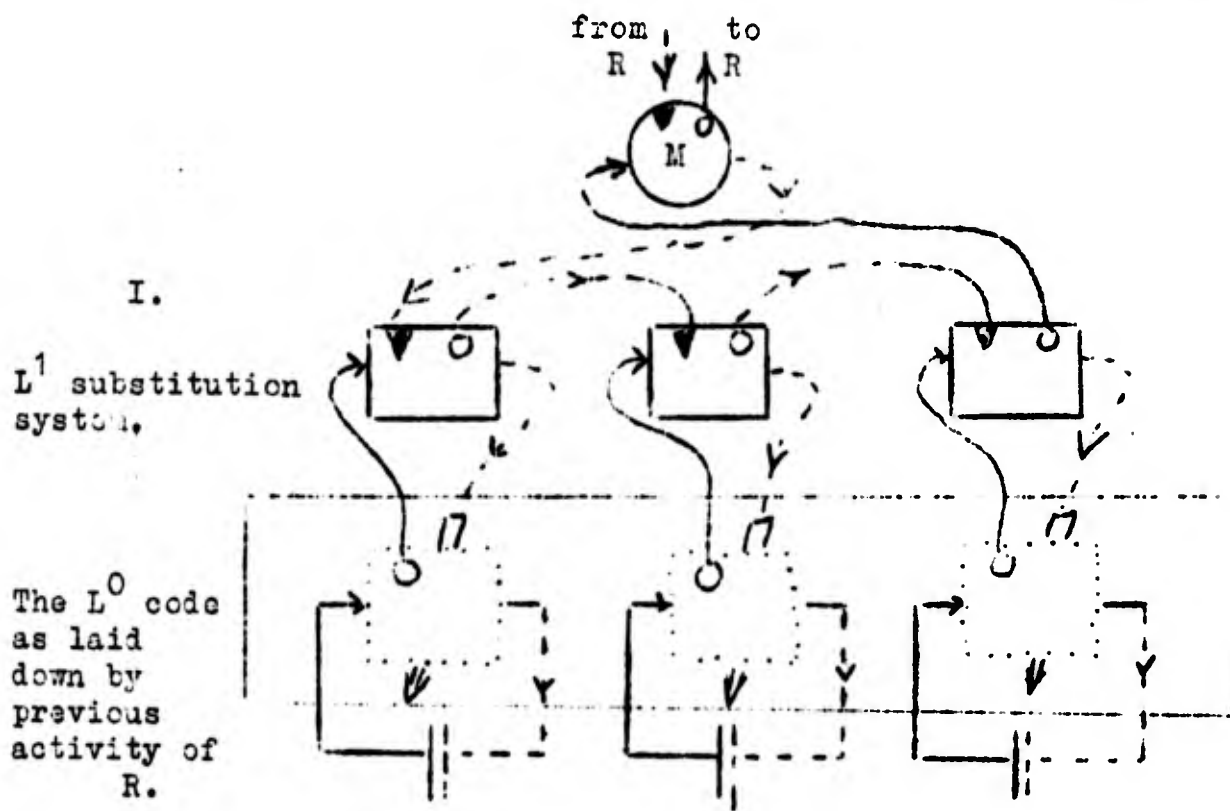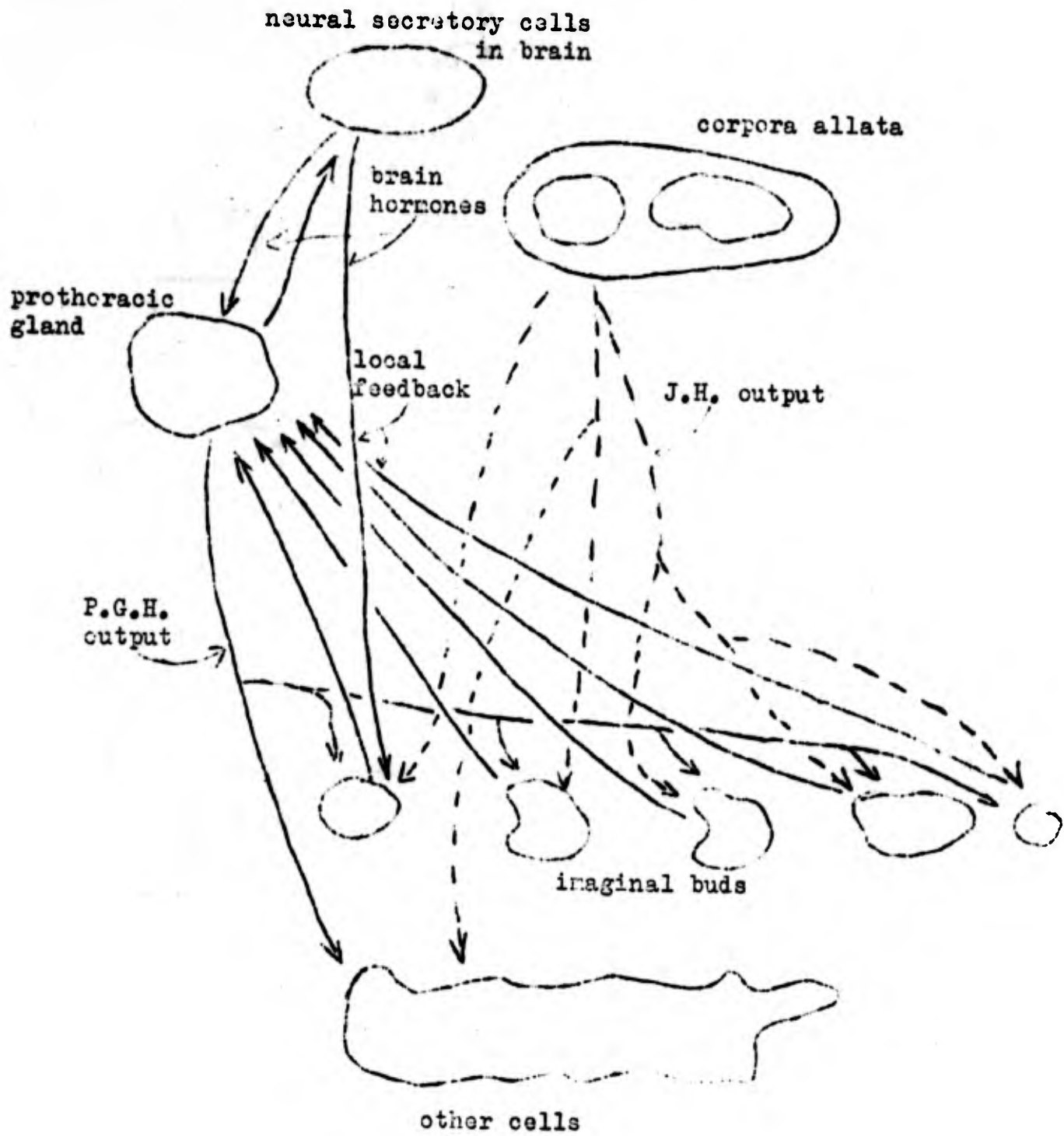DIAGRAM 27.

from   to
R   R

I.

L[1] substitution
system.

The L[0] code
as laid
down by
previous
activity of
R.

II.

DIAGRAM 28.

neural secretory cells in brain

corpora allata

brain hormones

prothoracic gland

local feedback

J.H. output

P.G.H. output

imaginal buds

other cells

DIAGRAM 29.

The organism being imprinted.
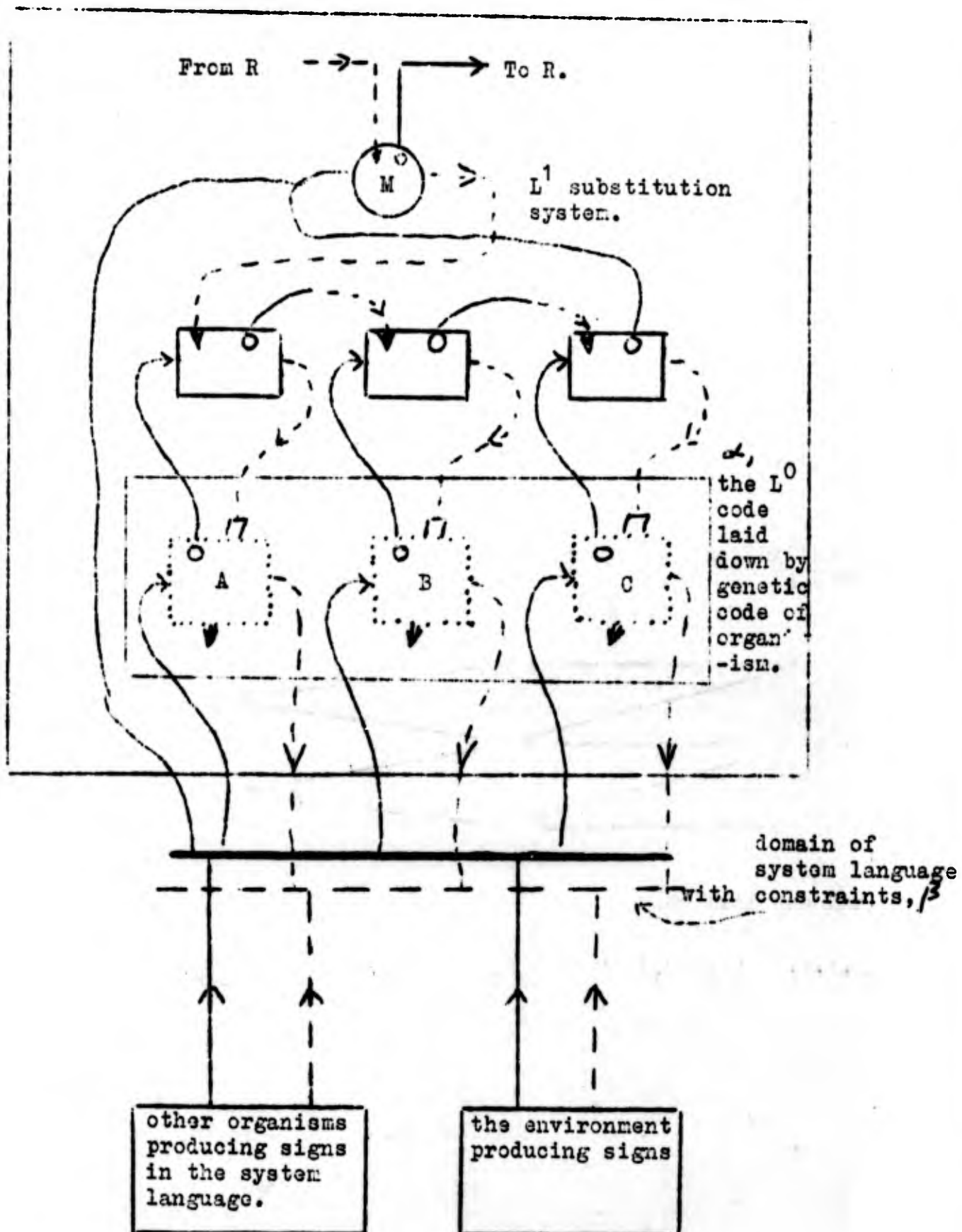
DIAGRAM 30.

α allows

$(A = A_1$ or A_2 or A_3 or $A_4)$

$(B = B_1$ or B_2 or B_3 or $B_4)$

$(C = C_1$ or C_2 only)

β allows

$(A_1$ or A_3 or $A_4)$

$\begin{cases} B_1 \text{ or } B_2 \text{ if } A_1 \text{ and} \\ B_2 \text{ or } B_4 \text{ if } A_2 \text{ and} \\ B_4 \text{ only if } A_4. \end{cases}$

$\begin{cases} C_1 \text{ if } B_1 \\ C_1 \text{ or } C_2 \text{ if } B_2 \\ C_4 \text{ if } B_4. \end{cases}$

Hence the substitution can proceed along certain paths, namely:-

substitution A	substitution B	substitution C
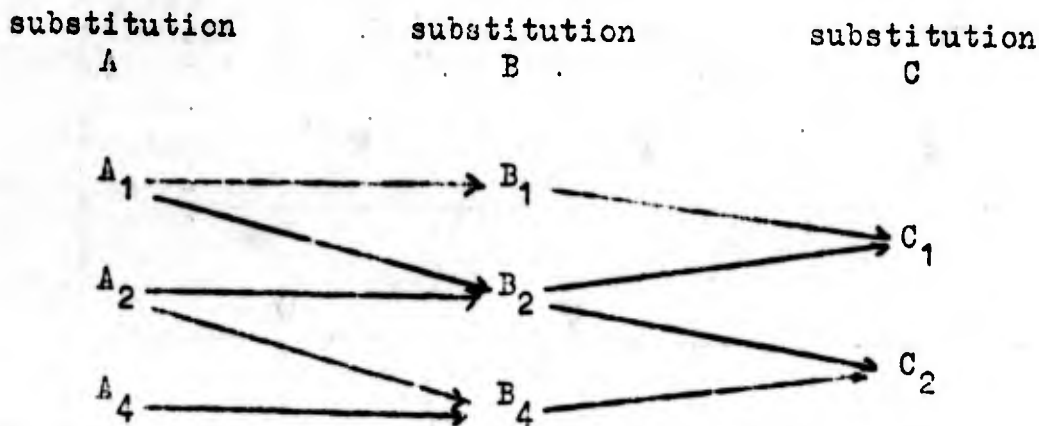
and may lead only to :-

$A, B, C, = (A_1 B_1 C_1)$ or $(A_1 B_2 C_1)$ or $(A_4 B_2 C_2)$ or $(A_2 B_2 C_1)$ or $(A_2 B_2 C_2)$ or $(A_2 B_4 C_2)$ or $(A_4 B_4 C_4)$

DIAGRAM 31.