Communications
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INFORMATION OVERLOAD
SURCHARGEMENT DE L'INFORMATION
1976.

by: James R. Taylor

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UNIVERSITY DE MONTREAL

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[Information overload]

TITLE: Surchargement de l'information
1976

CONTRACT: OSU5-0233

CHAPTER I

AN INFORMATION PROCESSING THEORY OF TASK GROUPS

Group Processes, Programs and Structures

Objects, actions and systems

An action (Wirth, 1973), or event (Pritsker and Kiviat, 1969), or occurrence (Gordon, 1969),

> requires the existence of some object on which the action is executed and on whose changes of state its effect can be recognized. (Wirth, 1973, p. 2).

A system, as we shall be using the term, may be conceived of as a (finite-dimensional) state vector $\underline{x}(t)$, having the form:

(1.1) $$\underline{x}(t) = [x_1(t), x_2(t), \ldots, x_n(t)].$$

Each component, $x_i(t)$, $i = 1,\ldots,n$, qualifies an attribute or property of the object:

> If a system can be characterized by a set

> of variables,[1] with each combination of variable values representing a unique state or condition of the system, then manipulation of the variables simulates movement of the system from state to state. (Pritsker and Kiviat, 1969, p. 4).

Movements of the system from state to state are what we have just associated with the concept of "action" or "event".[2] Actions may be thought of as having a certain duration; however, in our discussion it will be found convenient to assume that actions "cause the status of a system to change at a discrete point in time. The behavior of a system is reproduced by examining the system at the event times". (Pritsker and Kiviat, 1969, p. 8).[3]

The notion of "object" need not be defined narrowly to mean a <u>single</u> object: a system may equally well be thought

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[1]More generally, "quantities" Klir (1969), or "dimensions" Krippendorff (1969).

[2]The terms "action" and "event" will be used interchangeably throughout.

[3]The restriction to a calendar of discrete events is defensible, given that the material we will be recording consists, for the most part, of speech acts. For discussion of the more general problem, see Ashby (1956, pp. 9-10).

of as "an aggregation or assemblage of objects[1] joined[2] in some regular interaction or interdependence". (Gordon, 1969, p. 1). A <u>state description</u>, $\underline{x}(t)$, may now be thought of as a vector of vectors, and, in certain circumstances, may be conveniently shown in matrix form:

(1.2)

$$\underline{x}(t) = \begin{bmatrix} x_{11}(t) & x_{12}(t) & \cdots & x_{1N}(t) \\ x_{21}(t) & x_{22}(t) & \cdots & x_{2N}(t) \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ x_{M1}(t) & x_{M2}(t) & \cdots & x_{MN}(t) \end{bmatrix}$$

A component of the state description, $x_{ij}(t)$, may be thought of as qualifying an entity "i" of the system, with respect to

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[1]"Entities" (Gordon, 1969; Pritsker and Kiviat, 1969); "Subsystems" or "Elements of a universe" (Klir, 1969).

[2]"Coupled", in the terminology of Ashby (1956) and Klir (1969).

one of its attributes or properties, "j".[1] We assume the system to be characterized by at most M components, measured along at most N dimensions or attributes.[2] An instantaneous state description "fixes" or isolates out of its temporal context one configuration of the values of the variables of a system: it has some of the characteristics of a photograph.[3]

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[1]Cf. Schultz and Melsa (1967): "The <u>state of a system</u> at any time t_0 is the minimum set of numbers $\underline{x}_1(t_o)$, $\underline{x}_2(t_o)$, ..., $\underline{x}_n(t_o)$ which, along with the input to the system for $\underline{t} \geq \underline{t}_o$, is sufficient to determine the behavior of the system for all $\underline{t} \geq \underline{t}_o$.

[2]Both the identification of components and of variables is discretionary; depending on one's point of view, a system can be characterized by an infinite number of variables (cf. Ashby, 1956): "Every material object contains no less than an infinity of variables and therefore of possible systems". (p. 39). The choice of components and variables may be arbitrary, or may become research activities as such, e.g., "cluster analysis", "factor analysis", etc. (Cf. Green and Carmone, 1970; Lazarsfeld and Henry, 1968).

[3]It may be well to emphasize that the concept of "system" is a construct, what Bellman and Kalaba (1965) refer to as a <u>superimposed</u> structure, not necessarily intrinsic to the basic physical structure. "What we call the state of a system ... depends, or should depend, upon what we wish to know about the physical process, what we can observe or measure, the accuracy of these observations, and, generally, upon the scientific and mathematical developments to date". (pp. 2-3). Ashby (1956) suggests a similar idea when he describes a system definition as "listing the variables that are to be taken into account. The <u>system</u> now means, not a thing, but a list of variables". (p. 40). As in the case of a photograph, much depends on the choice of point of view of the observer.

Figure I.1 shows how a group might be analyzed in these terms.

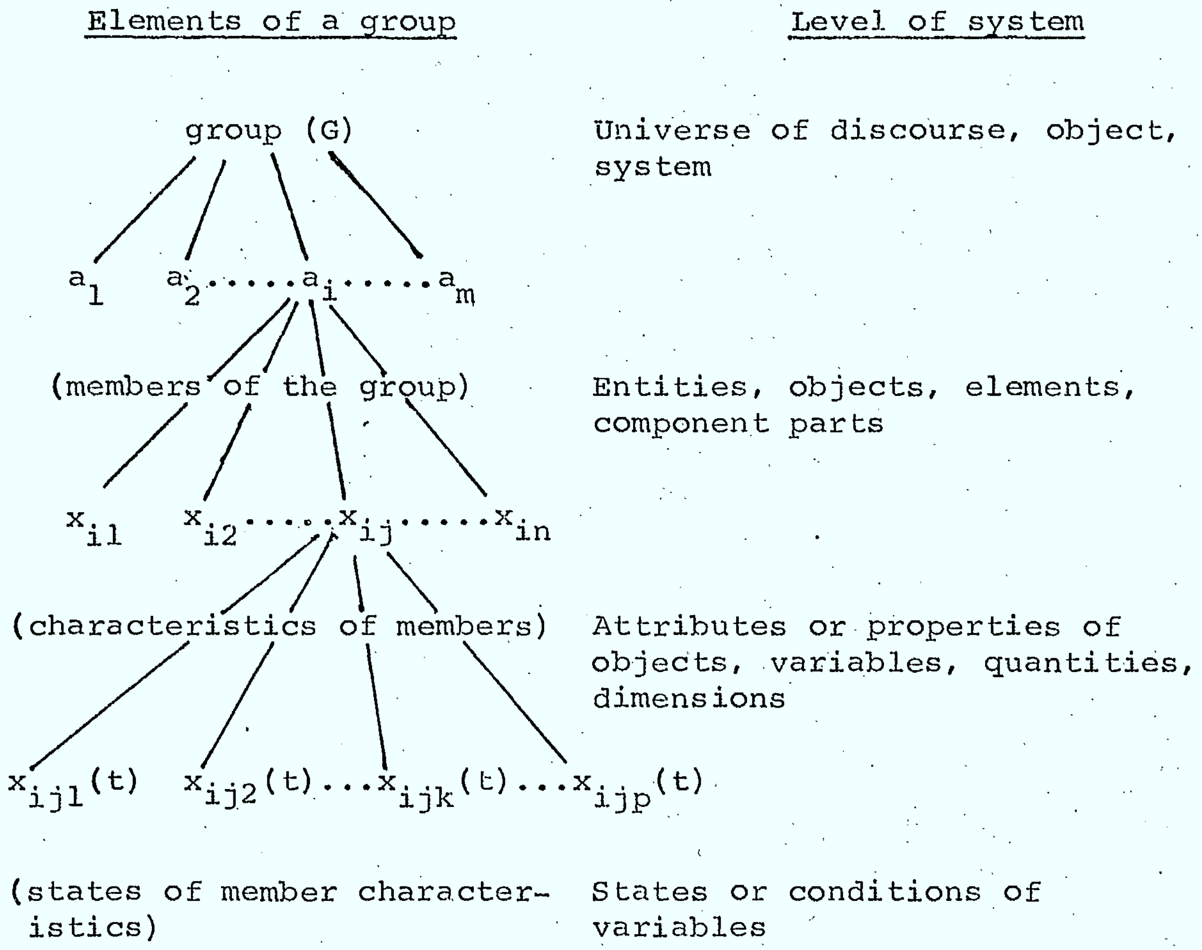

Figure I.1

As we have noted, actions or events correspond to changes in the values entered in at least one cell of the state description vector or matrix, $\underline{x}(t)$, and hence modify the states of at least one attribute of one element of the system. Whether one elects to consider events or states is a matter of point of view, the difference being between what has been termed a particle-orientation (in which case the times at which system changes occur are treated as attributes of the entities) and an event- or message-orientation (in which case the times at which system changes occur are treated as attributes of the activities) (Gordon, 1969).[1] We must take care not to read too much into the distinction; as Krippendorff (1969b) has noted (assuming interdependence between elements of the system):

> A formal comparison of the transformations accounting for the behavior of each of a system's parts with the transformations representing possible communication processes reveal them to be formally equivalent. Both pairs describe processes of information transmission. The former describe processes within, the latter across the communicators. Both can be treated by the same analytical techniques.[2]

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[1]Pritsker and Kiviat (1969) suggest that it is useful to think of entities as nouns, attributes as adjectives, and activities as verbs. In general, synthetic languages used for simulation of systems tend to be explicitly particle- or event-oriented. It is possible, as Sapir and Whorf proposed, that natural languages can also be so classified.

[2]Cf. Ashby (1956, p. 143) "By 'message' I shall mean simply some succession of states that is, by the coupling between two systems, at once the output of one system and the input of the other."

Processes and transformations

Let us now consider the idea of a "process". Intuitively, a process can be simply thought of as a sequence of instantaneous state descriptions of a system, which records its "behavior" or its "performance" over a period of time. Figure 1.2 suggests one way in which we could visualize such a sequence of changes of state in the variables of a system.

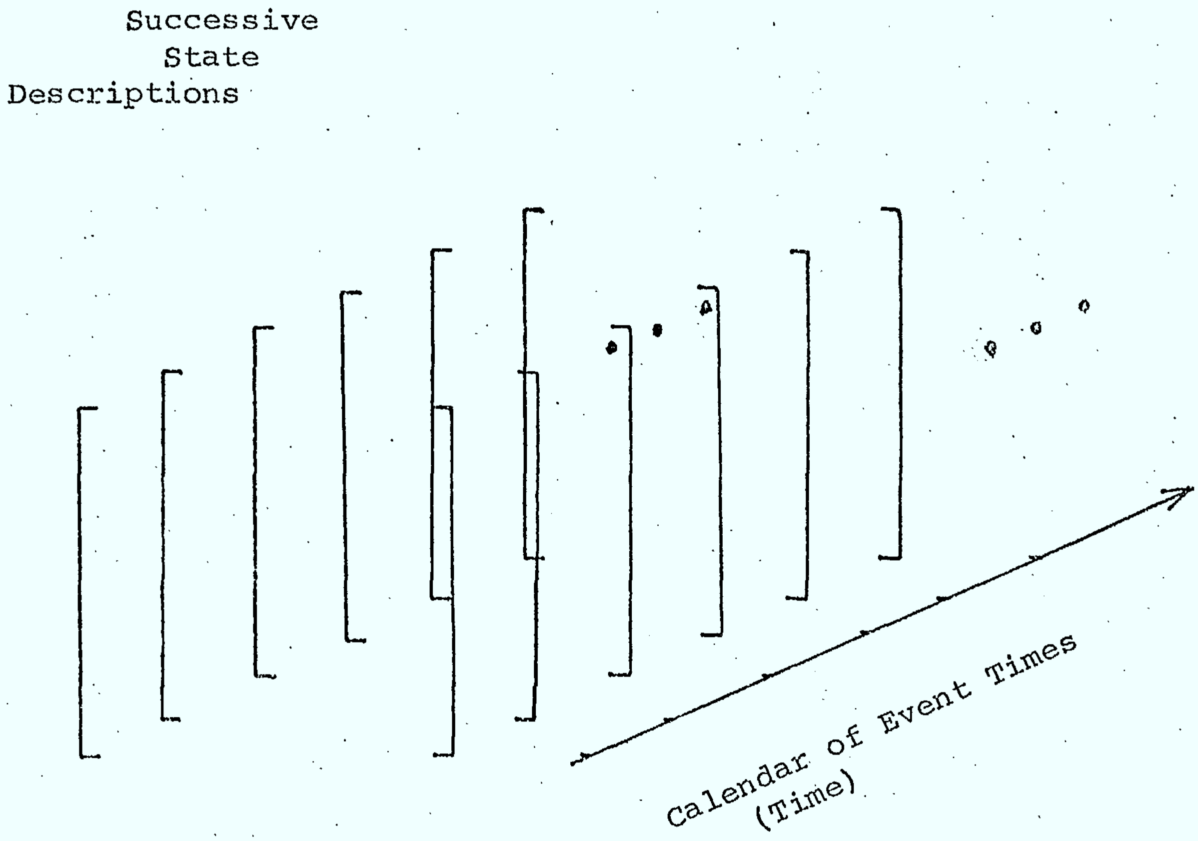

Figure 1.2

Let us now introduce a notational simplification by replacing the symbol $\underline{x}(t)$ by the symbol $\underline{p}$. The protocol, or time history, of the system may now be thought of as a vector $\underline{P}$ of vectors, having the form:

(1.3) $$\underline{P} = [\underline{p}, \underline{p}_1, \underline{p}_2, \ldots \underline{p}_t \ldots \underline{p}_T].$$

Since $\underline{p}_0$ is the initial state of the system, we set $\underline{p} = \underline{p}_0$ to initiate a process. Each succeeding value of $\underline{p}$ (e.g., $\underline{p}_1$, $\underline{p}_2$, $\underline{p}_t$, etc.) can be viewed as the state of the system recorded one time unit later. We refer to $\underline{p}$ as the representative point (Ashby, 1956). Then $t = 0, 1, 2, \ldots, t, \ldots, T$ are the event times (assuming here that the process is finite, and terminates at time $\underline{T}$). The movement of the representative point $\underline{p}$ from one state to the next is termed a transition, and the set of states through which the system passes before reaching a point of equilibrium or entering a cycle, a transient.

The vector $\underline{P}$ can be given a second interpretation: it defines a state space. A transformation is a function $\mathcal{T}(\underline{p})$, having the following property: a transformed point, $\underline{p}_t = \mathcal{T}(\underline{p}_{t-1})$, $t = 1, \ldots, T$, is a member of the set $\underline{P}$ for all $\underline{p}$ in $\underline{P}$. A transformation is, in effect, a set of transitions. Thus, for example, if $\underline{p}_0$ is the initial state of the system, then $\underline{p}_1 = \mathcal{T}(\underline{p}_0)$ is the succeeding state, $\underline{p}_2 = \mathcal{T}(\underline{p}_1)$ the next succeeding state, and so on. The vector of vectors $\underline{P}$ is said to represent a <u>multi-stage process</u> (Bellman and Kalaba, 1965), and $\underline{P}$ can now be written in slightly different notation as $[\underline{p}, \mathcal{T}(\underline{p})]$. The transformation, $\mathcal{T}(\underline{p})$, is referred to by Ashby (1956) as a <u>canonical representation</u> of the system.[1]

If each succeeding event were completely independent of the previous event, and proceeded from random causes, the change of notation would not be useful; if however, the system moves from state to state in accordance with relatively well-defined operating rules, and hence exhibits a "typical" behavior, then the use of the second notational form represents a considerable economy.

These "well-defined operating rules" may be termed the program of the system.[2]

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[1]Note that a canonical representation of a system no longer includes specific representation of time coordinates, and hence may be thought of as summarizing, in tabular form, the potential lines of behavior of a dynamic system.

[2]Cf. Klir who describes a "complete" program as the "instantaneous state together with the set of all other states

An example

In order to further clarify these concepts, and their possible interpretation, let us consider a simplified example of small group behavior.

The task we are about to look at is borrowed from Mackenzie (forthcoming), and is similar to tasks developed by Leavitt and others in the so-called "communications net" tradition of research.[1]

We will consider an experimental group made up of five members. After a preliminary training period, in which the requirements of the task and working procedures are explained, each member of the group is situated in an experimental cell, where he is allowed to communicate with some, or all, of the other members of the group by written means only. A quantity

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of the system, and the set of all transitions from the instantaneous state to all states of the system in time." (Klir, 1969, p. 45). According to Wirth (1973), a program describes "a sequence of state transformations of the set of its variables". The definitions can be adapted to account for non-deterministic systems by assigning probabilities to transitions. Note that the system so defined is state determined.

[1]See for example Shaw (1964). Description of the tasks is included in Appendix I-A.

of information (for example, a pair of symbols written on a piece of paper) is assigned to each member of the group by the experimenter at the beginning of the experimental run. The task of the group is to make a list of all the original symbols, to communicate the list to every member, and to submit (each member individually) the complete list to the experimenter. (Variations to the task may require that repetitions be removed, a common order of presentation be decided on, etc., but these will not concern us at this point.)

<u>Sequence of events</u>

We first borrow an (event-oriented) analytical procedure from Flament (1965).[1] We will subsequently reconsider the same phenomena within a particle-oriented framework.

There are five members of the group, A, B, C, D, and E, and five quanta of information to be distributed, a, b, c, d, and e.[2] Suppose each member to begin the task with one piece of information: the initial information held by A we assume to

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[1]See also Mackenzie (forthcoming).

[2]A "quantum" of information may itself be a set, e.g., $a = [a_1, a_2]$, if desired.

be a; by B, b; by C, c; by D, d; by E, e. In order to show succeeding communication events within the group we use a matrix representation, in which senders of information are shown on the ordinate, and receivers on the abscissa. Thus, for example, the initial localization of information (prior to communication) can be shown as follows:

RECEIVERS

SENDERS	A	B	C	D	E
A	a				
B		b			
C			c		
D				d	
E					e

AN INITIALIZATION MATRIX, SHOWING THE INITIAL LOCALIZATION OF INFORMATION IN THE MACKENZIE "TYPE A" TASK SITUATION.

Figure I.3

The task conditions also specify a final localization of information (which we will term a Milestone Matrix, following the MacKenzie terminology), which can be shown as follows:

RECEIVERS

		A	B	C	D	E
	A	a	a	a	a	a
	B	b	b	b	b	b
SENDERS	C	c	c	c	c	c
	D	d	d	d	d	d
	E	e	e	e	e	e

A MILESTONE MATRIX, SHOWING THE FINAL LOCALIZATION OF INFORMATION AS REQUIRED BY THE TASK CONDITIONS IMPOSED BY MACKENZIE'S TYPE A TASK.

Figure I-4

Inspection of the columns of the Milestone Matrix indeed shows that the objective of the task has been accomplished: each receiver now has available the total sum of information distributed by the experimenter.

By substracting one from the other, we obtain the difference between the Milestone Matrix and the Initial Localization Matrix, and this constitutes a third matrix which Flament terms a <u>task model</u>, since it specifies which transfers of information may occur if the task is to be completed:

<u>RECEIVERS</u>

<u>SENDERS</u>		A	B	C	D	E
	A		a	a	a	a
	B	b		b	b	b
	C	c	c		c	c
	D	d	d	d		d
	E	e	e	e	e	

FLAMENT'S TASK MODEL, SHOWING NECESSARY TRANSFERS OF INFORMATION IN ORDER TO COMPLETE MACKENZIE'S "TYPE A" TASK.

Figure I-5

Assuming normal face-to-face conditions, the required transfers of information could occur in five simple operations, the order of which is arbitrary: each person in turn simply informs the others, verbally or by visual display, as to what information he holds. In a communication net-type experiment, however, there are in general constraints placed upon the communication situation: the individuals are not normally face-to-face; they may not be able to communicate verbally; and they may not be able to communicate directly with some other members of the group at all. In such a case we should expect the transfer of information to be somewhat more complicated, to take more time, and perhaps to require a definition of communication roles which have the effect of differentiating some members of the group from other members. To reduce this latter complication, let us consider a case where the members are organized into a so-called "Circle" network (with possibility of symmetric roles), as shown below:

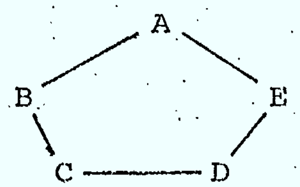

Figure I-6

By means of this graphic presentation we indicate that there exist physical channels permitting communication between A and his two "neighbors" B and E, B and his neighbors A and C, C and B and D, D and C and E, and E and D and A, and no others. A cannot communicate directly with C or D, for example, nor B with E and D, and so on.

We can now describe a Channel Matrix, corresponding to the graphic representation of the network above:

RECEIVERS

SENDERS		A	B	C	D	E
	A		a			a
	B	b		b		
	C		c		c	
	D			d		d
	E	e			e	

CHANNEL MATRIX - SHOWING AVAILABLE PHYSICAL CHANNELS AND CONSTITUTING A PHYSICAL COMMUNICATION NETWORK.

Figure I-7

The existence of a channel does not however guarantee its use. Let us suppose that our group decides on a rule that every member of the group will keep on transmitting all the new information he has or obtains to the person on his right until the task is complete. We could then show the resulting communications in an Occurrence Matrix (where each item of information has been indexed by the time at which it was transmitted).

RECEIVERS

SENDERS	A	B	C	D	E
A		a(1) e(2) d(3) c(4)			
B			b(1) a(2) e(3) d(4)		
C				c(1) b(2) a(3) e(4)	
D					d(1) c(2) b(3) a(4)
E	a(1) d(2) c(3) b(4)				

OCCURRENCE MATRIX - INDICATING ACTUAL COMMUNICATIONS SENT (INDEXED ACCORDING TO THEIR EVENT TIMES WITHIN ONE GROUP RUN).

Figure I-8

Assuming noiseless channels and perfect memory, the cells of the Milestone Matrix will be filled in four steps, and the group will then have terminated this phase of its activities.

Had the group chosen another procedure (for example, "everyone send his information to a central position, where it will be collated and the complete list redistributed to everyone") the entries in the occurrence matrix would have been quite different.

From a consideration of even this rather trivial example, we can make certain generalizations. First, it is clear that, viewed from an event-oriented perspective, there is already a quite large universe of events that could have occurred, independently of whether they did or did not in fact occur. Secondly, events may be constrained either as a function of externally-imposed constraints (existence or non-existence of channels) or of deliberately chosen procedures governing individual (and group) behavior. Finally, we might note that in the latter case, the rule or procedure adopted by the group, and associated with a particular Occurrence Matrix, can often be quite easily written down.

Sequences of state transitions

Let us now examine more carefully this latter question of rules within the particle-oriented system of exploration developed earlier.

The system we wish to describe has five elements or sub-systems: A, B, C, D, and E (i.e., the five members of the group), and five variables, A(v), B(w), C(x), D(y), E(z) which refer to the states of information of each member of the group. We will use the symbol "A(a)" to mean "A has information 'a'", and similarly for the other variables. Where necessary for clarity, a time referent is shown by indexing the variable: e.g., $A(v)_{t=i}$.

With each communication event (message), we can associate one or more transitions in the values of the variables of the system, that is to say in the state of information of the members of the group. The first such transition, or set of transitions, occurs when the experimenter initializes the value of the five variables, that is, when he provides each member of the group with the information which he is to transmit to other members of the group. Let us represent this initialization as follows:

(1.4) $I \longrightarrow A(a) \;\&\; B(b) \;\&\; C(c) \;\&\; D(d) \;\&\; E(e)$

The complete Occurrence Matrix can now be re-stated as a table of transitions (where we leave out of account the time referent):

(1.5)

OPERANDS		TRANSFORMS
I	$\longrightarrow$	A(a)&B(b)&C(c)&D(d)&E(e)
A(a)	$\longrightarrow$	A(a+e)
B(b)	$\longrightarrow$	B(a+b)
C(c)	$\longrightarrow$	C(b+c)
D(d)	$\longrightarrow$	D(c+d)
E(e)	$\longrightarrow$	E(d+e)
A(a+e)	$\longrightarrow$	A(a+d+e)
B(a+b)	$\longrightarrow$	B(a+b+e)
C(b+c)	$\longrightarrow$	C(a+b+c)
D(c+d)	$\longrightarrow$	D(b+c+d)
E(d+e)	$\longrightarrow$	E(c+d+e)
A(a+d+e)	$\longrightarrow$	A(a+c+d+e)
B(a+b+e)	$\longrightarrow$	B(a+b+d+e)
C(a+b+c)	$\longrightarrow$	C(a+b+c+e)
D(b+c+d)	$\longrightarrow$	D(a+b+c+d)
E(c+d+e)	$\longrightarrow$	E(b+c+d+e)
A(a+c+d+e)	$\longrightarrow$	A(a+b+c+d+e)
B(a+b+d+e)	$\longrightarrow$	B(a+b+c+d+e)
C(a+b+c+e)	$\longrightarrow$	C(a+b+c+d+e)
D(a+b+c+d)	$\longrightarrow$	D(a+b+c+d+e)
E(b+c+d+e)	$\longrightarrow$	E(a+b+c+d+e)
A(a+b+c+d+e)	$\longrightarrow$	A(a+b+c+d+e)
B(a+b+c+d+e)	$\longrightarrow$	B(a+b+c+d+e)
C(a+b+c+d+e)	$\longrightarrow$	C(a+b+c+d+e)
D(a+b+c+d+e)	$\longrightarrow$	D(a+b+c+d+e)
E(a+b+c+d+e)	$\longrightarrow$	E(a+b+c+d+e)

The set of transitions so determined meets the requirements already stated for a transformation, T; the association is closed, single-valued and surjective or everywhere defined. Given any p, $\mathcal{T}(p)$ can be determined immediately. The transformation includes an identity transformation.

An important characteristic of the process represented by this transformation, $\mathcal{T}$, can be better seen by showing the transformation as a tree:[1]

(1.6) ABOUT HERE

It can now be immediately observed that the transition between the initial state I and the set of terminal states occurs in a number of steps through repeated application of the transformation $\mathcal{T}$. The system displays a line of behavior, or trajectory, having transient states, and resulting

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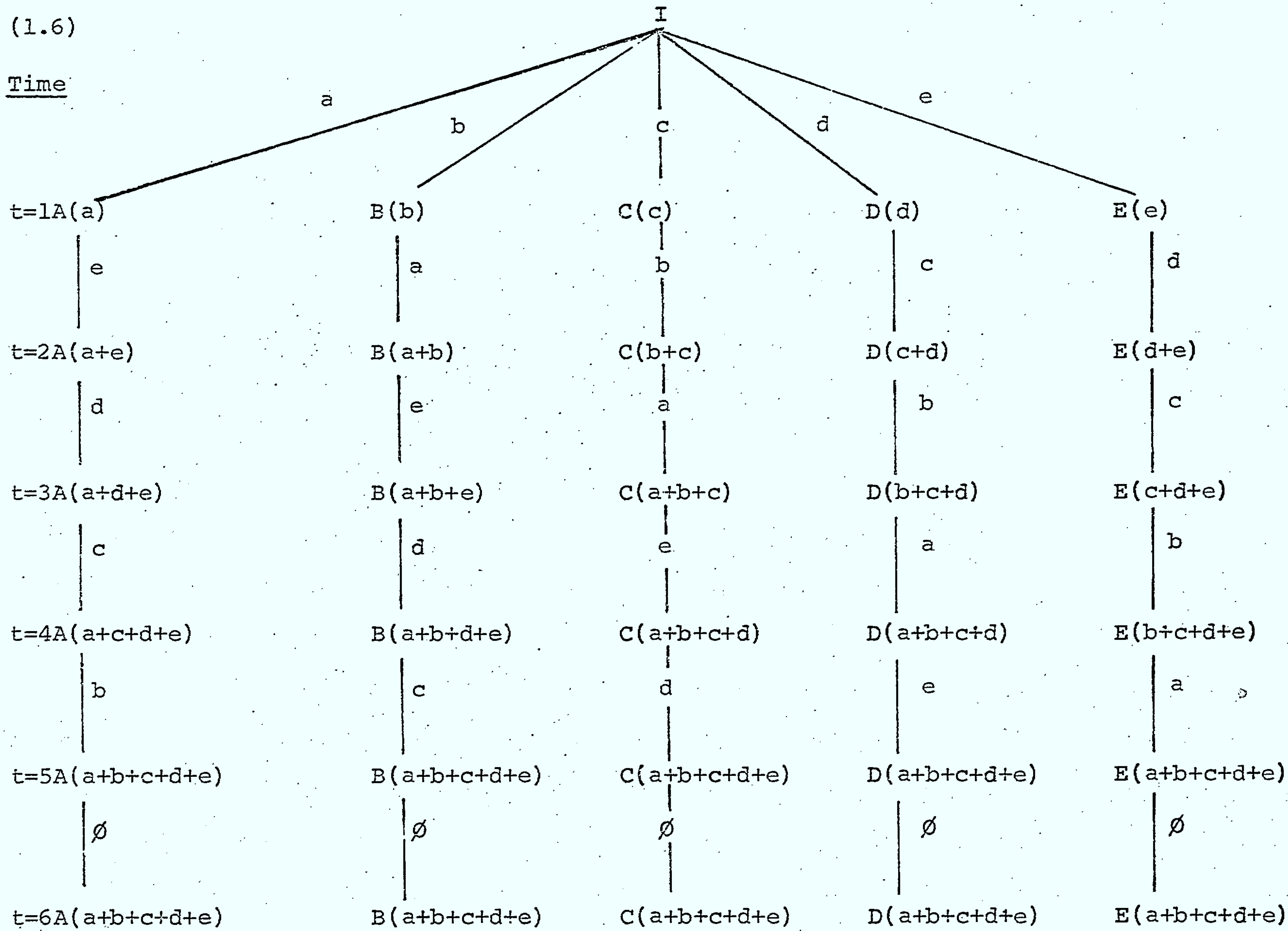
[1]The relation between state and event is shown in (1.6) by indexing each transition, "$\longrightarrow$", by a letter which indicates the message event which has occurred, associated with that particular change of state, e.g., "$B(b) \xrightarrow{a} B(a+b)$", means that person "B" has received a message containing the symbol "a", as well as B's state of information has changed (b) to (a+b).

(1.6)



Time
I
a
b
c
d
e
t=1A(a)
B(b)
C(c)
D(d)
E(e)
e
a
b
c
d
t=2A(a+e)
B(a+b)
C(b+c)
D(c+d)
E(d+e)
d
e
a
b
c
t=3A(a+d+e)
B(a+b+e)
C(a+b+c)
D(b+c+d)
E(c+d+e)
c
d
e
a
b
t=4A(a+c+d+e)
B(a+b+d+e)
C(a+b+c+d)
D(a+b+c+d)
E(b+c+d+e)
b
c
d
e
a
t=5A(a+b+c+d+e)
B(a+b+c+d+e)
C(a+b+c+d+e)
D(a+b+c+d+e)
E(a+b+c+d+e)
Ø
Ø
Ø
Ø
Ø
t=6A(a+b+c+d+e)
B(a+b+c+d+e)
C(a+b+c+d+e)
D(a+b+c+d+e)
E(a+b+c+d+e)

in a set of terminal states, in which no further changes of state are observable. Each row of the tree representation corresponding to a time coordinate can be thought of as a vector and represents a state description of the system at one instant in time. Each arrow corresponds to a communication event, the transmission of a piece of information. The Milestone condition is attained at t=5. The tree is a time history, or protocol, as opposed to a canonical representation of the system.[1]

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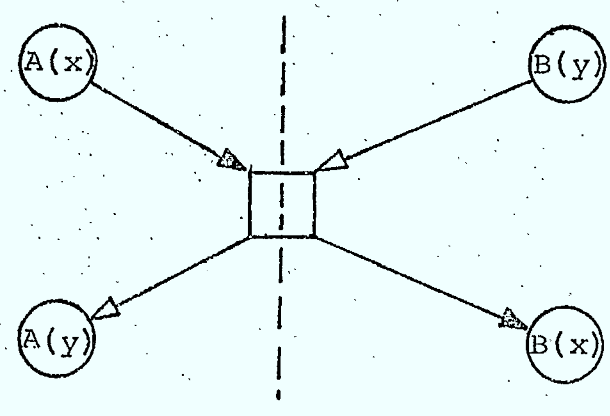
[1]A somewhat different means of representation using Petri nets has recently been proposed by Holt (1974). Holt shows eventive interactions between partners, where transfers are concerned, through the use of representations such as the following:



The nodes which are shown as circles represent states; squares stand for events. An event of transfer necessarily implies change of state of two individuals through the mediacy of a single event. Empty arrowheads indicate that the person (A or B in the case here) does not possess the object of

If we know the canonical representation of the system, we can derive its protocol; conversely from its protocol we can deduce its canonical representation.

The group as information-processing machine

Let us consider (1.6) in a slightly different way.

We define an alphabet A = [p,q,r,s,t,] as shown in (1.7):

(1.7) p = [a,b,c,d,e]

q = [e,a,b,c,d]

r = [d,e,a,b,c]

s = [c,d,e,a,b]

t = [b,c,d,e,a].

The elements of the alphabet correspond to the communication events, or transmission of information, in (1.6).

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transfer; filled arrowheads stand for possession.

Holt's proposal appears to open up extremely interesting new possibilities. While his approach is not followed here, the two approaches are fully compatible.

We define also:

(a) a finite nonempty set $\underline{S}$, called a set of <u>states</u>;

(b) a subset $\underline{F}$ of $\underline{S}$, called a set of <u>final states</u>;

(c) a distinguished element $\underline{s}_0 \in \underline{S}$, called the <u>start state</u>;

(d) a unary function $\underline{f}_x : \underline{S} \rightarrow \underline{S}$ for each $\underline{x} \in \underline{A}$, called the <u>transition functions</u>.[1]

The set of states corresponds to the node vectors of (1.6), the start state to "I", and the final state to the vector of states obtained at $\underline{t} = 5$. The transformation constitutes one transition function; a different one would be obtained had the group chosen to circulate its data clockwise rather than counterclockwise, as in the given example, or if it had adopted a "centralized" structure, for example around A.

Given the network constraints of the type described as a "circle", the group can produce a sequence such as (1.8):

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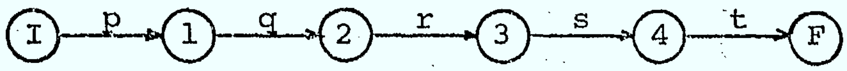
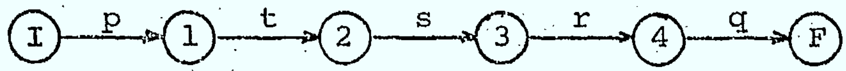
[1] Engeler (1973, p. 30).

(1.8)



Had the group chosen the clockwise procedure, a sequence such as shown in (1.9) would have resulted:

(1.9)



Another form of organization, such as the centralized, would have produced a different sequence (and required us to enlarge our alphabet).

Some sequences, such as p - s - q - r - t, could not have occurred under the restricted conditions described above.

This means of defining the transformation emphasizes the essential relationship between group information-processes and finite state machines, or automata. It also serves to point up the similarity between lines of behavior, and what mathematicians term "language", as we see in the next section.

We shall see in the succeeding chapter that this interpretation accords well with the actual performance of groups in their information-processing activities.

A program as a constraint

Earlier it was observed that rules of procedure serve to constrain the behavior of a system to values less than their maximum theoretical potential. It was also noted that programs can often be quite simply stated. Let us consider these matters somewhat more closely.

An example will serve to illustrate the main points. Suppose the system under analysis represents again a small task group experiment similar to the one described before. The system has five variables as before. However, we relax the conditions to permit any member of the group to communicate with any other member of the group at one time (the so-called "all-channel" communication net of Bavelas-type experiments). In addition, the five quanta of information, labelled as before "a", "b", "c", "d", and "e", are initially distributed randomly (with replacement). This means that each variable may be in one of 32 different states (including the possibility that some members receive no information). It is now possible to construct a set of all the possible state descriptions of length 5, where each component of the state description may be in one of the 32 different states defined above. The set of all possible initial state descriptions has cardinality 32^5 (33,554,432). The set of all possible transformations which result in the attaining of the milestone condition, given an initial distribution, is obviously much greater (potentially infinite, in fact).[1] Suppose the group is asked to repeat the same type of task a number of times, each time with different initial conditions. Suppose also that the group always follows the same rules of procedure, i.e., describable in terms of a unique transformation. The resulting set of actual lines of behavior, or trajectories, which varies as a function of the initial states, is obviously a subset of the set of all possible lines of behavior which take the system from an initial to a milestone condition. Let us term a line of behavior which takes a system from an initial to a milestone condition a block. Transitions within the blocks are what we have referred to as actions.

A program is defined as a finite set of procedures which characterize a set of lines of behavior (as the term is

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[1]Assuming that we allow for the possibility of cycling; while this is unlikely for single tasks, it is more plausible in the case of difficult tasks, i.e., where the final state is not easy of attainment.

used above), in the sense that it will recursively enumerate the elements of the set.

Less formally, the concept of a program can be interpreted somewhat differently. As Wirth (1973) has noted: "Each action must be describable in terms of a language ... its description is called a statement." In other words, groups can be expected to verbalize the programs they follow. Since a block is made up of a sequence of actions which describe a process, a process is more generally interpreted as a set of statements describing a process, although its "textual ordering is not, in general, identical with the ordering in time of the corresponding actions". (Wirth, 1973). A program thus specifies a pattern of behavior, independent of its realization by a particular processor.

Further characterization of processes

To this point, only very simple stationary processes have been considered (i.e., processes which can be described by a single transformation). Since we will wish to consider processes that change (as the result of group solution of multi-phasic problems, for example), and since we will want to consider how groups select one line of behavior in particular from the available repertoire of potential trajectories, it is necessary to introduce certain additional concepts.

A process where the form of transformation, $\mathcal{T}$, is dependent on the stage of activity of the system, that is, on the time at which the transition occurs, is termed <u>nonstationary</u>, or <u>time-dependent</u>. Formally, our previous definition of a process can be revised as follows: we say that $\underline{p}_t = \mathcal{T}_t(\underline{p}_{t-1})$, $t = 1,\ldots,T$, is a member of the set $\underline{P}$ for all $\underline{p}$ in $\underline{P}$.

It can be expected that groups which have not yet learned the task can be expected to "try on" different lines of behavior until they hit on one which is satisfactory. Hunting behavior of this type is by nature nonstationary.

It is equally possible that over-familiarity with a given type of task, or boredom, or fatigue, will motivate the group to change its behavior. In this case also, the process is time-dependent.

A second kind of process with which we will be concerned, implicit in some of the preceding discussion, are processes with stop rules.

A multi-phasic program consists of a set of transformations, where transitions between transformations may depend on the attainment of a certain condition, to be termed a milestone condition which corresponds to what we have called a final state. Since a single transformation describes a block, which is to be interpreted as a set of actions, it may be helpful to think of a block as a subroutine within a main program, and of an action as a statement within the program. Task groups typically pass through several phases of activity resulting in changes of the pattern of behavior.

A stop rule can be defined as follows: Let $v(\underline{p})$ be a function defined on the vector $\underline{P}$, where the range of the function has two values, 0 and 1. A stop rule expresses the idea that the process continues until the condition, expressed by the constraint, $v(p_i)=0$, is satisfied, at which point the process stops.

The number of stages of the process, in this case, depends on the starting point.

A set of lines of behavior such as is typically associated with a multi-phasic task can be thought of as an overall transformation which is a product or composition of elementary transformations, each typifying behavior appropriate to the particular phase of the problem which engages the group's attention. The output of one phase constitutes the input to the next, in that it serves to initiate the succeeding process.

A multi-stage decision process is described by a set of vectors of the form:

(1.10) $$[\underline{p}_0, \underline{p}_1, \underline{p}_2, \ldots, \underline{p}_t, \ldots, \underline{p}_T; \ \underline{q}_0, \underline{q}_1, \underline{q}_2, \ldots, \underline{q}_t, \ldots \underline{q}_{T-1}]$$

where $\underline{p}_t = \mathcal{T}(\underline{p}_{t-1}, \underline{q}_{t-1})$ for all $\underline{t}$ in $\underline{T}$. $\underline{q}_t$ is interpreted as the choice of transformation, $\mathcal{T}$, at the $\underline{t}$th stage of the process. The addition of a decision vector, $\underline{q}$, assumes that the group has an influence over the process at each stage. It assumes on the part of the group a capacity for self-programming (functions in fact as a "controller", in the Ashby sense). The decision may be to obey the experimental instructions; on the other hand, it may introduce independent choices (including refusing to go on with the task, and walking out of the experimental cells, as occurred in one run!).

It is of course possible that group processes are inherently unstable, due, for example, to the great number of essentially random or accidental and non-recurrent causes which can act on the group at any given moment and result in changes of its behavior. Processes which are less than completely deterministic are termed <u>stochastic</u> <u>processes</u>. In this case, the state vector, $\underline{x}(t)$ or $\underline{p}$, is a random vector, the entries of which consist of two parameters, an expectation and a variance. The deterministic process may then be thought of as a limiting case, where the variance being zero, a single parameter, equivalent to the expectation, suffices. If we assume independence between the random effects which act on the system and which produce deviations from the expectation at each stage, (i.e., one-time only disturbances), we can still consider the system to be state-determined, in that the value of $\underline{p}$ at time $\underline{t}$ is a function of $\underline{p}$ at time $\underline{t-1}$ with probability $\underline{q}$. If there is autocorrelation between the disturbances at times $\underline{t-1}$ and $\underline{t}$, (i.e., if there is a <u>systematic</u> disturbance over time), it may be that our definition of the system is not optimal, and may impel us to re-define the variables of the system.

While this classical treatment of deviations from the purely deterministic situation is a satisfactory solution mathematically, it is one which we will attempt to avoid in this present study, since in practice, for research with small groups, there are considerable difficulties. First, as Wiener (1948) noted, this kind of treatment works best where the investigator has access to long runs of data from observation of systems with stable transition probabilities. This condition is not generally fulfilled for the kind of small-group data with which we are concerned: Groups learn and in so doing modify their behavior over time, sometimes more than once; and, according to our observations, different groups adopt very different programs of activity. While both of these constraints can be overcome with sufficiently large samples, so that we could obtain distributions over a given population, in practice, this is a strategy which we cannot yet adopt. We therefore accept a self-imposed and more restricted strategy which consists essentially in a study of single cases. This has the effect of forcing us to adhere for the most part to the assumption of pure determinism, and makes salient the problem of finding an optimal principle for the decomposition of data.

A first principle for the decomposition of data

We thus adopt as a working principle for the analysis of group performance that processes can change as a function of:

(a) problem phase,

(b) time,

(c) decisions taken by the group itself, or communicated to the group by the experimenter.

(a) and (c) are identifiable either from *a priori* knowledge of the experimental conditions, or from direct observation of the group's behavior.

(b) must be inferred from observation of the group's performance.

Process and structure

The concept of *structure* of a system is susceptible of exact definition following from the definition of process.

The notion of *group structure* can be defined in two ways.[1] These may be termed the *state-transition* structure,

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[1]See Klir (1969).

and the structure of *universe and couplings*. The former, or ST-structure can be defined as follows:

> *The system $\mathcal{S}$ is a given set S of elements s_i together with a set of transitions between the states; every transition may, but need not, be associated with a probability of its occurrence.* (Klir, 1969, p. 55).

A structure of universe and couplings, or an UC-structure, is defined as follows:

> *The system $\mathcal{S}$ is a given set G of elements a_i, together with their permanent behaviors, and a set of couplings between the elements on the one hand, and between the elements and the environment on the other.* (Klir, 1969, p. 55).

For our purposes, the elements are the members of the group, and the environment is the experimenter. The behavior of an element is determined from knowledge of the quantities or attributes (such as the state of information of members of the group), and a time-invariant relation defined on the set of quantities. The coupling of two elements supposes that the output of one can act as an input to the other, and vice versa, and that one can meaningfully speak of the composition of their respective behaviors.[1]

The definition also makes mention of "permanent" behavior; since our knowledge of group behavior is based on a restricted sample of activity, for a temporally constituted group, we can at best hope to determine the structure of the group over a limited range of its activity set. Our analysis of data must therefore be limited to a consideration of the hypothetic structure of the group system, i.e., corresponding to its relatively permanent behavior. (Klir, 1969, p. 44).

For a UC-structure, but not for a ST-structure, it is meaningful to speak of the set of relations holding between elements of the universe, i.e., members of the group. This fact will prove to be important in the sequel, when we turn to consider the dynamics of coordination within groups.

Elementary communication data

Many experiments with groups have used the general procedure outlined here (see, for example, Christie, Luce,

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[1] See Ashby (1956, Ch. 4).

and Macy, 1952). (1.6) thus has an interesting interpretation: since the protocol, or time history, of the system constitutes a record of the changes of state of the system's variables, it can be thought of as data. Such data will be found to satisfy Krippendorff's criteria for minimal communication data.

The following are the set of minimal formal requirements for communication data as stated by Krippendorff (1969b):

(1) There are many distinct sets A, B, ..., Z of observations.

(2) Each observation may be described in terms of (classified or scaled along) one or more dimensions, i.e., $A \subset \prod X_e$, $B \subset \prod X_f$, ..., $Z \subset \prod X_m$.

(3) One or more kinds of many-valued relations are specified among the observations, e.g., $R_1(a,b,c,d)$, $R_2(a,b,c,\ldots,z)$.

(4) Some relations imply other relations, e.g., $R_1(a,b,c,d) \Longrightarrow R_3(a,c,d)$.

(5) Three- or higher-valued transformations (involving time) are specifiable over at least two distinct sets of configurations, e.g., $T(R_1 x R_2)_{t-1} \Longrightarrow (R_2)_t$.

With respect to our previous discussion, we may state these criteria, informally, as requiring, first, the system to have at least two elements, or component parts (thus excluding from the domain of communication study systems composed of one object only). Secondly, condition _2_ requires that we can state a set of characteristics or variables of the system with respect to which we will obtain measures.[1] Criteria _3_ and _4_ provide for the possibility of structure, or constraints, within the system. The fifth criterion (indeed the "essential" criterion) is intended to assure "conditionality of behavior" across individuals, a _sine qua non_ for the very existence of communication. This means that _dependence_ between observations can be observed or discovered when time is taken into account: the _output_ of the elements of the system is now to be taken as functionally related not only to their own previous states, but also immediately to the previous states of at least one, and ultimately to all of the other elements which we have defined as belonging to that system.[2]

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[1] Cf. Ashby (1956, pp. 99-100).

[2] Cf. Ashby (1956, pp. 55-58). Ashby defines a _channel of communication_ as existing between two elements of a system, A and B, if "over a series of tests, A has a variety of different values--B and all other conditions starting with the same value throughout--then the values that B changes to over the series will also be found to show variety".

Otherwise the system is decomposable into simpler sub-systems which are not functionally related one to the other: which do not, in fact, "communicate" with each other.

Let us now consider these minimal requirements for communication data with respect to the example given above.

First, we have identified an object having five components, each of which is described in terms of one dimension, the state of information of the individual. The object, or group system, has one input (I), which is interpreted to be the experimenter.

Secondly, we can specify many-valued relations among the observations; we can for example state a binary relation, "neighboring", which we define as either receiving messages from or transmitting messages to, allowing us to state that A neighbors B, B neighbors C, B neighbors C, etc. This relationship could have been ascertained independently from knowledge of the physical network characteristics, but can equally well be inferred from the data.[1] In spite of

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[1]Note that the asymmetric "sender-to-receiver" relationship is not necessarily ascertainable from knowledge of the topology of the network, if the group chooses to ignore the availability of certain half-channels.

the great simplicity of the system, we could state a ternary relationship which we can call "one-step relay" by taking into account simultaneously two periods of time. Thus B relays for A and C. Finally, some relations, e.g., that of "two-step relay" imply others, such as "one-step relay".

Since the network is perfectly symmetrical, none of the relations discriminate particular roles. Had, however, the group elected to send their information to a central person, the situation would have been quite different. In this case, after two transitions, the information set of the central person, say C, would contain the information of all four others, while the information set of the relayers, say B and D, would contain the information of the end-men's sets, but not the contrary. Such a situation is typical of a simple hierarchy, and suggests an analogy with kinship data, an analogy which has been exploited by Mackenzie in his recent work, in that he speaks in such cases of "cousin" and "uncle" relationships. Thus we are dealing with a simple case of social structure, and as is generally the case, social structure is associated with restrictions either on the network of communication, or on the content of the messages transmitted through its channels.

Finally, we note that a three-valued transformation, involving time, can be specified. For example, with the exception of the initialization phase, the value of A(v) at time _t_ can invariably be predicted from knowledge of two variables A(v) and E(z) at time _t_-1. Indeed, we could draw a diagram of immediate effects which would show the following pattern:

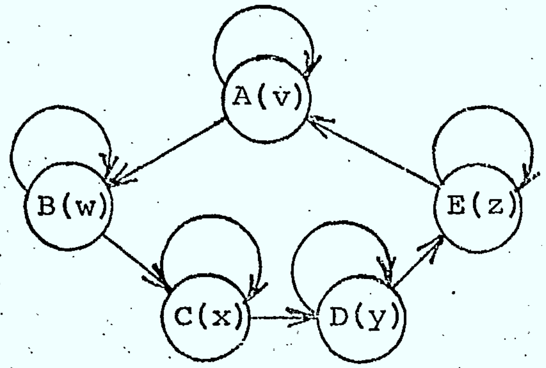

Figure I-9

This shows that each member of the group communicates with at least one other member, and the system is not decomposable. Furthermore, an assessment of ultimate effects would show that ultimately every member affects every other member. Our data allows us to state that communication exists. It also, although it is hardly what Krippendorff calls "rich" communication data, allows us to say something meaningful about the behavior and the structure of roles of the group.

Group process as a control system

Initial and goal information states

Initial inputs by the experimenter to the group are of two kinds: (a) goal states, and (b) initial information states. The group information state at any moment can be considered as a vector of five locations, or stores, partitioned into five separate chambers, each corresponding to the information initially received from the experimenter by one of the five members of the group. Figure I-10 suggests how this situation can be represented. At $t = 1$, for example, individual "A" holds only the information which has been communicated directly to him by the experimenter, i.e., $x_a = a$; the other four chambers of this store, x_b, x_c, x_d, x_e, are empty, as indicated by the non-shaded portions of the store corresponding to person "A". At $t = 2$, a change of the group information state has occurred, implying the communication of A's data to other members of the group.[1]

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[1]It should be noted that each individual has immediately available, through inspection of his own information state, knowledge of his own state of information and an image of the group information state.

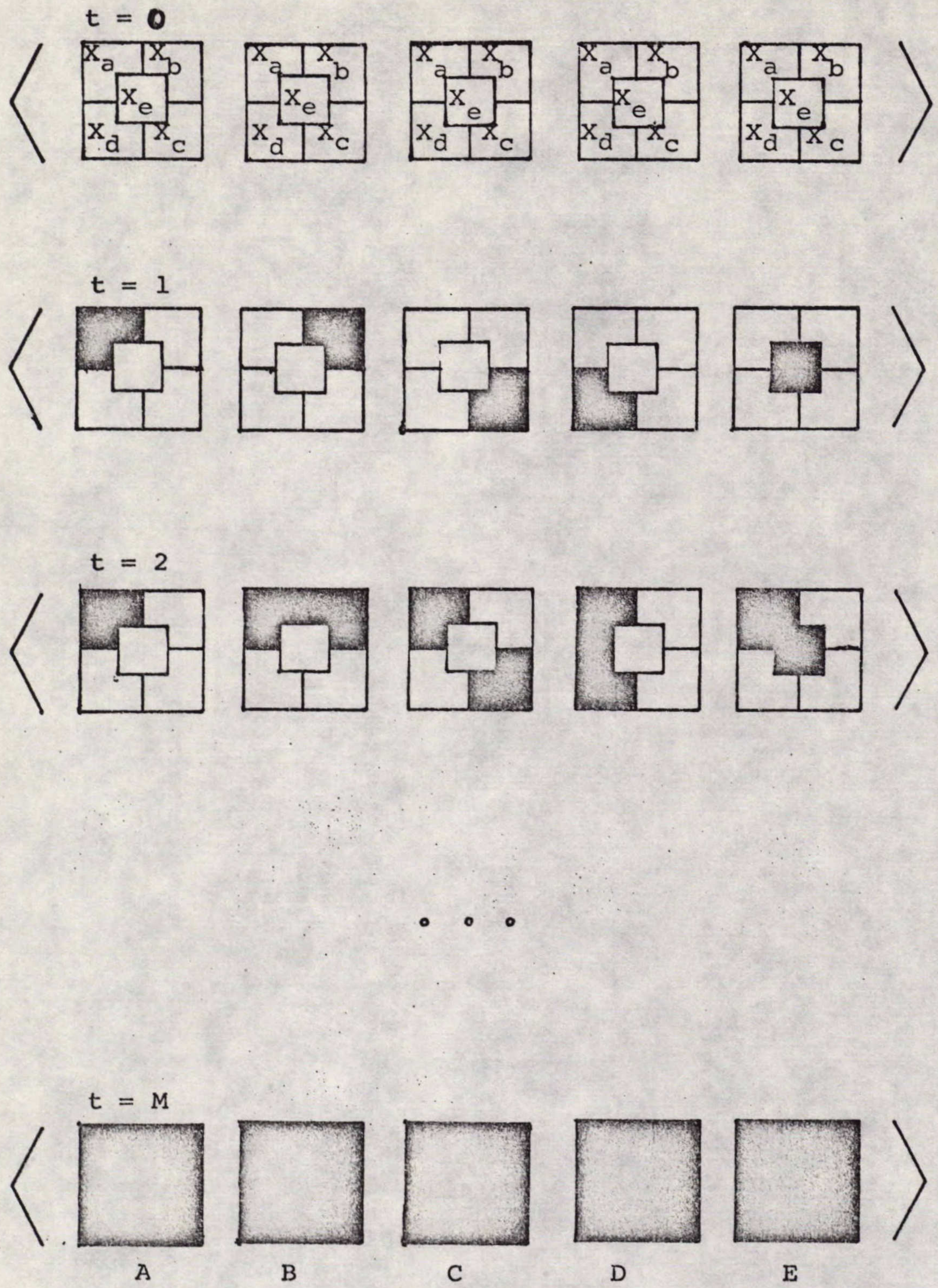

Figure I-10

The Group Information State at t = 1 represents the initial information state which results from the experimental intervention, i.e., distribution of data to individual members of the group.

The Group Information State at t = M corresponds to the goal state. The goal state is also set by the experimenter before the experiment begins, in that the experimental conditions specify that each member of the group must be able to make a complete list of all the data available to the group. Individuals can be thought of as setting up storage locations in anticipation of subsequent communications, based on knowledge of goal states.

The difference between the Group Information State at t = 1 and t = M constitutes a discrepancy, or mismatch, which can only be rectified by communication activities, carried out by the Group Network. In Figure I-10, the change in state between t = 1 and t = 2 constitutes a partial elimination of the discrepancy.

Characteristics of the group network

Figure I-11 suggests a means of representing the group network as a central processing unit. Initial and subsequent

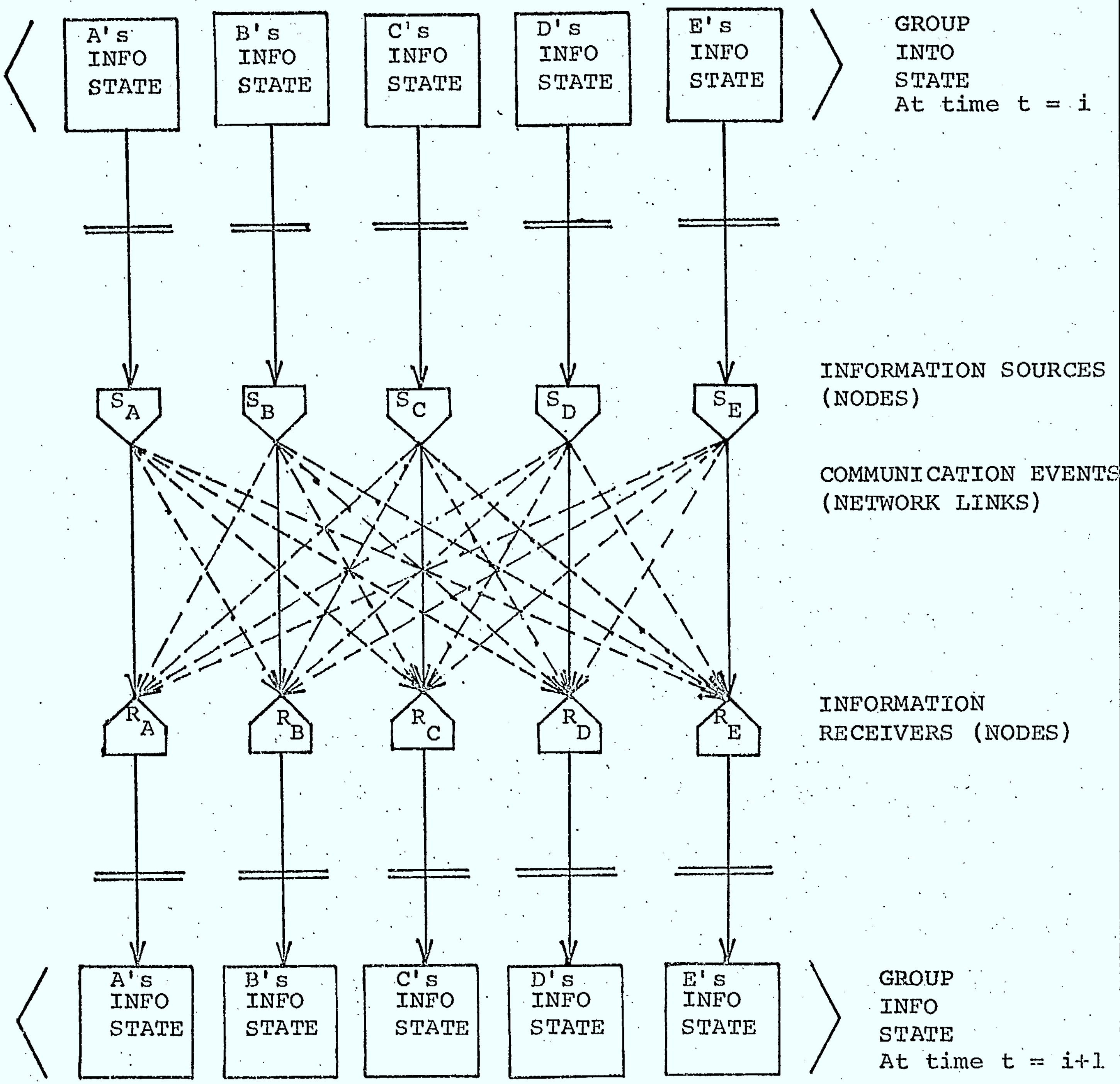
A's INFO STATE
B's INFO STATE
C's INFO STATE
D's INFO STATE
E's INFO STATE
GROUP INTO STATE At time t = i
S_A S_B S_C S_D S_E
INFORMATION SOURCES (NODES)
COMMUNICATION EVENTS (NETWORK LINKS)
R_A R_B R_C R_D R_E
INFORMATION RECEIVERS (NODES)
A's INFO STATE
B's INFO STATE
C's INFO STATE
D's INFO STATE
E's INFO STATE
GROUP INFO STATE At time t = i+1

Figure I-11

states corresponding to any change in the group vector (from $t = i$ to $t = i + 1$) are shown at the top and bottom of the diagram. Each transition corresponds to a different channel configuration, and to one step or action within the program for that group.

The potential network for an all-channel group (where any single individual may communicate to any other single or several members at one time) indicates that initially 5^{16} different communication events or transitions may occur, if we allow for multiplexing or the occurrence of simultaneous events. This situation corresponds to the case where members communicate by paper and "broadcasts" (i.e., carbons) are permitted. Each event corresponds to a different change of state in the Group Information State, and hence states of the Group Network and the Group Information Set can be taken to be mutually interdependent.

In the type of experiment with all channels open at all times, and where the possibility of simultaneous communication is excluded (as in our television-mediated experiments), there are only five possibilities: A informs the other four members, B informs the other four members, etc.

In general, it may be said that the costs of organization for a network of the latter kind are less than for the former.[1]

Since the information state at t = i is an input to the network, it constitutes a constraint on the choice of succeeding transitions.[2] Given an initial possibility space, the choice of a sequence of network configurations defines a transformation, and the structure of the information-processing network.

Control processes

It is possible, and useful, to interpret Group Information State and Group Network as elements in a generalized feedback control system (shown in block diagram form in Figure I-12. The Group Information State is interpreted as the "Plant" whose states are to be controlled within the control system, and the Group Network as the "Control Elements", or the machine

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[1]Mackenzie (personal communication).

[2]Note that the state of a storage location and a corresponding node in the network, while they must be in one-one correspondance, are nevertheless theoretically distinct. This distinction is discussed further in Chapter II.

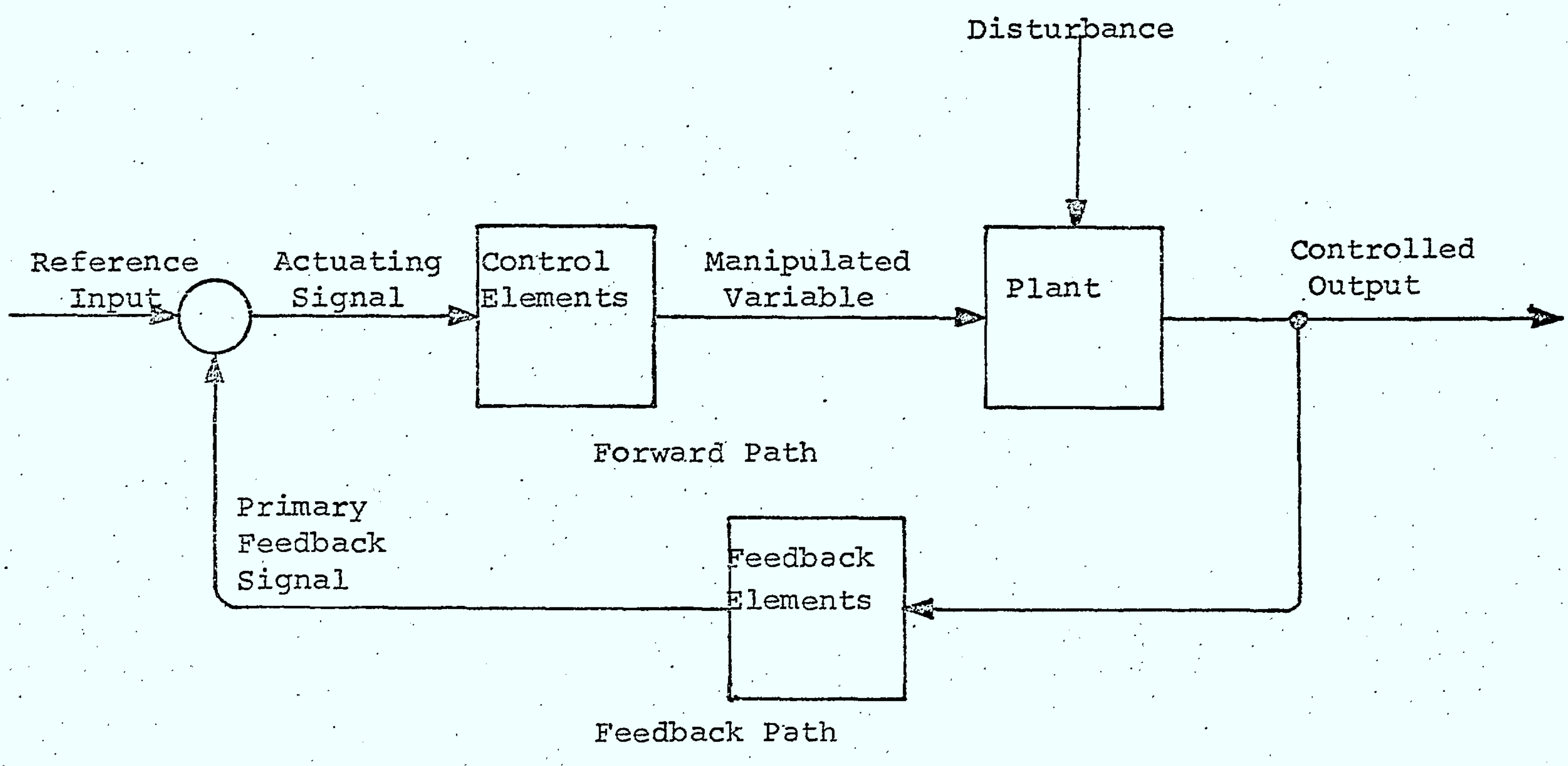
Disturbance
Reference Input
Actuating Signal
Control Elements
Manipulated Variable
Plant
Controlled Output
Forward Path
Primary Feedback Signal
Feedback Elements
Feedback Path

Figure I-12

whose activities produce changes in the Plant, or Group Information State.

There are two kinds of input: first the experimenter definition of goal states can be interpreted as the reference signal for the system; and secondly, since data input to the system creates a discrepancy between actual and goal states, it thus constitutes a disturbance to the system.

Feedback is an individual rather than a group activity. Each individual, separately, records changes in the Group Information State, and compares the existing with the desired state: since no member has a global picture of the complete vector of information states constituting the Group Information Set (each person has an image of the whole set, and complete knowledge of his own states), any single individual member of the group may decide to signal a mismatch (an actuating signal) which affects the Control Elements. An actuating signal may then initiate activity of the control elements: "On commence?" It may equally initiate a single communication event ("Quel numéro as-tu?") within the process as a whole.

The resulting output is said to be <u>controlled</u>.

The efficiency of the control system

The representation of group process given in Figure I-12 has the following limitation: once the organization of the Group Network (the choice of one transformation within the set of possible transformations) has been set, it is immutable. The Network can be thought of as having two inputs: (1) mismatch between actual and goal state, and (2) no mismatch. In the first case, a cycle of activity whose form is absolutely determined (i.e., for the deterministic machine) or describable as a stochastic process (for the probabilistic machine) begins, and continues until an input which indicates an absence of mismatch occurs, in which case the activity ceases.

A third possible input could be envisaged, signalling non-reception by an individual member of information (at some point during the cycle). This third input might result in re-setting the process back one notch to an earlier stage (resulting, for example, in the repetition of the event which had immediately preceded).

As it stands, however, the Group Network is in no sense self-programming, in that it has no capacity to determine or alter its own internal structure. To account for its organization, an outside agency must be assumed.

Given these constraints, certain things can be said with respect to the control system. It has been shown for example that, for a given problem of the type we have been considering, network structures can be ranked by equivalence classes according to a criterion of absolute efficiency.[1] Each class of group information-processing machine is capable of a given optimal level of performance and no better.

Secondly, it is known that a system such as that of Figure I-12 can be represented as a transfer function, where assuming only that the system is at rest prior to the application of input, the output can be described as a function of the input. Within the limits imposed by the type of data available, it is possible to say something concerning the performance characteristics of the system, including its speed of response, its relative stability and its accuracy (or allowable error).

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[1] For most recent discussion, see Mackenzie (forthcoming).

The cascading of control elements

Figure I-13 shows how a sequence of similar control systems could be linked in order to accomplish a multi-phasic task, or one with several milestone conditions. The output of the first system is seen to be a disturbance to the second. Suppose, for example, the group is asked first to make a list of all the symbols it jointly holds, and then to eliminate any repetitions in the list. We suppose the initial list to contain repetitions. The existence of such repetitions sets up a mismatch condition in the second system, in that the required information state is a list without redundancy.

In this situation, it should be noted that the nature of the plant and of the reference signal has been altered: the chambers now contain lists rather than symbols, and the reference signal is a non-redundant list. Similarly, although the Group Network has the same nodes, there is no reason why its internal organization may not differ from that in the first system.

Similarly, the output of this second control system may become input to a third (corresponding, for example, to a phase of activity resulting in the ordering of the list), and

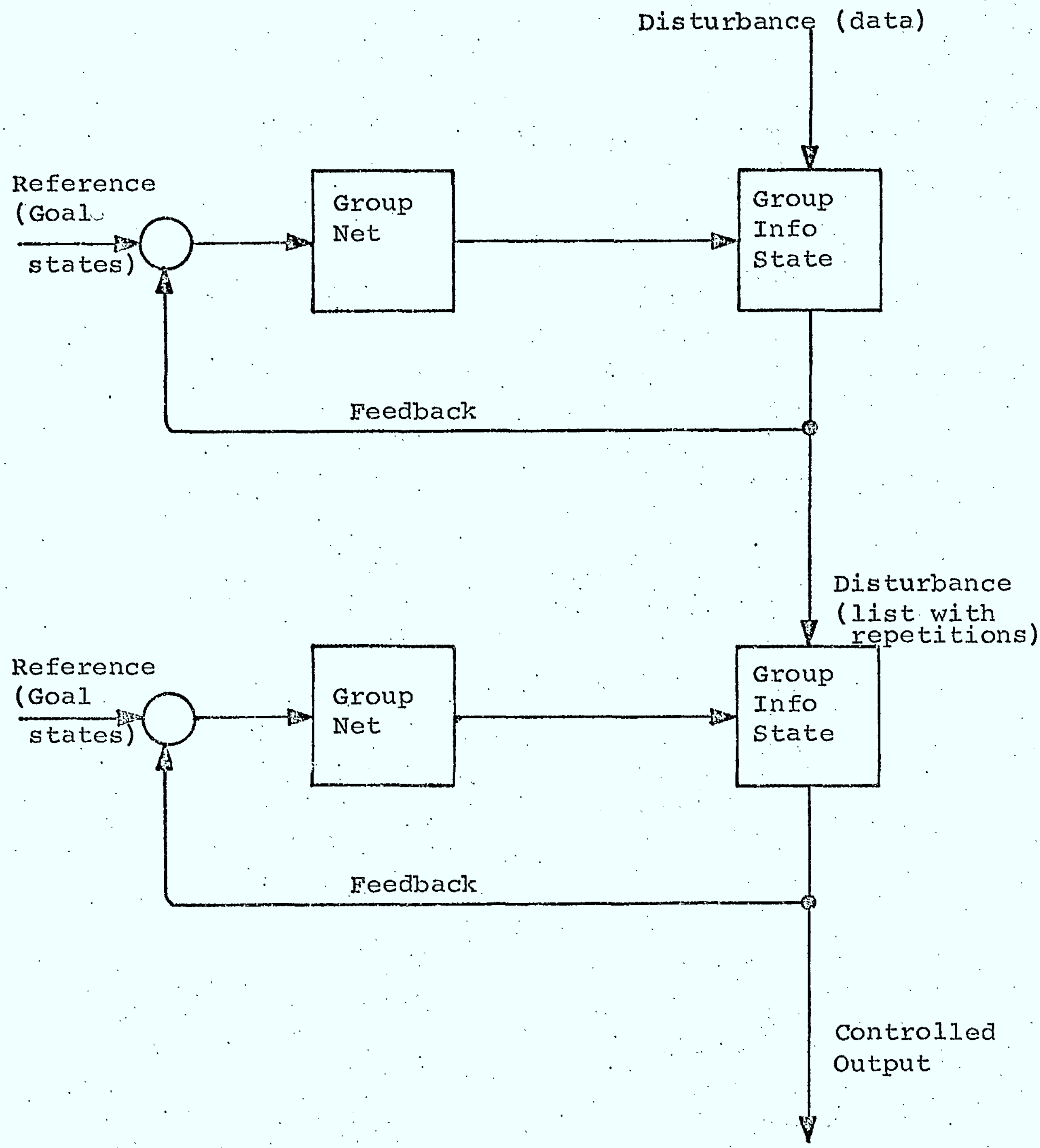
Disturbance (data)
Reference
(Goal
states)
Group
Net
Group
Info
State
Feedback
Disturbance
(list with
repetitions)
Reference
(Goal
states)
Group
Net
Group
Info
State
Feedback
Controlled
Output

Figure I-13

the latter's output, input to a fourth, etc. Eventually, the complete control system, composed of single components cascaded in series, will produce a "solution" and its full cycle will reach a point of equilibrium.

It is a generally accepted principle that any finite number of independent components in series where each is associated with a procedure may be algebraically combined by multiplication. Thus, the complete set of separate control systems may be conceived of as a single component, which contains a certain number of blocks. The experimental situation may then be described as one control system, such as shown in Figure I-14, where the controlled output is an attempted problem solution, the feedback elements are the experimental assistants, and the actuating signal indicates only whether or not the problem has yet been solved.

By analogy, the transfer function for the system may also in principle be determined. Overall system performance ratings can be assessed, with respect to varying inputs, and more particularly with respect to varying conditions of "load".

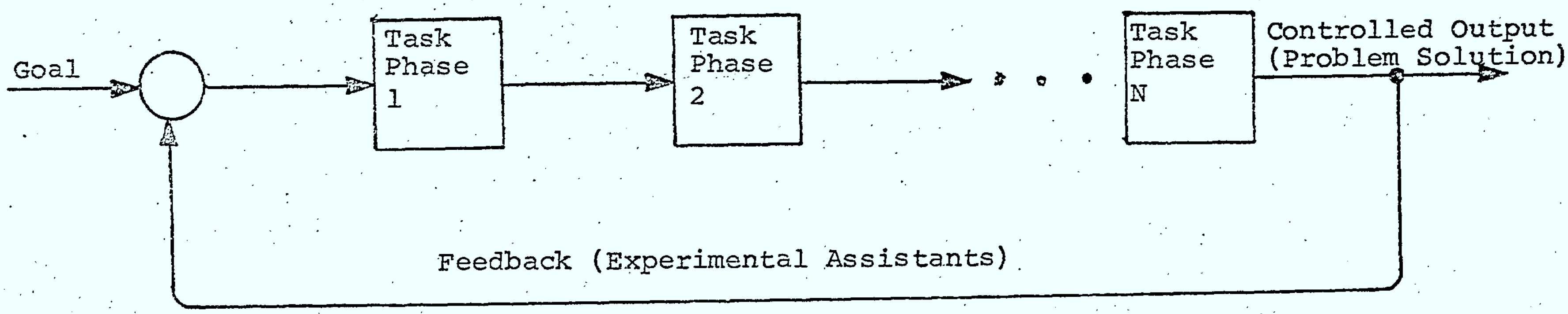
Goal
Task Phase 1
Task Phase 2
Task Phase N
Controlled Output (Problem Solution)
Feedback (Experimental Assistants)

Figure I-14

Executive functions of the group

It will have been noted that the overall control system, consisting of several blocks, has (like each individual block) no capacity for self-organization. This characteristic is not consistent with the reality of the group situation.

First, the group is quite capable of changing its goal states.[1] During the initial period of experimental briefing, the group records in its collective memory information concerning the problem context, including the sequence of required information states it must attain to arrive at a complete problem solution. At this point, the Group Network functions as a transducer, or channel (which may be more or less noisy).[2] Its memory is supplemented by experimental instructions posted on the walls of each experimental cell. While groups tend to respect the instructions, and to follow the "correct" sequence of reference signals appropriate to

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[1]In one instance, after a long frustrating attempt to solve a Type B task, the group simply got up and left their cells--a striking example of change of goal.

[2]It also functions as a transducer during the output phase.

each phase of the task, they may, on occasion, change them.

Secondly, the organization of phases of each task has some degrees of freedom. For example, elimination of repetitions in the list may be a group activity, or may become relegated to some individual for execution, and can no longer be considered a part of the group's activities as such. Choices of task organization vary from group to group, and, within a single group, may vary from task to task. Variations in task organization are particularly noticeable following an attempted solution to a problem which has not been successful. In this case, the group will not necessarily re-commence its cycle of activities at the beginning, but will "hunt" among its subroutines, often in apparently aleatory, or non-systematic, fashion, until it discovers a source of error.

Thirdly, the group is entirely responsible for its choice of internal organization of the Group Network. Network structure may vary from phase to phase, and within a single phase.

Finally, the group has a caretaker role with respect to the operation of its own physical channels, including decisions concerning choice of modality (verbal vs. visual).

We term these latter the self-regulatory, or executive functions, of the group. The group may shift from task mode to executive mode at any instant in time, such shifts often, or even normally, producing changes in the structure of the task-processing system.

The second principle of decomposition of data

The distinction between task activities and executive, or self-organizing, activities provides the basis for the second principle of decomposition of data.

To incorporate this latter aspect of group functioning, we posit the existence of an interrupt system.

The interrupt system

Interrupts, like information storage, are not a group activity, but an aggregation of individual activities. Any individual may choose to signal an error (or a success) at any instant in time, or may choose to bring into a state of recall the group's goals, its task program, its choice of modality, or its internal network structure. When he does so, his interrupt may have the effect of shifting the group's activities from one mode (e.g., task) to another (executive).

This feature of the interrupt system flows from a fundamental principle of systems with multiple components: No state of the whole can be a state of equilibrium unless it is acceptable to every one of the component parts, each acting in the conditions given by the others. (Ashby, p. 83).

This means that every member has some power of veto over the equilibrium of the group.

Let us now attempt to isolate some of the variables which affect the group regulator, since an understanding of the interrupt system is of critical importance in evaluating the performance of task groups.

Variables affecting the interrupt system

The interrupt system is to be interpreted as a vector of independent regulators--independent in the sense that there is no direct channel of communication between them. Each functions without being directly affected by any other (although they may indirectly affect each other as a result of events which occur within the group network).

The Interrupt System is affected by Group Information State variables, in the following way. Component A of the Group Information State vector affects component A of the Interrupt System vector, component B of the G.I.S. affects component B of the Interrupt System vector, and so on. This is necessarily so since the connection between G.I.S. and Interrupt system is intra-individual, and is not mediated by the Group Communication Network, except indirectly.

In order to explain self-regulatory activities of the group, it is convenient to enlarge the G.I.S. to include more variables, whose joint effect on the Interrupt System will explain shifts from Task to Executive Mode and vice versa. We define six variables which, it is hypothesized, correspond to different kinds of information stored in the group memory and to different group goals; four of the variables are task-related, two are what will be termed co-orientational variables.

Two task variables have already been discussed: required, or goal, information states (G.S.), and actual or present information states (P.S.). Both these states are initialized through communication with the experimenter, but the latter (P.S.) is continually updated throughout the task run.

It is posited that a discrepancy between a goal state and an actual state will cause an interrupt. These interrupts are of two kinds: (1) interrupts which report the non-occurrence of an expected event, and (2) interrupts which relate to the completion or non-completion of a phase of the task, or the task itself. Non-occurrence of an expected event will result from failures to hear, lapses of attention, imperfections of memory, etc. Single interrupts due to this factor normally have only local de-stabilizing effects. Interrupts due to a task mismatch condition have at least regional de-stabilizing effects. Accumulations of interrupts (including local interrupts) may combine to produce interrupts which differ on qualitative dimensions.

Other task-related variables

1. Task-completion time

Every activity which occurs within the group takes a certain time. We posit the existence in the group's memory of a counter which records actual time spent per problem, and actual time spent in the experimental laboratory. Since recorded time is subjective time, it is possible that the time counter is updated in discrete steps, and possibly at irregular intervals. In the sequel however, time will be taken to be a continuous variable, and actual time, measured by stop watch, will be taken to be a linear estimate of actual time, measured by members of the group subjectively.

Expected time equally has two components: an expected time per problem and an expected total time to be spent in the laboratory for the complete series of experimental runs. The latter variable of total expected time is to some extent pre-established before subjects enter the experimental cells, in that they are told that the whole experiment "usually takes about three hours or so". Expected time per problem is probably defined by how long the group took to resolve the previous problem, and hence is only determined following the initial run of a particular type of problem, for succeeding problems of the same kind.

Based on these considerations, we might take Expected Total Time to equal three hours, and Expected Time per Problem j to equal Actual Time for problem j-1.

The ratio AT/ET will be employed in the sequel.

We assume the Task-completion Time variable to have motivational force for individual members of the group. Subjects are paid a flat fee for their participation in the experiment, and can maximize their financial return by keeping time spent in the laboratory to a minimum. The experimental cells are warm and stuffy, chairs are not overly comfortable, etc., and after some hours spent in them, fatigue may become an important factor. Finally, there is an implicit factor of competition, and group pride will often motivate the group to want to perform well, and to find solutions as quickly as possible.

To incorporate this notion of motivation, it is assumed that there exists a valuation function defined on the domain of the variable AT/ET, perhaps corresponding to the intuitive notion of "satisfaction". The function could be defined, for example, as follows:

(1.11) Satisfaction = 1 - AT/ET.

The function is positive for $AT < ET$, zero for $AT = ET$, and negative for $AT > ET$. The function is bounded for positive values (≤ 1), but unbounded for negative values. (The assumption that negative satisfaction, or frustration, can increase without bound must be tempered by the possibility of a threshold, or step function, beyond which changes of goal occur.)

It is also possible that subjects expect to do better on each succeeding round, requiring additional specification of a weight modifying Expected Time.

We could assume, arbitrarily, the effects due to time spent per problem and total time spent in the experimental situation to be additive in their effect, leaving aside the possibility that there is an interaction between the two effects. While such interdependence may exist, it is extremely difficult to measure, and the additivity assumption probably does not introduce a major distortion.

It will have been noted that the two components of the Task-completion Time variable exert effects in quite different ways. The Total Time Spent variable has relatively small effects during early parts of the overall experiment, but increases proportionally in its overall effect late in the experiment. This would lead us to expect that task frustration, where it exists, has essentially local de-stabilizing effects early in the experiment, and more persisting effects at later periods.

2. <u>The Error-to-Success Ratio</u>

An Error-to-Success variable can be defined as follows:

(1.12) $$E\text{-}D = \sum E / \sum (E + S),$$

where $\sum E$ is the total number of errors committed to date,

and $\sum S$ is the total number of successes achieved to date.

Assuming that making errors is negatively motivating, and scoring successes, positively, a functional relationship between the Error-to-Success Ratio and Satisfaction could be defined, for example, as follows:

(1.13) $$\text{Satisfaction} = 1 - 2\sum E / \sum (E + S).$$

This function, like the previous, is bounded ($S \leq 1$) for positive values, and unbounded for negative.

Two points should be noted.

Errors resulting from submission of incorrect solutions to the experimenter should make a larger contribution to negative satisfaction than errors identified by the group itself; similarly, correct solutions should produce greater satisfaction. This feature can be incorporated by an appropriate weighting scheme. (Note however that errors and successes reported to the group by the experimenter occur relatively infrequently, by comparison with group-identified errors.)

Secondly, we probably should posit a "recency effect" with respect to the Error-to-Success variable: errors and successes committed in the distant past should be expected to affect satisfaction less than those occurring more nearly in time. To take account of this, errors and successes could be weighted by a factor "w_i" = $(T - t)/T$, where "t" is the distance in time between the present time of occurrence of error, and the time at which each previous error or success occurred. Summing over total errors and successes to date, weighted in this fashion, determines the present value to the Success-to-Error Ratio.

In general, Task-completion Time and the Error-to-Success Ratio are known to be positively correlated.[1] Both contribute to the variable of satisfaction, but because of the inter-correlation, their effects need not be assumed to be purely additive. If we assume the Task-completion Time variable to be more consequent in its effects, the contribution of the Error-to-Success Ratio can be qualified by introducing a weighting in the function relating Error-to-Success to Satisfaction, which is determined empirically as the correlation between Task-completion Time and Error-to-Success Ratio. Since the correlation is positive, the effects are still additive, but proportionally less so.

The resulting melding of effects due to time and error is termed the "total task satisfaction" variable.

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[1] See for example Shaw (1974).

Co-orientational variables

Two co-orientational variables are identified: the Group-Experimenter Relationship, and Group Structure.

1. Group-Experimenter Relationship

In accepting to take part in an experiment, members of the group establish a relationship with the experimenter. Such a relationship has some definite reward value, positive or negative.

In general, subjects expressed interest in the details of the experiment, and in post-experimental de-briefings most declared the experience to have been pleasant. There was the novelty of the laboratory itself, with its modernistic television-mediated tele-conferencing gear, the challenge of the task, the interaction situation with a group of others in an unusual setting, and of course the financial remuneration.

While these intangible (for the most part) rewards undoubtedly varied from person to person, they seem to have been sufficient to justify acceptance of a situation charac-terized by a strong dominance relation, where to some extent subjects functioned, and felt themselves to be functioning, as guinea pigs.

The relationship between subject and experimenter is not necessarily constant, and may be re-interpreted during the course of the experiment. One group, for example, after failing to resolve B-Type tasks, began to doubt the motives of the experimenter, and question the "real purpose" of the experiment. This suggests that the definition of group-experimenter relationship depends on the time and error variables, and has the character of a step-function, or a frustration ceiling.

2. Internal Group Structure

The structure of the Group Network may vary from task phase to task phase, and from Task to Executive Mode. Corresponding to each group sub-process is a state-transition (ST) structure, and a universe of elements and couplings (UC) structure. The former definition of structure is equivalent to considering the group network as a single undifferentiated machine; the latter projects a set of relationships holding between members of the group.

It has long been known that choice of network structure in the task mode has an effect on the satisfaction of individual members.[1] "Decentralized" or highly participatory structures seem to contribute most to high morale; "centralized" or hierarchically organized nets are often more efficient, but less satisfying for those in peripheral locations. Recent work by Mackenzie and Sabidussi indicates some of the possibilities and limits of obtaining scalar measures of degree of centrality in such cases.

Group structures for the executive mode seem to have been less studied, and measurement problems here are slightly different. The key executive phase is network organization; neither goal-setting nor program-organizing activities take up much total time; network organizing activities however are all-pervading throughout the group's life.

<u>The network organizer</u>

The Network Organizer has two functions: <u>routing</u> and <u>scheduling</u>.

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[1]See for example Shaw (1964).

a. Routing

A routing procedure is a decision rule which specifies, for any given state of the system, what event is now to occur.

Suppose some member of a group, A, sends a message to the others: "Everybody send your data to me!" This is a routing message, and the route to which it refers is shown in Figure I-16:

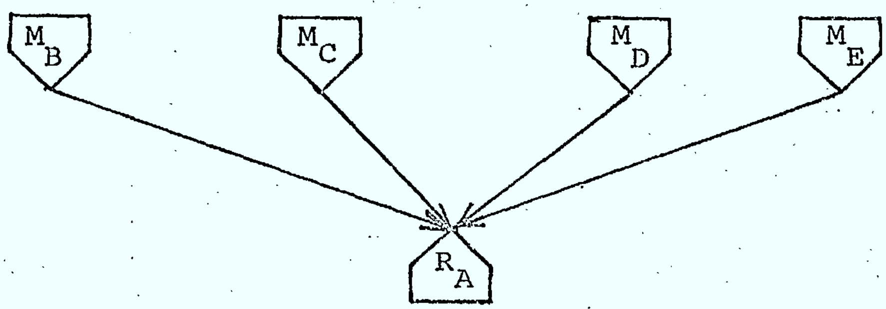

Figure I-15

Figure I-17 illustrates the route which was employed in the example developed in the earlier section on group processes.

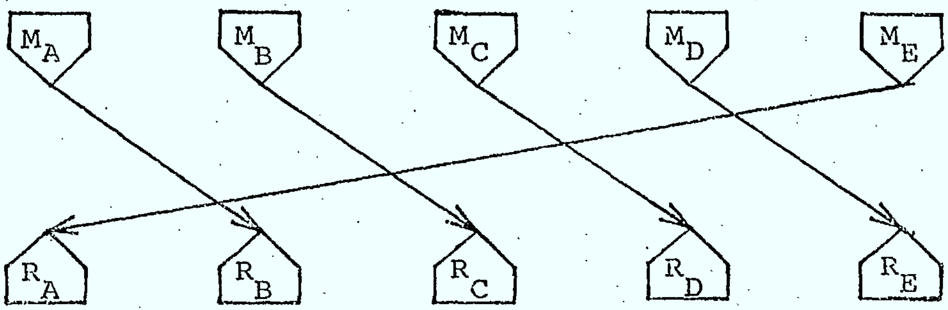

ILLUSTRATION OF ROUTING PROCEDURE CORRESPONDING TO A UNICURSAL CIRCLE NET CONFIGURATION.

Figure I-16

A routing procedure may specify (and for non-multiplexed networks, must specify) not only which events are to occur, but also in what order.

b) Scheduling

A schedule determines when each event occurs (and since it specifies an ordering in time, overlaps with the concept of a routing schedule, in that from a schedule, a route can be inferred, but not the converse).

For many kinds of networks, the problem of when and how to "seize" the network, where simultaneous occurrence of two communication events is strictly excluded, is a major problem.[1] In order to prevent over-talk, communicators in such networks commonly resort to the use of control messages, providing for the sign-on and sign-off of communicators on the network. An interpellation message, for example, "calls up" a potential source, and gives him access to the network. An intercept is a self-claim to access to the network. A sign-off is a voluntary relinquishment of access, and a priority override is an attempt to "bump" someone off the network.

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[1]See for example Jaffe (1970).

Each time the circuit is disconnected, the network is readied for the next operation to be carried out. Thus, a communication event, or action, takes the form of an exchange of information sandwiched in between sign-on and sign-off activities.

For the groups with which this report is concerned, the route is trivial (See p.   above). For our groups, the routing procedure is usually not stated explicitly, but is arrived at through scheduling activities.

Scheduling activities, for the most part, consist of <u>strictly dyadic</u> exchanges. A scheduling event usually specifies not only <u>when</u> an event is to occur, but refers to, or indexes, <u>which</u> event it is to be (i.e., the route is always implied). The effect of a scheduling message (from a potential receiver to a potential source) is to make the recipient of the message "an immediate <u>target</u> within the goal-system of the originator", in Mackay's words (Mackay, 1969). The person who assumes responsibility for scheduling events within the group network becomes a controller, or <u>dispatcher</u>, for someone in the group. Scheduling becomes a means of establishing a relationship of subordination between couples of individuals; the relation so defined is binary.[1]

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[1]Note an apparent paradox: the individual who acts as dispatcher is in fact a controller, hence claims a dominant role for himself. However, his individual acts of control may often take the form of questions, which, as Mackay has noted, are "basically a purported <u>indication of inadequacy</u> in the originator's state of readiness, calculated to elicit some organizing work to remedy the inadequacy. It is as if the questioner uncovered and held out the incomplete part of his organizing system to the receiver for his attention." As such they have only an <u>invitational</u> force on the receiver. Use of the question format serves to "play down" the real dominant-submissive relationship.

The relationship can also be "played up". Kelley (196), in a perceptive analysis of threats, argues that more is communicated in a threat than the mere content of the manifest message. A threat, in his analysis, would have the following implications: (1) that the interests of the individusla involved in the threat sequence are opposed, and (2) that the interests of the threatener ought to have priority over those of the person who is threatened (the logical response condition for a threat is compliance). Thrests are appropriate to conflict situations, in that they may assure regulatory stability, and eliminate certain undesirable oscillations. In non-conflict situations, with acceptable regulatory structures, there should be no need to resort to threats: simple questions and requests should be adequate. In this situation, a threat or arbitrary request (that is, one which is not warranted by the position of the originator), implies a derogatory evaluation of the recipient, constitutes a claim of superior power, implies the latter's vulnerability, and evidences a change in the threatener's conception of the relationship. It may arouse aggressive reactions and hostile feelings on the part of the recipient.

The structure of the component responsible for organizing network task structure can be interpreted as the outcome of a N-person game: each individual can be thought of as choosing a strategy, based on decisions as to whether to attempt to control the task actions of the other N - 1 individuals in the group, and whether to accept other's attempts to control his own behavior. When each individual has determined his own strategy, the resulting structure is fully defined.

Conversely, from an existing structure, individual strategies can be inferred.

Each outcome can be assumed to be more or less rewarding for individuals within the group, and because the interactions are dyadic the valuation mapping is defined on a set of binary relations, as shown in Figure I-17:[1]

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[1]Where each couple is mapped to the set [1, 0], indicating which couples are members of the relation.

	A	B	C	D	E
A	(a,a)	(a,b)	(a,c)	(a,d)	(a,e)
B	(b,a)	(b,b)	(b,c)	(b,d)	(b,e)
C	(c,a)	(c,b)	(c,c)	(c,d)	(c,e)
D	(d,a)	(d,b)	(d,c)	(d,d)	(d,e)
E	(e,a)	(e,b)	(e,c)	(e,d)	(e,e)

DOMAIN OF THE RELATION: X_i controls X_j, $i,j = 1,\ldots,5$

Figure I-17

The choice of control structure is subject to a constraint, which may be called the <u>cooperative principle</u>: if the group does not coordinate its activities in the task situation, everyone loses--error rates climb, time spent increases, etc. The purpose of dispatching is to achieve "a maximally effective exchange of information" (Grice, quoted in Katz, 1972).

This means that the control relation must contain at least one (and preferably only one) couple per column (Fig. I-17).

A perfectly centralized procedure of control would correspond to a row of Figure I-17, for example, $R = \{(a,a), (a,b), (a,c), (a,d), (a,e)\}$. A decentralized procedure would make, for example, everyone his own controller (a reflexive relation which is statistically unlikely to occur on the basis of chance alone, and is usually the result of training), or everyone at once controlling someone else, and being controlled by someone (an "off-diagonal" solution which defines a transitive relation). A special case of the latter is a pure symmetric relation (which does not arise in 5-man groups).

Most relations of dominance are more or less centralized (asymmetrical) and/or hierarchical (transitive).

There is evidence to support the assumption that centralized control networks are more efficient than decentralized ones, under conditions of low load. (Kleinrock, 1964). Thus, the cooperative principle tends to push groups towards centralized relations. Under conditions of high information-transmission load, centralized networks are less efficient, depending on the capacity of the central node. Hence, considerations of efficiency suggest the acceptance by the group of centralized structures.

Brehm (1966) has argued however that <u>any</u> restriction on the set of "free" behaviors of an individual sets up what he terms "psychological reactance", or a tendency to resist the influence attempt. Since a group has regulatory needs, and regulation results in external selection of behaviors by others in the group, some degree of reactance might be thought to be present in the group at all times.[1] How much reactance is present in any given situation should depend on the degree of subordination, the expressed friendliness of regulators, and perhaps on the activity of the regulators.[2]

Effects due to reactance may be mitigated by the adoption of a normative structure, since:

> norms serve to depersonalize interpersonal influence, reducing the need to see compliance as a personal matter by introducing supra-individual values as its basis (Kelley, 196).

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[1]This seems to be also the theoretical position of Bales (1949): "The social system in its organization, we postulate, tends to swing or falter indeterminately back and forth between these two theoretical poles: optimum adaptation to the outer situation at the cost of internal malintegration, or optimum internal integration at the cost of maladaptation to the outer situation."

[2]Freedman *et al.* have proposed that acts of behavior can be mapped to dimensions of affection, dominance and activity. (See also Coffey (1950), Osgood, Suci and Tannenbaum (1957), Borgatta and Crowther (1965).)

Mackenzie similarly posits "behavioral constitutions", in effect locally stable configurations of roles, accepted by the group, providing for a division of labor necessary to complete the task. Although acceptable to the group, these charters may be unequally satisfying to individuals.

The notion of "behavioral constitution" can be given a game-theoretic interpretation.

Let P_{ij} be the preference of individual "i" ($i = 1,\ldots,M$) for relation "j" ($j = 1,\ldots,N$). Let R_G be a rule which assigns a value to each subset S of the members of the group based on their respective strategies, and resulting in a network structure. Since the structure is a relation, R_G is said to define a _characteristic function_. Let St_A be the actual structure of the group: we term St_A the _adopted constitution_. An _ideal constitution_, for any given group, will be a group structure which maximizes the characteristic function. A difference between an ideal and an adopted constitution for change will be termed a _capacity for change_.[1]

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[1]Mackenzie (forthcoming).

There are many reasons why a group might adopt a constitution which is less than ideal. As noted, the exigencies of the task situation push the group towards the goal of co-ordinating their activities. It may happen that initially some one individual is more active than the others, perhaps because he or she is less intimidated initially by the experimental situation, so that the group cedes to this individual an authority which produces a group structure that is ultimately not satisfactory to a majority of members of the group. Even given this less than optimal situation, insofar as it relates to preferences of the group for certain kinds of decision structures, the resulting structure may continue to be accepted if the task payoff is adequate. If task rewards are unsatisfactory, conditions may be produced which make salient the group's capacity for change.

Attempts to change the group decision structure constitute interrupts. These are said to bring the group structure into a condition of recall, and such interrupts are sometimes termed votes.[1] Where capacity for change exists,

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[1] Mackenzie (forthcoming).

such interrupts may lead to modification of the group structure. Interrupts may also occur where there is no capacity for change, for example, where the ideal constitution of the group results in negative payoffs for some one, or perhaps, two, members. In such a case, assuming no resulting change in group structure, the system may be permanently unstable, depending on the strength of the group norm, and its controlling effects on individual dissatisfaction.

Operation of the interrupt system

In the preceding discussion, a subjective factor "satisfaction" has been introduced which is extraneous to the system, vaguely conceptualized, and difficult to measure directly. It is furthermore inessential.

Figure I-18 shows a flow diagram of the task/control system.

Input to the network consists of experimental instructions (goal settings), data, and indications of success or failure of attempted solutions. Output of the network consists of attempted solutions.

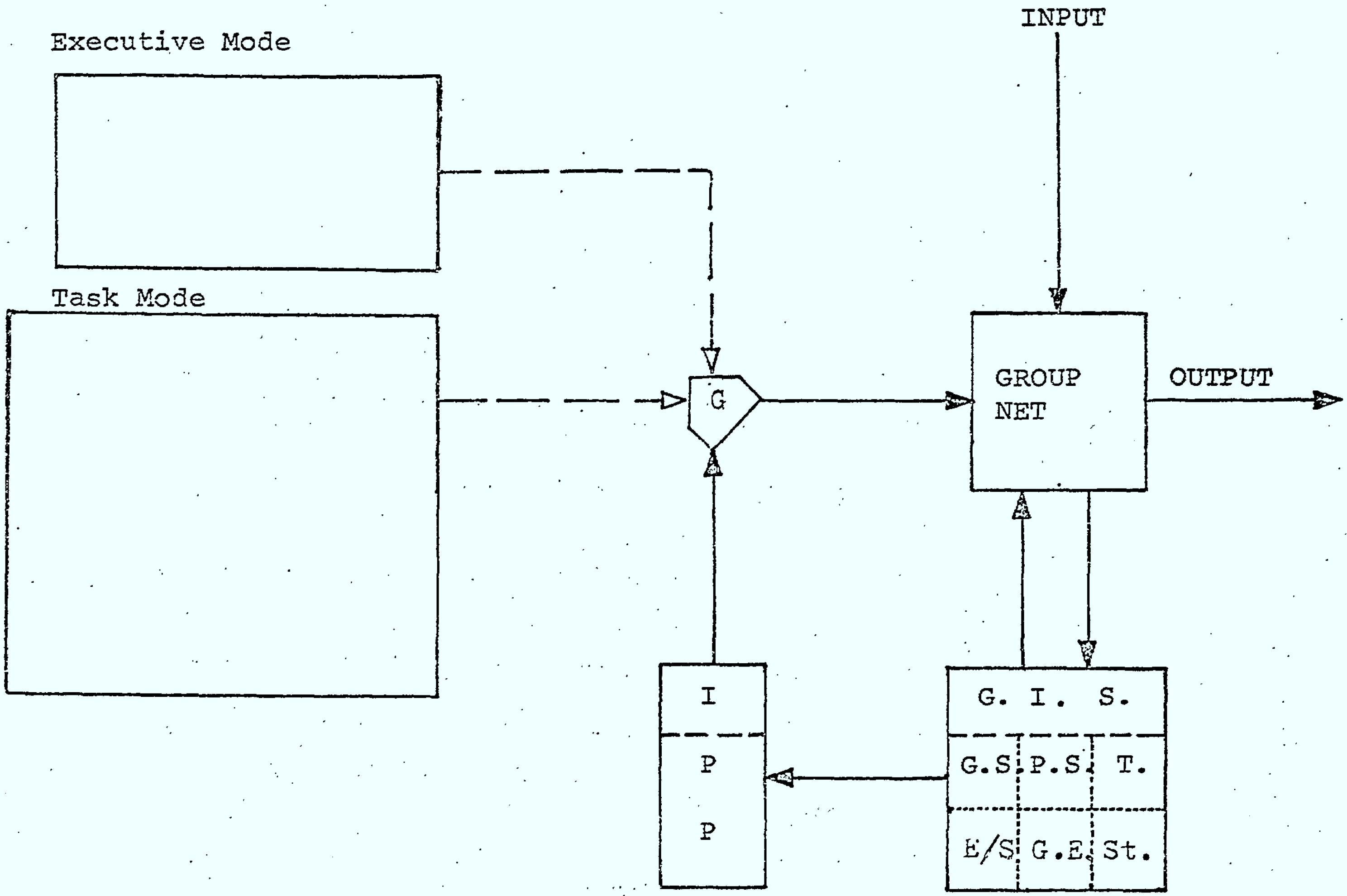
Executive Mode
Task Mode
INPUT
G
GROUP NET
OUTPUT
I
P
P
G. I. S.
G.S.
P.S.
T.
E/S
G.E.
St.

Figure I-18

The Group Network is linked to a memory (Group Information State) which records goal states (G.S.), present information states (P.S.), relative time (T), error-success counts (E/S), group structure (ST), and group-experimenter relationship (G-E). As the group passes through the phases of the task (Figure I-13), and as it shifts back and forth from task to executive mode, the internal structure of the Group Network undergoes change. Task and executive modes are represented at the left of the diagram: they are not to be read as part of the flow diagram itself, but as a way of showing in shorthand form the dynamic changes in network structure (which would otherwise have to be drawn in the form of a concatenation of components such as in Figure I-13).

The interrupt system is shown to depend on the Group Information State. It is to be thought of as a black box, having two parts. The first part is to be viewed as a set of functions, defined on the set of Information States of the group memory, the range of the function corresponding to interrupts by individual members which attempt to change the behavior of the Group Network. While it may be heuristically useful to term these "satisfaction" functions, or something similar, the task of the investigator is simply to describe the behavior of the black box, which means simply to imagine any set of functions which will explain the behavior of the system. Since input to the black box, and output from it, can be deduced from observables, the task is a straightforward (if difficult) problem in estimation. That is to say, if we represent the output of the interrupt system by "I", and its input by T, E/S, St, etc., then our task is to find a function: I = f(T, E/S, St), which explains the experimentally obtained results, and no more. Nothing prevents us from interpreting the function as effects due to frustration, but such an interpretation is not necessary.

The second part of the Interrupt System is a Program Pointer, which may be conceived of as a pushdown stack of some kind, permitting groups, after an interruption, to return to the earlier point of their operations where they left off when the interruption occurred.

The Gating Mechanism "G" conceptualizes the notion of change of mode from task to executive, from subroutine to subroutine, and from one executive phase to another.

What can be inferred concerning the internal organization of the Interrupt System? It is probably useful to think of it as having a number of thresholds, which result in different <u>kinds</u> of output as different kinds of input occur. Figure I-19 suggests how these thresholds might be conceptualized.

INPUT	OUTPUT
1. Single communication event fails (e.g., message not heard)	Ask for repeat. Go back one step.
2. Subtask a) incomplete	Suggest start on subtask
b) complete	Suggest group go on to next task
3. Too much time; too many errors	Suggest a change in program procedure
4. Wrong group structure	Try to get group structure changed
5. In spite of program changes and group structure changes, still too many errors	Suggest a change in group goals--Go home!

POSSIBLE THRESHOLDS IN THE INTERRUPT SYSTEM

Figure I-19

While this is likely to be a very rough approximation of the actual behavior of the Interrupt System, it indicates possibilities for lines of investigation, which respect the hierarchical organization of both task and executives modes of group functioning.

Measuring performance characteristics of task groups

The adoption of a control system model of task groups leads to the question of the relative efficiency of such groups considered as regulators. Two measures are of particular interest: the capacity of the group as a channel, and the stability of the system under various conditions of input.

1) Channel capacity

To complete its task the group network must accomplish transfers of information. Two sources of information are available to the group, and they are utilized in differing proportions for Type A and Type B tasks. These sources are the experimenter and the group itself.

a. Input information (experimenter-originated)

The initialization phase of each task serves to give the values of each component of the group state vector a certain variety (in the present case, a variety of 2, or 1 bit). At the end of the data-sharing phase, the variety of each component has increased to 7, or 2.81 bits. (The variety is less than additive due to redundancy in the list.)

The difference in the initial and subsequent variety is due to the intervention of communication processes, wherein variety spreads from component to component in successive steps. The capacity of the group network as a communication net can be measured. It varies with such factors as internal structure, the nature of its physical infrastructure, presence of noise, etc.

Measurement of channel capacity is an important index of group efficiency since the capacity of the group as a regulator cannot exceed its capacity as a channel of communication.[1] Channel capacity thus establishes an upper bound for measurement of the overall efficiency of the system.[2] For Type A tasks, measurement of channel capacity offers no particular problem, since the group operates essentially in

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[1] Ashby's law of requisite variety.

[2] Questions of the efficiency of groups organized into different structures have been extensively studied in the communication net literature. See, for example, Bavelas (1950), Christie, Luce, and Macy (1952), Luce, Macy, Christie, and Hay (1953), Mulder (1959), Glanzer and Glazer (1961), Mackenzie (forthcoming). Effects of coding noise (semantic confusability) have been studied by Macy, Christie and Luce (1953), and transmission noise by Heise and Miller (1951). Effects due to modality (e.g., television) seem to have been less studied.

an open loop, or simple throughput mode, and in Chapter III measures of channel capacity will be given for several groups.

b. Group-originated information (individual inputs)

In addition to information input directly by the experimenter, information is stored at individual locations of the network, corresponding to such factors as pre-existing knowledge, problem-solving skills, etc. For Type B tasks, these intra-individual sources of information become an important source of variety, and account for many communication processes, in that all the elements for the solution of the problem are not given by the experimenter.[1]

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[1] With MacKay, we argue that: "Unless the organism happens to be organized exactly to match the current state of affairs, work must be done to bring it up to date: work not only in a physical, but in a logical sense. The 'logical work' consists in the adjusting and moulding of the conditional-probability structure of the organizing system: the formation, strengthening or dissolution of functional linkages between various basic acts or basic sequences of acts.. Information can now be defined as that which does logical work on the organism's orientation.... The amount of information received by an organism can then be measured by measuring ... the logical (organizing) work it does for the organism ... They are necessarily relative measures, since they measure the impact of information on the given receiver. 'Amount of information' measures not a stuff, but a relation."

The amount of information stored at individual locations in the net cannot be easily ascertained, since it is not subject to experimenter control. One can proceed as follows, however: it is known which transfers of information _must_ occur within a perfect system in order to regulate the disturbance created by the presentation of a problem. For any given group, its channel capacity for a given type of activity can be estimated on the basis of the time it takes to transmit essential information. Communication of information which does not contribute to solution of the task (e.g., repetitions, incorrect or out-of-phase attempted solutions, non-task-related communications, etc.) can be ascertained from inspection of group protocols. Given this information, the _relative efficiency_ of the group can be determined, when measured against the ideal situation.[1]

Where, due to a lack of inadequate information stored within the group, it finds itself unable to regulate the disturbance, we say that the group is in a condition of _information overload_.[2]

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[1]For complete discussion, see Mackenzie (forthcoming).

[2]This definition of information overload differs considerably from that most commonly found in the literature

Additional sources of variety within the group relate to its self-organizing functions, in particular its task-organizing, net-organizing and channel-supervision functions. Since such functions are essential to task completion in a partially self-programming network, estimates of channel capacity must take them into account.

(a) Task organization

Initial experimenter instructions include information concerning the task procedures required for solution of the task. Since these are identical for all members of the group, there should be, initially, little need for communication. However, for difficult tasks, where the procedure may not be equally understood by all members of the group, or in cases where, even for simple tasks, the group solution has been reported back incorrect, the group must decide on a new or changed task program. In such a case, there may be variety in perceptions of an appropriate response,

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on the subject (see, for example, Miller, forthcoming), where the load factor is taken to be a direct function of experimenter-input information. Our definition emphasizes the ratio between size of disturbance and available information. (For more detailed discussion, see Taylor, 1973.)

and group coordination needs imply a necessity to communicate in order to arrive at a common understanding. Such communication takes up channel capacity.

(b) Net organization

It has been argued that each individual may have a preference for a given form of network organization, as expressed in routes and schedules. Group coordination needs require that such preferences be transmitted.

(c) Channel-supervision

Part of the group's organizing work requires a decision concerning the choice of modality--verbal vs. visual. Failure to utilize the visual channel to full advantage may seriously diminish subsequent capacity to communicate task-related information.[1]

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[1] A similar point is made by Moray (1970) with respect to cognitive systems: he posits a limited capacity central processor "whose organization can be flexibly altered by internal self-programming" and argues that total brain capacity can be allocated in different ways depending on task type, and task phase. He also argues that such self-programming activities take up capacity. It seems obvious that actual channel capacity is determined by both intrinsic physical limitations, and also by the effectiveness of the

Stability

a. Task stability

The objective of the group is to bring values of the state variables within acceptable limits (goal states). These acceptable limits are all associated with attaining problem "solutions" within certain time bounds. When this occurs, the system is at rest.

Our hypothesized activity system proceeds as follows: when a disturbance occurs (data arrive), the group tries on one information-processing procedure. If this fails, the interrupt system "vetoes" the choice of this procedure, and the group tries out a second line of behavior, and so on until essential values of the state variables are attained. Over a series of relatively easy (Type A) problems where there is redundancy in the pattern of disturbances, and where the group has sufficient variety in its repertoire of responses, patterns of behavior will stabilize.

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organizational plan. Problems of measurement of capacity, in such circumstances, are considered further in Chapter III.

When the size of the disturbance increases, and where there are inherent limitations of members of the group to solve elements of the problem, the group begins to range more widely over its domain of available behaviors, and to draw on additional sources of stored information. If regulation cannot be achieved, the group's behavior will not settle at a point of equilibrium, oscillations of various kinds may appear in its line of behavior, and in general it may be thought of as exhibiting "unstable" behavior.

Type B, or high load, tasks may produce de-stabilizing effects; low load, or Type A, tasks generally do not.

b. Regulatory stability

A second course of potential instability arises from the fact that each individual within the group is a regulator for the group network. Any program for the network proposed by one member may be vetoed by another.

A network structure defines roles for each individual, roles which may be more or less rewarding. To illustrate the possible disequilibrating effects inherent in this situation, let us consider the situation where individual A proposes a structure which makes him central, and individual B similarly proposes a structure which makes B central. If A's structure is adopted, let us say that A receives a payoff of +1, and B, -1; if B's structure is adopted, the payoffs are reversed. Let us suppose that other members of the group are indifferent, and hence receive a payoff of 0. Let us now add a payoff associated with successful completion of the task; let us suppose that each member receives a payoff of +1 for completing the task, and -1 for failing to complete the task. If A's structure is adopted, he gains +2, B gains 0, and the others, +1. The adoption of B's structure produces a similar profile, except that A's and B's payoffs are reversed. It is in the interest of most members of the group to adopt one or the other of the structures, and once adopted, further challenges from the individual who has failed to have his structure adopted can only reduce the overall group payoff. If the latter continues to interrupt, additional sanctions may be applied by the group, further reducing his payoff.[1]

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[1]See, for example, Schacter (1951) for a demonstration of the effects of deviancy on the tendency to reject the deviant member.

c. Relationship between task and regulatory stability

The above argument suggests that regulatory stability can be attained by a group even in the absence of complete consensus concerning group structure.

However, it can be asked whether this equilibrium remains stable when task payoffs are reduced to zero, as will be the case for overloaded groups who cannot attain to problem solution in an acceptable time. In this case, supposing A's constitution to have been adopted, the latter's payoff falls to zero, but not below since he still has the gratification of being in an interesting role.[1] B's payoff falls to -2, so that his incentive to interrupt is increased; and, more importantly, the payoff of those members indifferent to the choice of group structure falls to -1, making them presumably more receptive to a challenge by B, and adoption of a new structure. If this succeeds, B and A will simply have reversed roles; if the new structure does not lead to success, the

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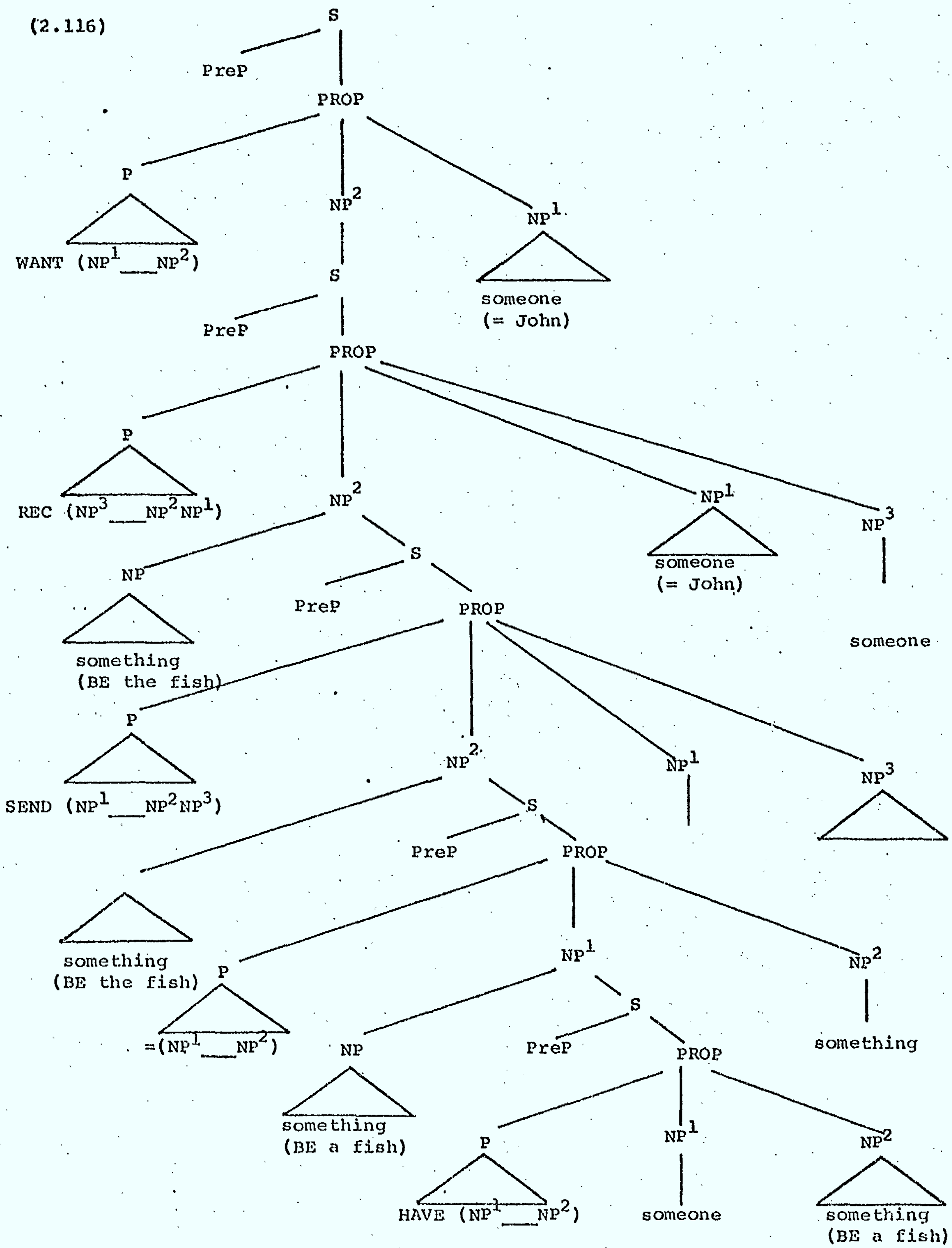
[1] It has been shown by Leavitt (1951), Shaw (1954) and Trow (1957) that structural measures such as centrality and autonomy are possitively correlated with individual satisfaction, and that the amount of satisfaction varies with personality needs (Berkowitz (1956), Shaw (1959)).

group may enter an oscillatory phase, alternatively according leadership to B and A until a breakthrough occurs, or the group disbands.

It is thus posited that task and regulatory stability interact, and in Chapter III, we will consider evidence to this effect.

(2.116)



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(BE the fish)
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PROP
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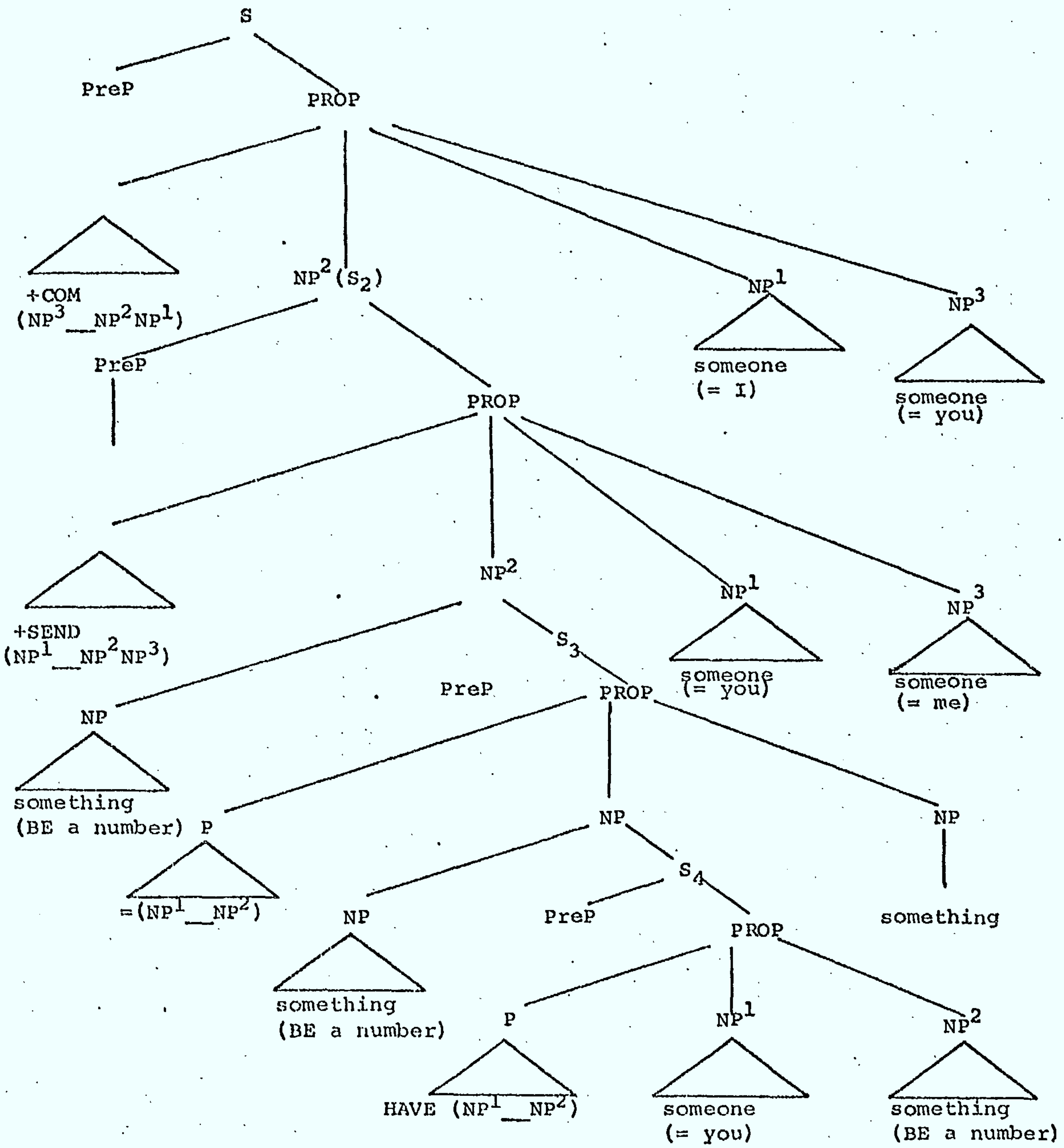
(2.149)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NP3
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NP
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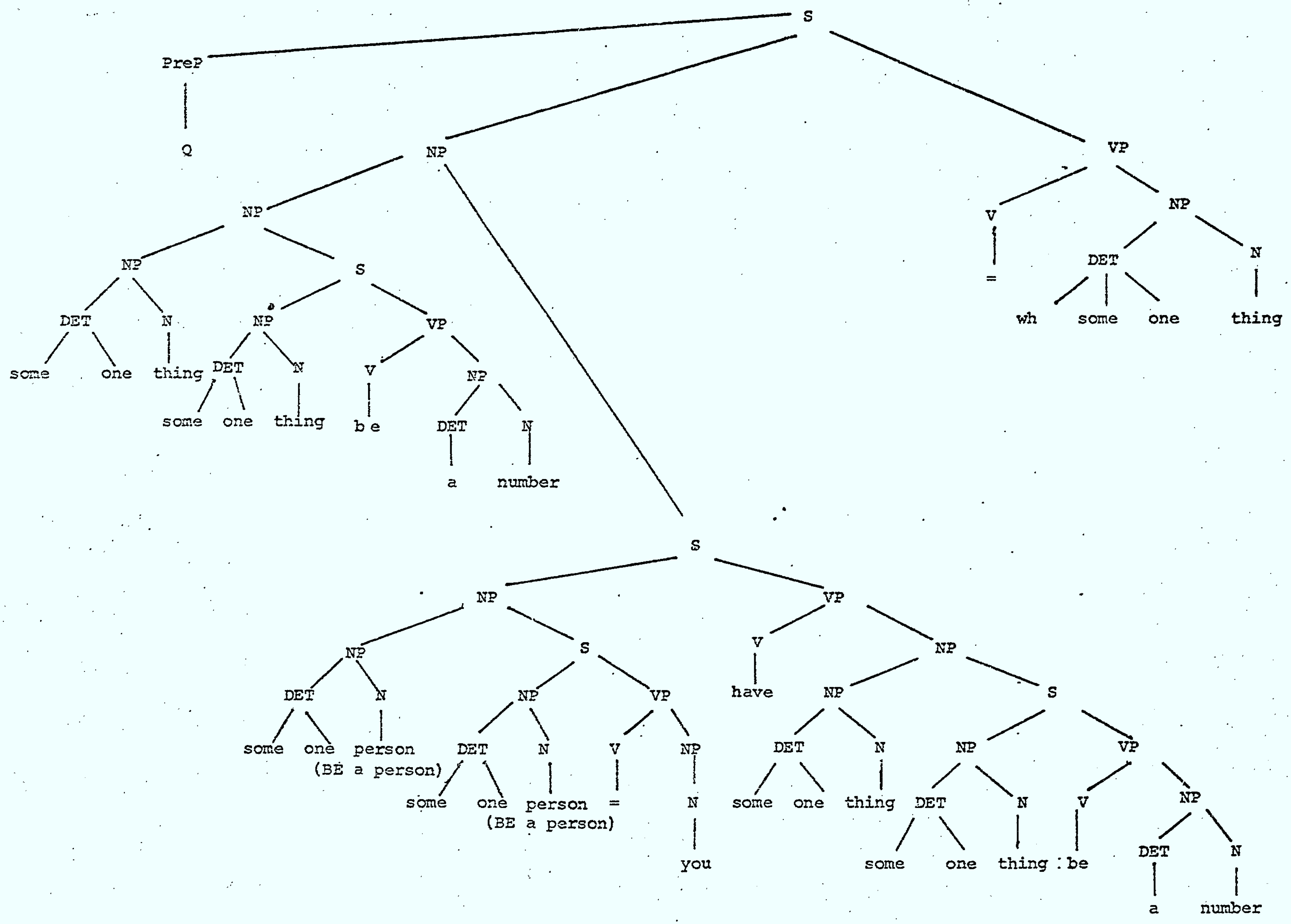
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