SIMULATING LEARNING WITHIN THE COMMUNICATION NETWORKS

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Concern for the effects of different patterns of interaction upon group processes led to the initial interest in the Communication Network Experiments (CNE). These experiments were one strategy for the study of group structure under controlled conditions.

Bavelas (1) originally defined the problem as follows:

> Imposed patterns of communication may determine certain aspects of group processes. This raises the question of how a fixed communication pattern may affect the work life of a group. Do certain patterns have structural properties which may limit group performance? May it be that several communication patterns are all logically adequate for the successful completion of a specified task? Or will one result in significantly better performance than another?

With these questions he developed the experimental procedures now standard in Communication Network Experiments (CNE) to systematically build a theoretical structure and subject it to empirical tests.

Due to the formal theoretical tone of Bavelas' original work and the ensuing popularity of his experimental technique, many investigators have been disappointed that the research findings on communication networks have not led to a rigorous theory of group structure.

The lack of unifying concepts seems to warrant further elemental research (2). Davis (3) noted that although the experimental method has enabled researchers to use observable individual behaviors as the foundation for cumulative empirical relationships, the amount of confusion which has occurred in the study of networks is surprising. It appears that groups organize in specific schemes and perform at speeds independent of communication freedom and of the network in which the group is operating.

Several criticisms may be leveled against most CNE to date. Two are of primary concern. First, data from psychology have indicated that during individual learning there are three distinct phases--an initial transition period, a period of acceleration in response rates, and then a 'steady state' in response rates. Once this final phase is reached, behavior remains typically stable for long periods. Only one of the previous CNE was designed or conducted in such a way that a steady state could be achieved. Consequently, groups may have been either in the process of organizing or searching for the optimal sequences of messages when the experiments were terminated. If the data from individual psychology suggest that these transition states are the rule rather than the exception, the research strategy for CNE should be reversed. Rather than manipulate large samples for short time periods, smaller samples should be examined for a longer duration to determine the effects of learning.

Finally, previous studies failed to include a basis property of social interaction behavioral consequences of either positive or negative reinforcement. This seems particularly critical since the literature (4) indicates that most behavior, or change in behavior, is predicated upon environmental consequences perceived or imagined.

To date CNE have been marked by inconclusive and inconsistent findings (5). Reexamining the last three questions posed originally by Bavelas, one can still not find satisfactory explanations for what may be missing variables or relationships.

PROPOSED APPROACH

This study attempts to use a unifying concept--the psychology of individual learning--as an elemental explanation for some of these disparate findings. More specifically, the effort will be directed toward a more comprehensive explanation of task productivity for various networks.

The basic approach proposed in this study is to construct a model of the initial learning process within the CNE paradigm that will account for the data over time, given the routing channels or networks. The criterion of appropriateness for the model is that it will reproduce observed behavior as measured by the time for task completion required for the entire group. By constructing a model of the CNE which includes individual learning (in the form of feedback and reinforcement) this investigation was designed in the anticipation that the output or results of the model will resolve some of the previous inconsistent findings.

Two questions will be posed:

1. Will various networks reach an equal rate of productivity?
2. Why will some groups confronted with a task develop more or less rapidly in a productive fashion and in some cases fail to find systematic behavior to accomplish the task efficiently?

The first question is suggested by Burgess' work (6) indicating the eventual attainment of a steady state for problem solving by two different networks (Circle and Wheel). Other frequently used networks may also exhibit this type of behavior. If learning and reinforcement will produce this similar effect in other networks, the inconsistent results previously recorded may be explained by examination of the transitory state in which other experiments terminated (25 to 60 trials).

The basis for the second question stems from the indirect implication that individual learning rates are not the same for each network. Due to the complexity of stimuli (paired comparisons) and their combinations which must be performed by each member, the absorption rate of 'better channels' may account for differences in cumulative solutions over time for each structure. Stated simply, it is not a matter of knowing the structure, but rather how many comparisons of behavior can be made and retained, so that an individual can identify those sequences which are most productive. It would appear that faced with more centralized CN these comparisons would be less complex, thereby explaining the rapid development of optimal or near optimal productivity for Wheel nets.

If a learning model can produce long-term data similar to human subjects, it will then form a basis for theorizing on the crucial relationships within the CNE.

The directions for this approach have been suggested by several researchers (7,8,9,10).

BACKGROUND ON PROBLEM

Burgess (11) integrated individual learning theory into a CNE paradigm. By specifically including learning concepts into his design, he found that Circle and Wheel networks can reach a similar steady state of performance. Although trial length for these two networks was significantly different (200-300 for Wheels and 500-600 for Circles) the nature of these structures became apparent. Performance of a network is a function of each member's ability to adapt to structures or environments of varying complexity. This adaptation was achieved by having each member learn his role in the task-structure through information feedback and reinforcement provided through the experimental process.

There have been previous simulation studies in the CNE. McWhinney (12) has written a computer program to simulate communication network behavior, but was apparently not completely successful. His lack of success in experimentation may be traced to the exclusion of some phenomena in group development, one of which was learning.

Marshall (13) attempted to simulate, with a more complex set of parameters, the results of CNE conducted by Cohen (14). His model was relatively successful in reproducing those data, but was not adaptable to slight changes in the network with which he validated his model.

METHODOLOGY

The research approach is to develop a general computer simulation model of individual behavior in communications networks which can be used to simulate the behavior of human subjects and test the model's ability to predict behavior in networks not previously examined over long periods of problem solving. The model should be considered as a vehicle which will be composed of and cause existing propositions from learning theory, communication theory, and the CNE to interact.

According to the rationale for an individual learning process, the design philosophy to be adopted is to construct a program representing the details of the structural aspects for the networks and separately construct a simulation of the individual's behavior. The simulated subjects can then be placed in any desired network and runs can be set for any number of trials. Additionally, from his work with human subjects Marshall (15) noted that individual learning rates are independent of the network.

There are several reasons why the proposed research will take the form of a computer simulation model:

1. A longitudinal study has been suggested by the need for the inclusion of transition states of learning. Swanson (16) studied groups that differed in knowledge of task and amount of prior experience working together. Groups that had worked together previously on a task exceed other groups in success of task performance and mutual satisfaction.
2. Most studies are non-longitudinal and present only a snapshot of continual behavioral processes within groups. Weick (17) states that this depicts a static view of organizations because mechanisms associated with processes of change, development, restructuring, and fluidity are not highlighted. The simulation strategy offers more acceptable methods to overcome this criticism.

General Discussion of the Model (see figure 1)

In the following description, terms which should ordinarily be applied only to humans are used to describe the characteristics of a symbolic model of human behavior. Henceforth, the model's equivalent of a human subject will be called a "MAN". The capitalization of the work MAN is done to make it clear that it is the model which is under discussion, not some aspect of a human subject's behavior.

In laboratory experiments, subjects sent messages at will until everyone signalled that he had the answer. The simulation program is not as flexible. Because of the sequential nature of the computer, sending messages proceeds as follows:

1. Each MAN selects a message to send (or decides to wait).
2. Each MAN chooses a permissible channel or other MAN to receive the message.
3. The messages are sent; all information vectors and matrices are updated and such other changes as may be required are made.

The basic time unit in the simulation was that interval of time in which each MAN had an opportunity to send or request one message to or from another network member. Such an exchange is called a round. A sequence of rounds ultimately leads to each MAN having the answer. Such sequence is called a trial. The accomplishment of successive trials consistutes the primary activity of the model's MEN.

To proceed through these three choices the problem-solving behavior exhibited in the model was composed of four stages (18). They are:

1. searching
2. comparing
3. remembering
4. altering behaviors.

These actions are performed by the MEN and are outlined with this classification.

Searching. Searching procedures required a MAN to decide with whom he wished to communicate, and what the nature of that communication would be.

The model MEN have only four possible messages to send. These messages are:

1. Data--a collection of symbols not understood to be the answer
2. Send me your data
3. Send me the answer
4. Waiting (this is not sent).

In the experiments by Cohen (19) all messages and scrap paper were collected and examined. His conclusions from the content analysis yielded the classifications used in the model. Marshall (20) reported that it seemed as though subjects frequently did not respond appropriately, if at all to more complicated messages. Also, it often appeared that more complex messages did not have a great effect upon subject performance. He, too, suggested this classification of messages.

Each man, then, had two primary sets of probabilities (arranged in matrices) which described his propensities for selecting each type of message to each other MAN in the network. The first matrix contained the probabilities for selecting one of the four actions only. The second matrix described the network or channels available to each MAN to send these messages. This method permits the specification of any communication network.

Comparing. A MAN was required to compare his current behavioral choices (selection of channel and message) with recent actions of other members, as they may have placed expectations or demands upon him.

Prior to selecting either a message or a channel, a MAN had to be aware of his progress toward a solution. His choices could be modified as a consequence of experience in previous rounds.

A MAN had to determine whether:
1. he had the answer
2. data for answers had been requested of him and by whom
3. the state of his information vector had changed during the last round.

A set of rules along rational lines were developed for this operation.

This procedure may be inconsistent with the mental processes of human subjects. Although there is little experimental evidence to indicate the sequential nature of this process, it was adopted to reflect similar observable behavior in subjects.

Remembering. The "memory" of the MEN is imperfect. They do not remember what messages were sent or received from trial to trial. The results and actions for only the last round are stored in each MAN's memory. With regard to the memory of human subjects, initially a subject does not know what network connects him with others and even when he determines this does not exhibit behavior indicative of his knowing the best routing scheme for task success. What apparently occurs is that a subject will hypothesize an organizational scheme which appears appropriate and will adopt suitable behaviors. Clearly, the memory of human subjects in these experiments was far from precise.

Altering Behaviors. Changing behavior, in the S-R tradition, suggests some effects of learning.

In this study, the incorporation of learning took the form of a linear model developed by Bush and Mosteller (21). They postulate that one subset of the sampled stimuli becomes conditioned to the response that occurred, and another subset becomes deconditioned to that response. Their formal model for reward training and rote learning permits reinforcement for one class of responses and no reinforcement for making all other responses. The assumption is made that the individual process in CNE more closely resembles reward training than any other. Symbolically, their proposition can be expressed as follows:

$$P^{t+1} = \alpha + (1-\alpha)P^{t} \qquad \text{where } t = \text{the trial number}, \quad 1-\alpha = \text{base rate of change}$$

When a trial is completed the model proved for a MAN to compare the number of rounds for the previous trial (PT) to the number of rounds for the current trial (CT). When PT = CT, the types of messages or channels used are recognized to be no more effective than any combination or permutation of messages and channels which were employed during the previous trial. In a loose sense a MAN realizes that his actions did not permit the number of rounds to decrease relative to the last trial. Therefore, his probabilities for selecting either a message or channel would not be positively reinforced or incremented.

Specifically the crude learning model in this study operated in the following manner. When time taken to solution (number of rounds) improved over last trial, such that CT < PT, anthropomorphically, a MAN would think he had done something better than last time. The tendency to repeat these actions, according to the "law of effect" would then be incremented.

DISCUSSION

A four-MAN network was used to simulate a Circle network, validate the results against a benchmark laboratory study (22) and simulate the outcomes for an all-channel network.

The findings tend to support three hypotheses which are formally stated below. The hypotheses are as follows:

1. In the long run, productivity measured by time units to solution for both Circle and All-Channel networks are similar.
2. Solution rates measured by solutions per trial are similar for both Circle and All-Channel networks, in the long run.
3. The fewer the levels of hierarchical structure, the sooner an optimal rate of productivity is reached. All-Channel networks reach a steady state solution rate in fewer cumulative solutions than Circle networks.

The first hypothesis was clearly supported by the findings in this study. Overall, the level of productivity in problem solving for both networks approached and maintained the minimum time (in rounds) required to complete successive tasks. There were no differences in these times, as both networks used three or four message opportunities after long run experience.

The second hypothesis was also supported by the findings. The solution rates achieved in the long run for both Circle and All-Channel networks were the same. Between 0.33 and 0.25 solutions per trial were recorded for each network in all replicated runs after substantial experience.

The third hypothesis was clearly supported by the findings of this study. Circle networks, which are two step hierarchies, require a minimum of two relays to reach any other member of the network. These networks took longer to reach a steady state solution rate, approximately 300 trials. In contrast, All-Channel networks, which are one step hierarchies and require one relay of messages to reach any other group member, achieved a steady state solution rate earlier than Circle networks. They achieved this solution rate at slightly more than 200 cumulative problems. Groups in the All-Channel networks will solve problems with fewer communications, and reach minimum times for solution before the two step hierarchy.

In summary, group problem solving behavior exhibited a substantial transition period evidenced by an acceleration in the solution rate leading to a steady state. Contingencies of reinforcement permitted both networks to achieve and maintain these steady state periods. Additionally, the networks differed throughout the transition periods: the Circle performed initially at a lower rate than the All-Channel; it reached a steady state somewhat later than the All-Channel and it took the Circle substantially longer than the All-Channel to reach optimum organization. These observations are based on a rough comparison on the ranges of break points in transition states, or achievement of steady states, between the two networks.

CONCLUSIONS FROM THE EXPERIMENTAL PHASE OF THE STUDY

The findings on the productivity variable indicate that, in the long run, the fewer the levels of hierarchy in communication networks, the sooner optimal levels of productivity are achieved. It appears from a visual comparison that the All-Channel and Wheel networks reach more efficient task performance levels sooner than Circle networks. Also, the questions about productivity investigated by previous studies have been premature in their findings. The data produced in this study question the exclusion, in earlier studies, of the long run effects of learning and reinforcement in CNE.

The findings on time to solution for the networks studied indicate that transition stages are evident for both Circle and All-Channel networks. Further, the transition stage is of shorter duration for All-Channel networks. Minimal times to solution are achieved sooner by the lower level hierarchical networks.

The findings on the solution rates indicate a substantial difference in performance between networks characterized by single and multiple levels of hierarchy. Optimal solution rates are reached sooner under All-Channel networks than Circle networks. This finding partially supports the Burgess (23) hypothesis that Wheels achieve maximum solution rates sooner than Circles. Only during long-term experimental conditions--recognizing and employing learning and reinforcement--do these findings become evident.

The results of the total replications and experiment indicate that the behavior exhibited in communication networks is a very lawful phenomenon which can be described precisely by a power function of the form $Y = AX^B$. Additionally, the communication structure affects the behavior of groups indirectly, by either handicapping or facilitating the group members in their attempts to organize themselves for efficient task performance. There is, for example, a difference in the networks with regard to the time it takes to reach a steady state.

The findings of this study argue for the design of socio-psychological experiments to permit the observation and analysis of the entire developmental histories of groups from their transition periods to their steady state periods. The findings also suggest that one important variable which must be included to explore properly the effects of various communication networks and possibly social structures in general is learning.

One conclusion which can be drawn from previously asserted differences in solution rates between communication structures, in which there were no physical limitations favoring one network over another, is they were a function of experimental artifacts. Had previous experimenters included reinforcement contingent upon behavior, and had they observed their experimental groups over sufficient time periods, the collection of a vast array of contradictory findings may have been avoided.

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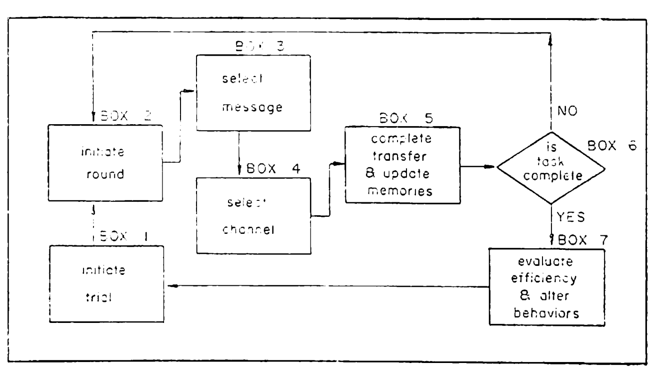
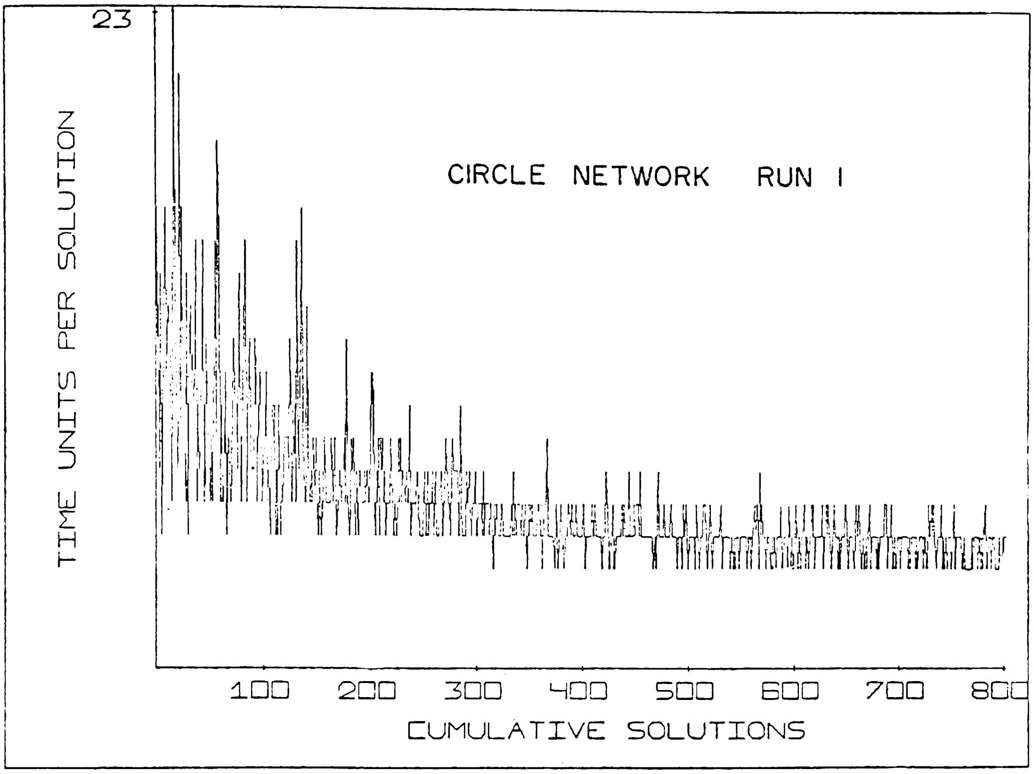
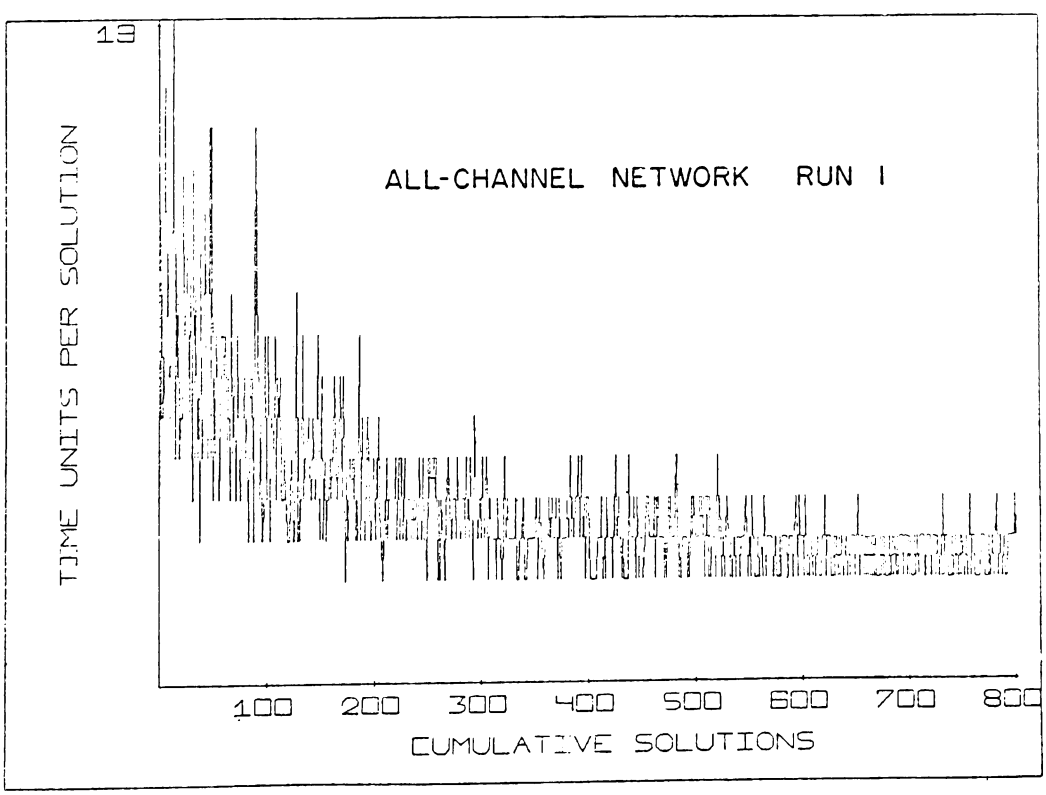


BASIC MODEL PROCESS
FIGURE


23
TIME UNITS PER SOLUTION
CIRCLE NETWORK RUN I
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS


13
TIME UNITS PER SOLUTION
ALL-CHANNEL NETWORK RUN I
100
200
300
400
500
600
700
800
CUMULATIVE SOLUTIONS