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ABSTRACT
A communication arc from A to B represents the transmission of a single message from the first system A to the second system B. What are all the ingredients of a communication arc required for the sending of a message? What compatibility conditions between these two systems must be satisfied in order for communication to take place? Further, what does each ingredient comprise and just when do these compatibility conditions work? Answers to these questions are sought through the use of the natural theoretical framework provided by graph theory. Although the discussion is restricted to a communication model, its applications extend to all real-world situations involving networks. The object of the investigation is to delineate the anatomy of a communication arc in sufficient careful detail that an arc can be recognized, synthesized, and analyzed. (For related documents, see ED 056 256, 257, and 259.) (Author)

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The University of Michigan

1. THE PROBLEM

A. The Utility of Graph Theory

Whenever a problem in the real world is studied seriously, sooner or later it becomes useful and necessary to introduce an appropriate mathematical model. Some of the worst of these have been statistical models which obscure the phenomena amid mountains of meaningless data. Other models range from the pure simplicity of set theory to the most abstruse mathematical theories.

One of the most useful contemporary models which is finding applications to a vast variety of real world phenomena is given by graph theory.[1,2] A graph may be described as the underlying topological framework of a network. In a network, there are entities or systems which can be represented by points and flows or messages between pairs of points which may be either one-way flows or two-way (symmetric) flows. The meaning attached to these flow lines between a pair of points is always taken from the real network which is being described in this graphical manner.

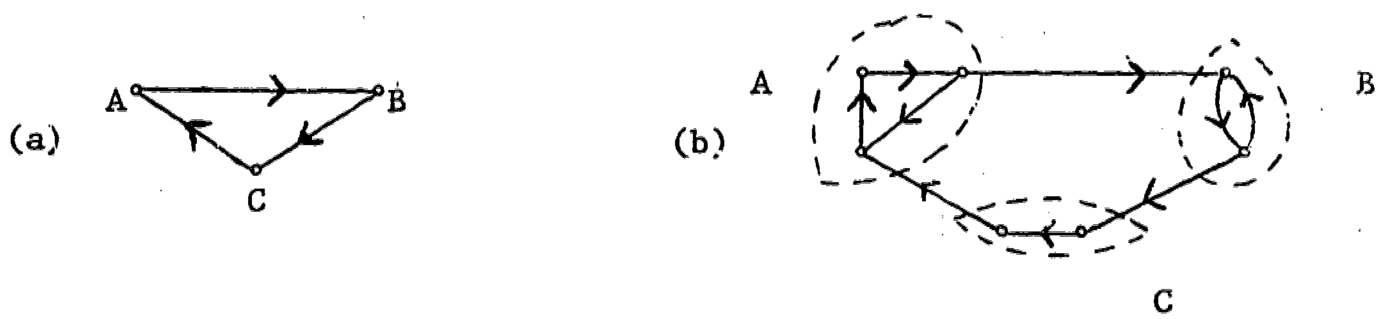

Figure 1.

Figure 1 suggests how graphs can be used to analyze structures at different levels of detail. Figure 1a shows the relationships among three systems represented by the points A, B, and C. Figure 1b shows the same system relationships but at a greater level of detail wherein each "point" can be represented as a graph which shows intra-system relationships as well as inter-system relationships. In Figure 1b we show systems A, B, and C as each having separate internal structures. It should be understood, however, that A, B, and C could have any internal structure whatever, including any number of points and any arrangement of one-way or two-way interconnection.

Examples suggest themselves from many sciences: social, physical, and natural. We mention only a few of these. If an electric network is being analyzed, the lines can represent any of the electrical elements in ordinary use such as resistors, condensers, inductances, vacuum tubes used as rectifiers (one-way flow), power sources, transistors, or even entire printed circuits. In electric networks the flow usually indicates electrical currents. If a chemical molecule is being described, the lines stand for chemical bonds and a number is attached to each line to give the number of electrons involved. In biological models there are many different levels of graphs playing upon each other. One graph can represent the different organs in the human body as its points. Each of the organs can, in turn, be regarded as a graph consisting of the component parts. Continuing, one gets eventually to the membrane level and then to the level of cells. This figure is a typical illustration of graphs within graphs in which each point of a graph is itself another graph. Sociometric questionnaires often ask individuals in a group, "Who is your best friend?" The resulting "sociogram" can be expressed equivalently as matrices or directed graphs. Similarly, directed graphs occur in structural role theory, where points can represent people, positions, or tasks, as noted by Harary and Oeser.[3] Last, but certainly not least, in studies of communication it has been useful to delineate communication networks in which people or clusters of people are represented as points connected by arcs (directed lines) indicating communication of some message. Because all applications of graph theory to various fields follow a similar logic, we will restrict the discussion which follows to a communication model, understanding that application of the concepts to these other areas can be made with only minor changes of wording.

B. The Need for a Theory of Innovation Transfer

In the course of conducting a comprehensive survey of research and theory related to the diffusion and utilization of knowledge, Havelock[4] was impressed by the lack of research based on precise theoretical models of communication. Rogers[5] has identified over 1,000 empirical research studies related to the diffusion of innovations. Although many of these studies are fine examples of empirical research in social sciences, nearly all are based on a very limited and imprecise definition of the act of communication. Most of this research is still based explicitly or implicitly on a paradigm suggested by Smith, et al.[6] which subdivided the act of communication into components of sender, message, medium, receiver, and effect. Havelock[7] was able to categorize the vast majority of the 4,000 studies he reviewed into these categories. For example, approximately 1,000 studies were codable as concerned with characteristics of "receivers" whether they be persons or larger receiver units such as organizations, communities, nations, etc., slightly over 600 were concerned with characteristics of the "medium," and so on. Hovland[8], in his review article of 1954 on the effects of mass media, was similarly able to make effective use of the Lazarsfeld formula in summarizing a large quantity of research, and others through the years have made ample use of the same formula in writing books and articles and simply ordering their thoughts about the communication process.

The present authors remain impressed by the simple elegance of this "who-says what-to whom-by what channel-to what effect" formula, but we are also restless to move on to a more precise analysis so that future research on the communication and utilization of knowledge can be guided by a more coherent and integrated theory. In his latest work Rogers[9] moves a step in this direction via induction from his exhaustive review by proposing a number of theories based on the twin concepts of "homophyly" (similarity of senders and receivers) and "heterophyly" (different between senders and receivers). Havelock[10] proposed the concept of "linkage" as an elaboration of the Lazarsfeld formula, suggesting that truly effective and efficient one-way communication from senders to receivers presupposes prior two-way communication which sets up the channel for the prime message. Before they could arrive at an "agreement" on the primary message transmission, "senders" and "receivers" had to exchange meta-messages of various sorts to enable them to accurately simulate each other's internal processes. The contractual nature of message transmission was earlier noted by Bauer[11] in his excellent critique of the Lazarsfeld model. Havelock summarized his analysis by suggesting that effective transfer of knowledge from a "resource system" to a "user system" could be largely explained by the presence of seven (7) factors which he labeled "linkage," "structure," "openness," "proximity," "reward," "capacity," and "synergy."[12] The Havelock factors were reached inductively from his review, just as Rogers' "homophyly-heterophyly" propositions were derived. However, the challenge has remained to derive a set of factors of similar economy from the model itself by deduction. This is the challenge which we now take up and which we plan to follow through a series of papers until a fully adequate analysis of the process of knowledge transfer has been made.

B. Arcs

We have chosen as the starting point for this analysis the simplest form of directed graph consisting of just two points, A and B, connected by an arc (Figure 2) oriented from the first point to the second.

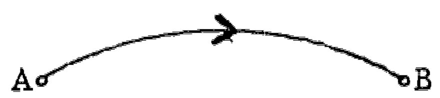

Figure 2. An arc

Actually, Figure 2 can be taken as a model of any act of one-way communication. If A is the "sender" and B the "receiver," then the line segment is taken as the message and the arrow head as the medium. As noted earlier, A and B can be persons or groups or networks or systems of any configuration, size, or complexity. In this paper we are going to undertake a thorough analysis of Figure 2 with the hope of delineating a useful set of necessary and sufficient conditions for a message to travel from one point to another. Thus our object is to study the anatomy of a communication arc in all detail. We want to examine its basic ingredients and dynamics. Only in this way can we hope to be able to construct arcs which are effective in sending needed messages from one system to another.

D. Demiarcs

In a first attempt to study the ingredients of an arc theoretically, Harary[13] noted that an arc can be broken down into two components named "demiarcs," one emanating from the source A and the other homing in on the target B. He suggested that the outgoing demiarc be called the "male" and the incoming demiarc the "female." An arc was never complete unless the male and female demiarcs were both present and meshed.

We propose that the demiarc concept is fundamental to our understanding of any act of communication. In other words, Figure 2 does not tell the whole story. The act is better represented as in Figure 3 where M represents the male demiarc (desire and ability to send a message), F represents the female demiarc (desire and ability to receive a message), α represents the message and μ a junction, or communication "medium" or "channel" which connects the sending and receiving demiarcs to each other.

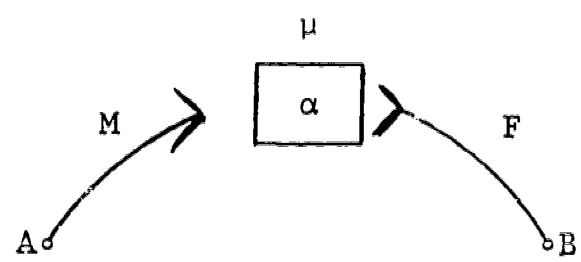

Figure 3. Two systems with their demiarcs, a message, and a medium

However, Figure 3 merely represents the communication act as a *fait accompli*. We are especially interested in analyzing the prior conditions necessary to create this act. How do all these ingredients come together in the first place? For those of us who are concerned primarily with "innovation," the transfer of new knowledge to new receivers, this was the crucial question. Thus, the initiating problem we wanted to pose was the following: "How does a new message α move from point A to point B?" It was assumed without loss of generality that α could be a message of any complexity or any type (e.g., words, products, beliefs, knowledge, skills, etc.) which was held initially at A but not initially at B. Message transfer has occurred when the message is at B. The question: How does it get to B from A?

E. Overview of Our Attack on the Problem

There appear to be two sets of conditions necessary to create a complete act of one-way communication. First of all a certain set of elements must be present in the situation, e.g., the sender (A), the receiver (B), the sender's male demiarc (M), the receiver's female demiarc (F), the message (α), and the medium (μ). These we will call "existence conditions." To use a simple but appropriate analogy, they must exist just as flour and water and an oven must exist before we can bake bread. But there is a second set of conditions that must be satisfied, which we call the "compatibility" conditions. Put simply, the elements must be brought together in a certain way. They have to be made compatible in space, time, and configuration just as the flour and water must be made into dough which must be put in the oven when the oven is at the right temperature and maintained there for a specified period of time and then removed from the oven.

These two sets of conditions, existence and compatibility, studied in sections II and III, and illustrated in section IV, suggest to us the basic anatomy and genesis of the one-way communication arc, but we recognize that the analysis of arcs does not stop here. There may be additional conditions which we have not discovered or properly understood, and there are undoubtedly many possibilities for more detailed analysis or microanalysis of these conditions. In section V we will make brief forays in these directions. However, we hope that what follows will be a stimulus and a challenge to others to extend, elaborate, or modify the paradigm which is conceived here.

II. INGREDIENTS OF AN ARC

We first list all the ingredients of an arc and then comment on each of them as well as on the connections between them and the set of all of them.

A. Existence Conditions for Communication Arc from A to B

1.1 A, the sending system

1.2 B, the receiving system

1.3 M, the male demiarc at A

1.4 F, the female demiarc at B

1.5 α, the message to be sent from A to B

1.6 μ, the medium along which the message is to be sent.

We propose that each and every one of these six ingredients must exist in order for an arc from A to B to become established: obviously there can be no arc without either of the systems A and B themselves. The male demiarc M must exist at A in order that the message be sent; but so must the female demiarc F exist at B. If there is no message α to be sent, then there is no information content of any kind whatsoever, and so there can be no meaningful arc. Finally, the medium μ must be present as a communication channel along which the message is sent.

Examples will serve to make these ideas more definite. In the first of these, A and B are people. Consider a typical university scene in which there is a tutorial meeting with A as the professor and B as the advanced graduate student. The professor is explaining a recent theoretical development to the student which he believes will be useful in his doctoral thesis. The male demiarc is displayed by the professor's eagerness to explain this theory and the female demiarc by the student's attentive and concentrated receptivity to learning it. The message is the theory itself and the medium is verbal communication within the same room. All the compatibility conditions needed for the consecutive connections from A to B to establish an arc are satisfied. The message α is at A to begin and reaches B at the end. A and B are near enough so that voices can be heard while speaking at normal volume and all these processes are taking place simultaneously.

Next, we see various ways in which an arc can fail to become established when one or more of the ingredients are missing. It is often used as a comedy situation in the theater for A to talk to B just after B has surreptitiously stepped off the stage; here only one of the two systems is present, namely the sender. The symmetry of the situation is convincingly seen in a motion picture scene from a war play in which two buddies, A and B, are shown with A talking to B, when a sniper's bullet suddenly picks off one of them.

In other situations A can be speaking to B, but B is so wrapped up in thought that the male demiarc is there but the female demiarc is absent, so that no arc can then be established. Again, the situation is symmetric: the female demiarc may be present as indicated by an eagerness of B to listen and learn, but the male demiarc is absent since the authority just won't talk.

Boy A might want to talk to girl B and she might want to be spoken to, so that both demiarcs are present, but A cannot think of what to say because he is temporarily shy. In such a situation all the ingredients, including the medium, are present except for the message.

A situation in which everything is present except for the medium is typically illustrated by a little boy watching a television program in which the transmitting equipment fails temporarily.

III. PUTTING THE INGREDIENTS TOGETHER: COMPATIBILITY CONDITIONS

Up to this point we have merely established the facts that (A) must have a message (α) which he is able to and wants to communicate (M), that a potential receiver (B) must be able and willing to receive (F) and that there must be a medium (μ) for sending the message.

It is as if there were a man (A) who had a car (α) he wanted to sell (M), a newspaper (μ) where he would advertise his car for sale, and another man (B) who wanted to buy a car (F). These are important preliminary facts, but we have not yet established the necessary and sufficient conditions for Mr. B to buy the car of Mr. A. Alternatively, we could imagine A as a research scientist who has just discovered a substance (α) which impedes the growth of certain types of cancer cells. He realizes the potential of his innovation as a therapy and is eager (M) to have his work utilized to this end. Elsewhere in the world there is a physician B who has critically ill patients with certain types of cancers. He wants and needs (F) some new therapies for these patients. What are the necessary conditions for transferring the knowledge from the scientist to the physician?

Some readers may protest at this point and say that it is meaningless to talk of car salesmen without considering the market economy in which they exist, or to talk of a scientist's work without a network of journal publications and other institutionalized communication mechanisms which tie him to the medical school, the medical profession, and the medical practitioner. Of course, we understand that such features are integral parts of the environment in which these phenomena exist. However, the point of this paper is to stand back from these obvious facts of life and strip down the act of communication to its essentials. The question, then, is not what actually exists between the research and the doctor or between the car salesman and the car buyer, but <u>what must minimally exist</u> between them before transfer can occur.

In broadest terms, we believe that given the existence conditions (1.1 through 1.6) stated earlier, the necessary and sufficient conditions for message transfer can be summarized in one word: compatibility. The six ingredients A, B, M, F, α, and μ must be compatible with one another. We have been able to distinguish four types of compatibility which we identify as availability (2.1), proximity (2.2), synchronicity (2.3), and mesh (2.4).

(2.1) Availability (Compatibility of Demiarc Boundedness)

Both sender and receiver must not only be willing to communicate (M and F) but they must also be mutually available. If one or the other is already busy or bound to a third party, communication between them is impossible. In the special terminology we have introduced in this paper, we would say that both demiarcs (M and F) must either be "free," uncommitted, unbound, or be bound only to each other. Figure 4 illustrates this problem. A and B cannot communicate because F_B is bound to M_C.

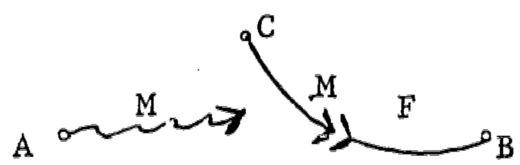

Figure 4. A cannot communicate to B

A free demiarc is one that is looking for an opposite sex partner but has not found one; hence, it is "available." In Figure 4 M_A, is a free demiarc. Before a message can pass from A to B, an arc $\overrightarrow{AB}$ must be formed, and before the arc can be formed, M and F must both be available to each other.

Mr. A cannot have made a prior arrangement with another party C to buy his car and B cannot have decided to buy a car from D. Research Professor A cannot have decided to give exclusive testing rights on his discovery to Dr. C, and Dr. B cannot have made a decision to get all his new cure ideas from source D.

We have all been in the position of trying to reach someone on the telephone when their line was "busy." This is a simple "availability" problem. The fact that our intended receiver is already talking to someone else is incompatible with our intention to form a communication link with him. Similarly, if we are about to call him but someone else calls us, we are no longer free to send the message in spite of our desire or need to do so. Our male demiarc is bound in the latter case; our friend's female demiarc is bound in the former case. Either situation is incompatible with message transfer from us to him. There is only one exception to this condition which is the case where M and F are both bound but to each other. Thus if I am already on the phone to my friend but on another matter, there is no availability problem for communication "α". I simply change the subject to α and the message slips across.

(2.2) Proximity

Proximity (compatibility in space) is one of the most fundamental compatibility conditions for message transfer. A message, particularly a new message, cannot be passed from A to B if A and B are separated from each other by "great distance." Sender and receiver must be available and accessible to each other and therefore they must occupy adjoining or overlapping space. This point may be obscured by the fact of modern technology. Contemporary methods of communication and transportation often makes spacial proximity a seemingly trivial matter. However, a mechanism such as the telephone is useful for the very reason that it overcomes distance and makes proximity trivial for certain kinds of communications. However, users of telephones must be in the proximity of telephones and their ears and mouths must be in very close proximity with the receiver. Moreover, in spite of all the technical gadgets which reduce proximity to a "trivial" matter, proximity remains empirically a very significant factor in the diffusion of innovations of all types. Spacial factors are almost always correlated with communication success. For example, a spoken message can be delivered at various distances from less than an inch up to several hundred yards, depending upon the condition of the air, noise, etc., but as distance increases, communication difficulty increases up to a point at which it becomes impossible.

(2.3) Synchronicity (Compatibility in Time)

Compatibility in time is an essential factor in message transmission. The message cannot be received before it is sent and in many cases it cannot be received too long after it has been sent. Furthermore, there is a time frame within which the act of transfer must take place; both sender and receiver have to manage their time and attention span for the duration of the message and have to schedule their behavior so that they are ready for each other at the same moment. A familiar comic device is to have two comedians speak simultaneously, pausing simultaneously so that neither can hear the other.

Some media, notably print, make the management of the synchronicity requirement far easier because they suspend the sender's message more or less indefinitely until the user is ready for it. Even for printed messages such as books, however, synchronization is still vitally important, e.g., the writer must take the time to write and the reader must take the right amount of time to read and he must do so after the writer has written. As the pace and complexity of our lives increase, such matters of time budgeting and scheduling become far from trivial matters.

(2.4) Mesh

We can now construct the situation of our inquiring car buyer, B, allowing the compatibility conditions stated above. Mr. A has the car (α), wants to sell (M), has no other buyer (availability), has brought the car to B's house (proximity) at a time (synchronicity) when B is home and has his money with him (availability). Mr. B wants a car (F), has no other car in mind (availability), and is able to devote time to the transaction now (synchronicity). Does he therefore buy the car? Not necessarily: B may not like the car; he may find that it is the wrong color, or the wrong size for his needs. It may be too noisy or ride too hard for him; or he may simply be unable to drive it. In our terms there is no "mesh" between B and α (the car). It may also be that B actually would do very well with this car but is incapable of perceiving its good qualities; all he can think of is that purple paint job and the animal odor in the back seat. Here there is no mesh between F (B's receiving senses) and the message α (the car). It may also be that the good qualities (e.g., mechanical reliability, gas mileage, etc.) of this car cannot be seen or appreciated in one demonstration test drive. In this case there is no mesh between the message, α, and the medium, μ, (the visual appearance, the test drive).It may also be that B never believes either appearance or test drives until he checks a car with his brother, in which case there is no mesh possible between B's quest, F, and the medium, μ. Corresponding mesh problems could have happened on A's side, also. He could have been incapable of driving the car to B's house; he could have been unable to explain its virtues adequately; and so forth. Altogether, we have identified seven types of mesh compatibility which have to be present before a message can be transferred. These are identified in Figure 5. Note that five of the "mesh" problems concern the message and its compatibility with the sender, the receiver, their demiarcs, and the medium. The medium must be able to mesh with the sending and receiving apparatus (M and F).

	α	A	M	μ	F	B
α		X	X	X	X	X
A	X					
M	X			X		
μ	X		X		X	
F	X			X		
B	X					

Figure 5. The Matrix of Mesh-Compatibility

IV TWO EXAMPLES

We have specified ten conditions[(1.1) through (1.6) and (2.1) through (2.4)] which we claim are necessary and sufficient for the transfer of a message from a sender to a receiver. Thus we propose that if all these conditions are met, message transfer will take place; whereas if any one of these conditions is not met, message transfer will not take place. If our formulation is correct, we feel that this analysis can be highly significant for future research and general understanding of communication phenomena of all sorts from the most simple to the most complex. These ten conditions offer essentially a diagnostic checklist of one-way communication problems. If we see a situation in which communication is failing to occur, we should find that one or more of these conditions is not being met. In most cases the diagnosis will be obvious enough, but sometimes a systematic tool of this sort should prove very helpful as it has in other areas.

Perhaps it is easier to grasp the significance of these points through examination of specific examples. Consider an event: a man is driving a car at a reasonable speed around a sharp curve when suddenly the car loses its stability and crashes into a tree, killing the driver. This terrible event might be the result of the failure of an arc. Suppose, for example, that the test engineers who worked on the development of this vehicle found a tendency toward instability in sharp cornering. This is a message, a message that could have saved the man's life if he had known it. Why did he not know it? Well, it could have been because the manufacturer had gone out of business after the engineers made the discovery (no A). It could have been that the manufacturer was reluctant to give out such negative data on its own products (no M). It could have been that there were no such data even though critics claimed there was (no α). It could have been that there was no effective way for the manufacturer to communicate to all owners (no μ). It could have been that the driver had no interest in or understanding of such engineering data (no F). And finally, it could have been that the poor man was already dead before the message got to him (no B).

It could also be that B was listening to his wife when the news report on the data came over the television (an availability problem). He may have been on a fishing trip in northern Canada when the story broke (a proximity problem), or he may have left on his fatal trip before the story broke (a synchronicity problem). Finally, he may have heard the message but did not understand its implications because it was couched in technical jargon with all sorts of qualifications (a mesh problem). We are sometimes lulled into a comfortable fantasy that truth will out, that knowledge will eventually get to the people who need it, but the communication arc analysis illustrates that the process is far from automatic. The example given is not fantasy:

some lives were probably lost because the arc failed, others saved because the arc succeeded eventually when a particular receiver decided he really needed to know (a very strong "F" in our terms) and went after the information just on the hunch that it was there. This strongly motivated receiver did a lot of digging and was eventually able to find a few engineers who were willing to talk (M), perhaps because they felt guilty and angry over the manufacturer's suppression of their findings.

The above example is a relatively simple one, involving the transfer of some discrete facts from a particular set of specialists to a receiver in a special situation, but it is also possible to make the same sort of analysis on a grosser level with complex phenomena. Consider the situation of a highly industrialized and technology-rich country like the United States trying to help an "underdeveloped country" like Zambia. To begin with, we have a substantial M problem because the Congress, and probably a lot of the American people, are not too eager to provide "foreign aid." Then there is the message: do we understand what we have to give? What is "development" anyway? Then there is the medium problem: can we send it over in ships? Air drop it? Put it in packages? And when we get it to the other side, will the Zambians be there eagerly waiting with a big female demiarc extended to us? Come to think of it, is there really a place called Zambia? (no B?) Most of these questions may sound a little bit naive in the 1970's but they were not asked by very many people when President Truman was talking about "Point Four" in the late 1940's, and there was not any country called "Zambia" then, either!

Compatibility conditions are equally problematic when we try to "help" other peoples. Many countries that need our help cannot use it because they are already committed to receiving aid from communist countries (availability).

They are frequently out of phase with our aid efforts, being ready for certain types of assistance when we are prepared to offer something else. Specific help almost always seems to arri·e too late (synchronicity). Lastly, we often have the wrong type of help in the wrong form, hospitals without doctors, or doctors without hospitals, tractors without mechanics, scientists without technicians, and on and on. These are all mesh prob'ems.

V. QUESTIONS STILL UNANSWERED

In this section we can only indicate rather briefly the directions which our sequel papers will take in the study of more complex communication networks.

A. Formation of a Path

It is not at all hair-raisingly obvious how to analyze and dissect the essential features of a directed communication path along which a message is to be sent. The natural first question is to study the smallest possible path with more than one arc. As a first stipulation, we take as completely under control the formation of a single arc. A directed path of length 2 from A to B to C is now shown. As long as no message is shown in Figure 6, and it is

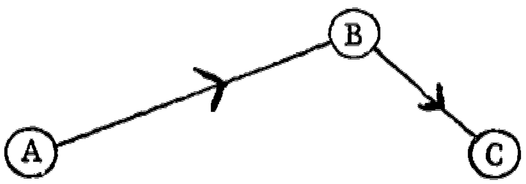

Figure 6.

assumed that exactly the same message α which is received at B from A is then sent along the second arc from B to C, there is no overwhelming problem of conceptualizing the process. But when, as is usually the case, the intermediate system B transforms the original message before sending it on (rediffusion, in the language of BBC-TV), there are considerable subtleties involved in the analysis. Our approach to this question considers the analogy shown in the table below between the formation of an arc from demiarcs as shown in Figure 2, and the formation of a 2-step directed path as in Figure 6. Only the message

TABLE 1

A → B		A → B → C	
Arc, Ingredients		Two-Step Path, Ingredients	
sender	A	sender	A
demiarc	M	first arc	A → B
medium	μ	intermediate	system B
demiarc	F	second arc	B → C
receiver	B	receiver	C

is not shown on either side of this table because of the complications indicated above.

B. Formation of a Link

A link is defined as a symmetric pair of arcs, one from A to B and the other from B to A. This is the structure of the smallest possible cyclic or feedback network outside of a single system. How does a link form? We

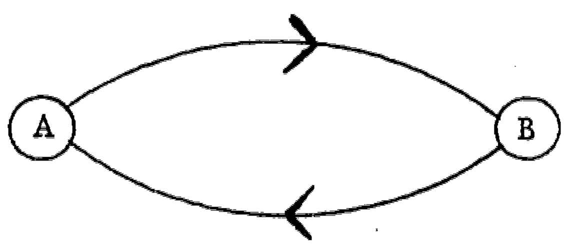

Figure 7. A Link

assume without loss of generality that its formation has been initiated by A in the sense that the arc A → B exists first, and the return arc B → A is needed. As a first approach, we can build up on the formation of a 2-step path just discussed above and consider that the link in Figure 7 can be obtained from the path of Figure 6, provided that system C can be identified with A so that they coalesce and become one and the same system. To indicate this process, we show (with C relabeled as A', the alter ego of A) in the next figure a sequence of three diagrams for the coalescence process.

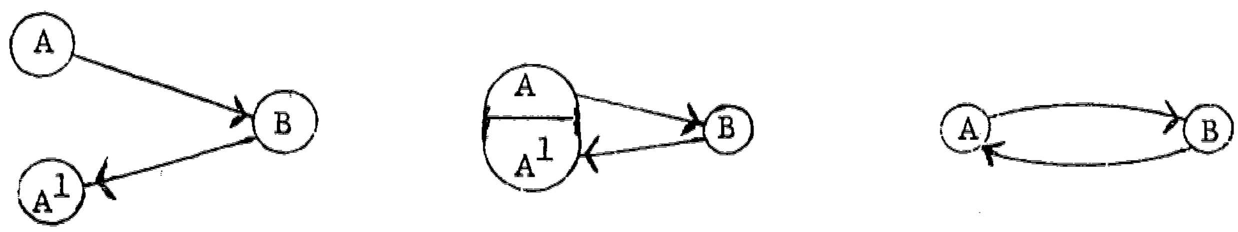

Figure 8.

C. Formation of More Complex Systems

Examples of some rudimentary communication networks which cry out for analysis are now shown. First, there are the longer paths.

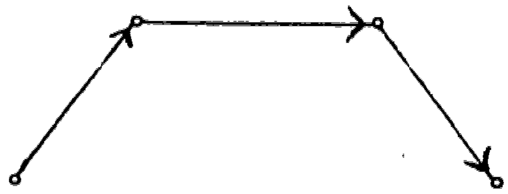

Figure 9. A Three-Step Path

Next, there are the directed cycles.

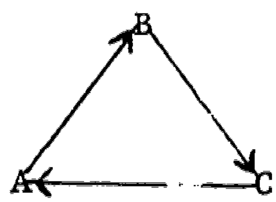

Figure 10. A Cyclic Triple

Then there is the other possible triple.

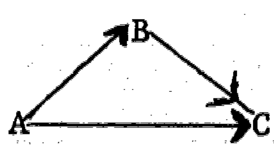

Figure 11. A Transitive Triple

In the case of a transitive triple, there is a different type of feedback than that resulting from a directed cycle in which a message α originates at A and a possibly distorted message α' returns to A. Figure 12 allows for α reaching C directly from A, while α' reaches C after α passes through B.

A semipath consists of distinct points and arcs which becomes an undirected path when the orientations on the arcs are ignored. Thus the two simplest semipaths which are not paths are now shown.

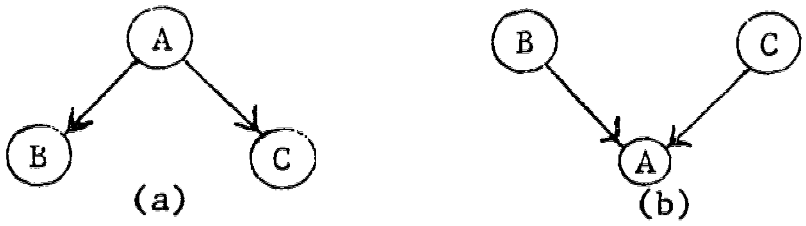

Figure 12. Two 2-Arc Semipaths

In Figure 12a, the question arises as to whether exactly the same message arrives at both B and C from A after possible distortion in the medium and along the respective demiarcs. On the other hand, Figure 12b poses the problem of how A integrates the information received from both B and C which may be not only different, but even contradictory.

There are several other triples which contain links. All of these are shown now.

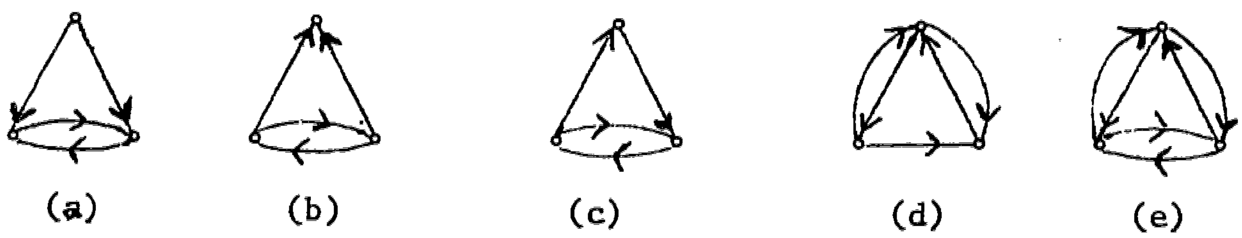

Figure 13. The Five Triples Containing Links

By definition, a directed graph is strongly connected (or, more briefly, strong) if every pair of points are mutually reachable along directed paths. The smallest strong digraph with more than 3 points which is not a cycle is shown.

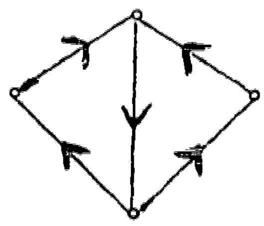

Figure 14. An Oriented Strong Digraph

A multitude of communication network structures representable by digraphs with only four points or fewer have been displayed in this closing section. The extension of our study of the anatomy of a single communication arc to those more complex configurations is far from trivial. The compatibility conditions multiply mercilessly and additional factors enter in an unavoidable way because distortion of the message in transmission through more than one arc must be recognized and handled. We plan to address ourselves to these questions in a series of sequels to this paper.

FOOTNOTES:

1. Harary, F. GRAPH THEORY, Reading, Mass: Addison-Wesley, 1969.

2. Harary, F., Norman, R., and Cartwright, D. STRUCTURAL MODELS, New York: Wiley, 1965.

3. Harary, F. and Oeser, O. A. A mathematical model for structural role theory, I. HUMAN RELATIONS, 15 (1962) 128-135.

4. Havelock, R. (in collaboration with A. Guskin) and others, PLANNING FOR INNOVATION THROUGH DISSEMINATION AND UTILIZATION OF KNOWLEDGE, Ann Arbor, Mich: The Institute for Social Research, University of Michigan, July, 1969, 500 pages.

5. Rogers, E. M. BIBLIOGRAPHY OF RESEARCH ON THE DIFFUSION OF INNOVATION, East Lansing, Mich.: Department of Communication, College of Communication Arts, Michigan State University, 1964, 58 pages.

6. Smith, B. L., Lasswell, H. D., and Casey, R. D. Propaganda, Communication, and Public Opinion, Princeton: Princeton University Press, 1946.

7. Havelock, op cit.

8. Hovland, Carl I. Effects of the mass media of communication. In Lindzey, G. (Ed.), Handbook of Social Psychology, Reading, Mass.: Addison-Wesley, 1954.

9. Rogers, E. M. and Shoemaker, F. F. DIFFUSION OF INNOVATIONS: A CROSS-CULTURAL APPROACH, New York: Free Press of Glencoe, 1970.

10. Havelock, R. op cit.

11. Bauer, R. The obstinate audience: The influence process from the point of view of social communication, AMERICAN PSYCHOLOGIST, 1964, 19, #5, 319-328.

12. Havelock, R. op cit. summarizes these seven factors as follows:
    1. Linkage: The number, variety, and mutuality of Resource System-User System Contacts, degree of interrelatedness, collaborative relationships.
    2. Structure: The degree of Systematic Organization and Coordination: a) of the resource system
       b) of the user system
       c) of the dissemination-utilization strategy.
    3. Openness: The belief that change is desirable and possible. Willingness and readiness to accept outside help. Willingness and readiness to listen to needs of others and to give help.
       Social climate favorable to change.

4

4. Capacity: The capability to retrieve and marshall diverse resources.
   Highly correlated with this capacity factor are: wealth, power, size, centrality, intelligence, education, experience, cosmopoliteness, mobility, and the number and diversity of existing linkages.
5. Reward: The frequency, immediacy, amount, mutuality of, planning and structuring of positive reinforcements.
6. Proximity: Nearness in time, place, and context. Familiarity, similarity, recency.
7. Synergy: The number, variety, frequency, and persistence of forces that can be mobilized to produce a knowledge utilization effect.

13. Harary, F. Demiarcs: An atomistic approach to binary relations and group dynamics, JOURNAL OF MATHEMATICAL SOCIOLOGY, 1971 to appear.