A Quantitative Analysis of Information Generation Properties of Structurally Different Networks

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Abstract

This paper tries to examine information generation properties of the network structure usually shown by arrows and nodes by the dynamic simulation analysis. The information generation means the augmentation of information stock (we call "base") of the network brought up by the network members. We introduce behavioral aspects into the analysis. In the past several researchers have approached to the task performances of the network structures by the experimentations involving actual persons. Our research puts emphasis on the information base on which tasks are accomplished. Therefore we will not touch the performances of achieving tasks explicitly. Our objectives are to examine how the structure of network has influences on the information base for accomplishment of tasks by its communication channels stipulated by the structure.

Introduction

The most important aspect of a network system is the information structure that designates the communication channels connecting the members of the network system in a specific way. The working of the network system is largely dependent on the behaviors of the members whose information bases for their decision makings are conditioned for growth to highly extent by the information structure. Our main concern is how the information bases of the members are determined or formed under the information structure.

The study on the direct relationships between the information structures (network strucutres) and the task performances ,or the comparative study of the task peformances of the network structures have been tried and reported by several researchers so far. The study by Leavitt (Leavitt, 1951) was the first experimental type research on the subjects. He compared the four structures' performances by giving a task to the four teams each of which represents one of the four network structures, and consists of five members(five nodes). The structures were the wheel, circle, line and Y structures. The task was for the team to detect a common card being held by all five persons to each of whom five different cards were delivered from six different cards. Under one of the performance criteria, the time to detect the correct card, the wheel and Y structures were proved to be superior. The worst structure was the circle. But when they changed the pattern of the cards to more ambiguous ones, the circle structure showed the best performance. Then he concluded that the wheel structure is suitable for highly standardized or routinized tasks and the circle structure is more appropriate for the tasks that need creativeness , flexibility, high morale and loyalty. He noted the information gap gap between the members brought up by the difference of the number of channels of communication available to each member under each of the structures. The gap could lead to low morale in the long run.

The study of the case involving three network members was conducted by Heise and Miller (Heise and Miller, 1951). Their conclusions were that given the tasks needing no communication the differences of the performances were of no significance. As the tasks were added complexity to require communication to some extent, the perfect structure where everyone could communicate with everyone else showed the best performance. Where the tasks needed communication most, the wheel structure under which only one member could talk with the others and there was no channel between the others, was the best performer.

The third study (Guetzkow and Dill, 1957) compared the three structures, the wheel, circle and perfect. But their research interests were different from the others explained above in hat they tried to follow the changing process of the structures. They hypothesized that the members under a particular structure might change or rearrange the structure into the the more suitable structures over time to improve their problem solving capacities. The study results obtained from experimenting on problem solving trials suggested that in both of the perfect and circle structures they tended to trim the communication channels permitted under the structures off. In sum the number of communication channels was adjusted downward in the case of too many channels in order to match with problem situations.

All these studies involved the real information processing of the tested persons in artificial problem situations. The performances of the tasks are thought to be determined by how and what information bases for their task accomplishment have been built interactively as to individual member and the whole via the effective communication channels that were developed on a given structure. The member's action is based on the information base.

Our research focus is not directly put on the relationship between the performances and the structures, but on the effects of the structures on the formation of the information base for task accomplishment. The research can be hardly done by the same type of experimentation as the studies above mentioned. We resort to the dynamic simulation by computer.

The framework for analysis

(1) the basic process in the model

The basic process here connotes the information processing for the formation of the information base. The processing includes the following two activities, generating new information and communicating or exchanging existing information. Let's call the former activity the generation activity and the latter the communication activity. The model analysis proceeds along the activities. Fig.1 depicts the basic process to be followed by the model.

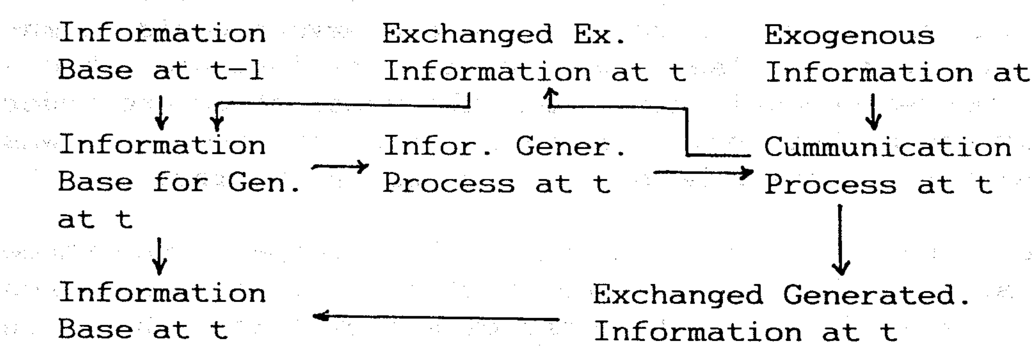

Fig. 1 The information processing in the model

Our focus will be put on the augmentation process of the information base. The information base of member i is defined as follows:

Information base at t =[information base at t-1]+[Exogenous Infor. of i]+[Exchanged Ex. Infor.]+[Generated Infor. of i]+[Exchanged Generated Infor.]

Exogenous information is the information each member obtains by informal channels of his own that are invisible and rely on his personal attributes. As we can't cope with the channels in the model explicitly, the amount of the information is given exogenously to each member. They exchange their own exogenous information each other through their formal channels allowed by the network structure. The exchanged exogenous information as well as his own exogenous information forms the information base for the information generation activity(that is taken as the auxiliary variable different with the information base as the level variable). Each member generates new information by reeditting, rearranging or cultivating the information base for the generation.The generated information is also shared through the communication channels among the communicated members according to the time length for communication.

Basically the information base increases as the exogenous information and the generated information are added amplified by the communication through the formal channels.

(2) the communication activity

We need to explain more about the communication activity. Each member in the network is assumed to make the decision of allocate his available time to the members with whom he can communicate under the structure. We hypothesize three types of decision rules for the allocation as follows.

Rule A: allocating the communication time more to the member whose size of the information base is larger. People are apt to communicate with ones having more information.

Rule B: allocating the time more to the members whose previous communicated information occupies less proportion of the total information received. People want to communicate with ones exchanging relatively scarce information.

Rule C: allocating the time equally to all of the members. In effect people want to deal with everybody equally.

The allocated time described above is not the actual time during which communication has happened,but the desired time.

(3) the determination of the actual communication time

The actual communication time is determined by applying a rule to the cross table of the desired communication time among the network members. Table 1 shows the desired communication time from member i to j decided by i. It assumes the network structure shown in Fig. 2. The arrows mean the channels that are formally permitted. 20, an element of row 1 and column 2, is the time member 1 wants to communicate with member 2. It's assumed each member has 60 minutes available for communication. The summation of the elements of (i,j) and (j,i) implies the total desired time for the channel i and j. Then Table 2 is

i\ j	1	2	3	4	5	6	7	total
1		20	40					60
2	40			10	10			60
3	40					10	10	60
4		60						60
5		60						60
6			60					60
7			60					60

Table 1 the disired time matrix for communication developed to indicate the importance of each channel in terms of the desired time for communication. The last column shows

i\ j	1	2	3	4	5	6	7	total
1		60	80					140
2	60			70	70			200
3	80					70	70	220
4		70						70
5		70						70
6			70					70
7			70					70

Table 2 the importance of communication channels

the total desired time for communication with member i. In the example, member 3 is the most desired person. Then each person has to cut the desired time, since it surpasses the available time of 60 minutes. We assume that the member of higher importance has priority to decide the time. For the decision we set the rule of deciding in proportion to the disired time. As to member 3, subject to the rule he allocates 36%(=80/220) of his total available time (now 60 minutes) to the communication with member 1. Then member 2 does 30% (=60/200) to memberl.

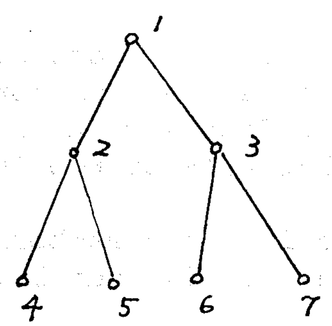

Fig. 2 Example

After all, member 1 spends 21.6 minutes with member 3, and 18 minutes for the communication with member 2, given 60 minutes of the total time available for communication at t. His idle time are 20.4 minutes. Member 2 and 3 have no idle time. Member 4 and 5 have 39 minutes idle time, and member 6 and 7 have to be silent for 40.8 minutes out of 1 hour.

(4) the information generation process

Each member of the network generates new information after the result of brain works. The information source of the generation is the information base at the end of the previous period plus the received exogenous information through the communication process, including his own exogenous one. If let the information source IS, the amount of generated information, GI, is assumed to follow the next Logistic equation.

$$dGI/dIS = a\,GI\,(K - GI) \qquad (1)$$

The solution of the equation with being minused 1 is;

$$GI = K/\{1 + (K - 1)\exp(-a\,IS)\} - 1 \qquad (2)$$

where a is a constant determining the efficiency of the generation and K is the maximum level of the generation impose by by human capacity. The meaning of -1 is let GI zero when IS=0.

The Logistic pattern reflects the increasing efficiency of the generation due to the learning effect for the early stages of the development of the information base and the decreasing efficiency due to the saturation effect for the later stages of the development. The same pattern is applied to every member.
(5) the determination of the information base
The information base has been defined already elsewhere. Again we define the information base of member i at the end of t as Si(t). Then Si(t) is calculated as follows:

$$Si(t) = Si(t-1) + Fi(t) + Gi(t) \qquad (3)$$

where,

Fi(t) : the amount of the exogenous information member i acquires during t. It is rewritten as;

$$Fi(t) = \sum_{j \in FS} Fij(t) + EIi(t) \qquad (4)$$

where,

FS : the set of the members with whom i can talk.

EIi(t): the amount of the exogenous information i acquires from his own informal information channels ,or sources.

Fij(t): the amount of information i obtains from member j. Fij(t) is calculated as follows.

$$Fij(t) = (CTij)x(EIj(t))x(T)x(CE) \qquad (5)$$

where,

CTij : the actual communication time between i and j. It's measured by the fraction of T, the time available for communication during t.

EIj(t): the exogenous information member j gets out of his informal information channels during t. It's given in the process and in priciple all equal for all j.

CE : the efficiency of communication between i and j. It holds for every adjacent two members connected by the formal channel stipulated by the structure.

Gi(t) : the amount of the generated information member i acquires from the communication through the formal channels. Gi(t) is defined in the same way as (4).

$$Gi(t) = \sum_{j \in FS} Gij(t) + GIi(t) \qquad (6)$$

where,

GIi(t): the amount of information member i generates by himself.

Gij(t): the amount of the generated information member i obtains from member j during t. Gij(t) is calculated by the following formula.

$$Gij(t) = (CTij)x(GIj(t))x(T)x(CE) \qquad (7)$$

where GIj(t) is the amount of information j generates. GIi and GIj are subject to the equation of (1) or (2).

The analysis
(1) the structures to be analysed
The structures we pick up for analysis are 9 structures as exhibited in Fig. 3. Each structure has 8 members. The number is arbitrary and may be a factor for sensitivity analysis.

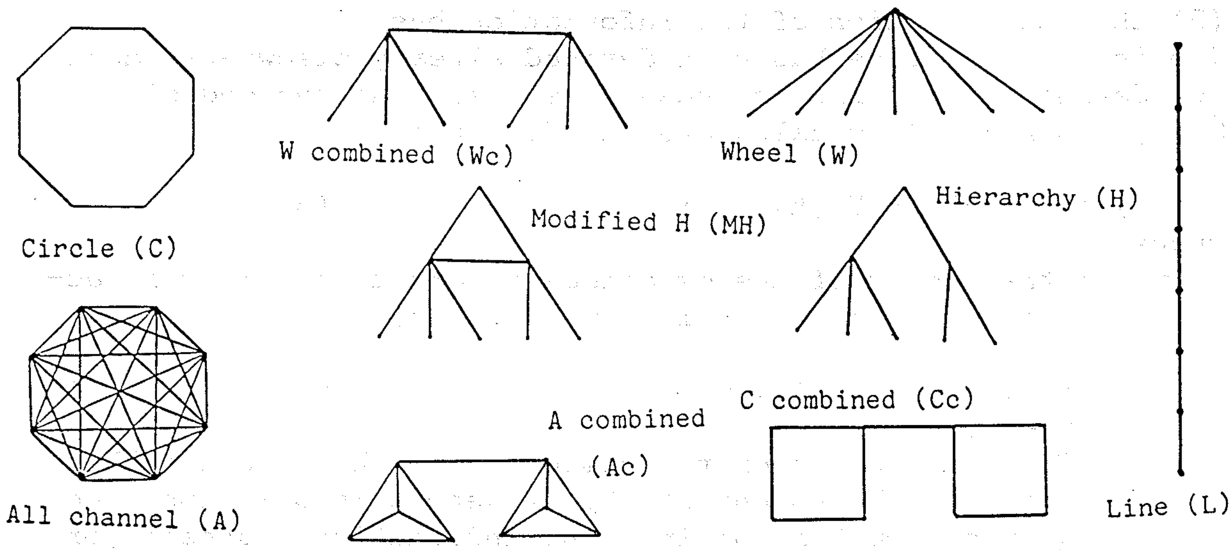

Fig. 3 the structures to be analyzed

(2) the length of simulation time
The length of the simulation analysis should be such that we can discern the differences of the performances significantly among the strucutres.
(3) the performance criteria
The performance criteria of our interest are with respect to the capacities of generating and communicating information at both levels of individual and the whole network. Also as the result of the generation and communication processes, the size of the information base of each member would shape a particular distribution pattern. The pattern might indicate certain properties of each structure.
(4) the program language
The model structure is amenable to the DYNAMO or similar dynamic languages, but we use the FORTRUN for modelling. The reason is that we did start with the static situation. As introducing behavioral aspects into the analysis, we have started to need the framework of the dynamic systems.

When analyzing the information generation properties of a network structure, especially of human beings, we have to take behavioral aspects into account. Human behaviors , often purposeful, stand on present situations or status of interest. It sometimes invokes the adaptive behavior. All these attributes require the dynamic perspective of analysis. As going to the direction, we will have to become resorting to the DYNAMO.

The result

The summary of the simulation result is exhibited in Table 1. TIB stands for the size of the information base of the whole network. The figures means the sum of the members' information bases. Larger value implies the higher information generating capability. CV means the coefficient of variation of the member's information base at each period. The values under the column title "Max." are respectively the ratio of the smallest information base to the largest one(the upper row figure) and the largest information base value(the lower row figure).

item \ time			1	3	5	7	9	11	13	15	17	Max.
RULE A	H	TIB	0.9	2.1	3.7	5.8	9.3	17.5	54.5	130.0	216.4	0.24
		CV	0.06	0.10	0.12	0.15	0.20	0.35	0.65	0.41	0.29	46.3
	MH	TIB	0.9	2.1	3.6	5.6	8.7	15.6	45.8	115.1	200.9	0.22
		CV	0.06	0.10	0.13	0.16	0.21	0.37	0.72	0.48	0.33	45.5
	L	TIB	0.9	2.4	4.2	6.8	11.4	24.9	87.8	175.6	267.7	0.24
		CV	0.04	0.07	0.08	0.11	0.15	0.29	0.42	0.28	0.22	49.1
	W	TIB	0.9	2.0	3.3	5.1	7.8	12.7	30.0	92.6	175.5	0.31
		CV	0.06	0.09	0.11	0.14	0.18	0.28	0.59	0.33	0.22	41.4
	Wc	TIB	0.9	2.1	3.6	5.6	8.7	15.7	45.2	114.3	199.3	0.23
		CV	0.06	0.11	0.13	0.17	0.23	0.40	0.79	0.49	0.34	46.3
	C	TIB	1.0	2.5	4.5	7.5	13.1	33.8	131.7	237.2	342.7	1.00
		CV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.4
	Cc	TIB	1.0	2.4	4.3	7.1	12.2	28.1	111.7	212.5	313.8	0.80
		CV	0.01	0.02	0.02	0.03	0.04	0.07	0.07	0.05	0.04	48.3
	A	TIB	1.0	2.5	4.5	7.5	13.1	33.8	131.7	237.2	342.7	1.00
		CV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.4
	Ac	TIB	1.0	2.4	4.3	7.2	12.3	28.5	112.7	213.7	315.3	0.83
		CV	0.02	0.04	0.05	0.06	0.09	0.16	0.21	0.15	0.12	48.5
RULE B	H	TIB	0.9	2.1	3.7	5.9	9.2	16.8	53.3	141.8	232.3	0.40
		CV	0.06	0.09	0.11	0.13	0.16	0.25	0.38	0.21	0.17	44.2
	MH	TIB	0.9	2.1	3.7	5.8	9.2	16.6	52.4	140.9	231.3	0.40
		CV	0.06	0.09	0.11	0.13	0.17	0.27	0.44	0.24	0.18	44.0
	L	TIB	1.0	2.4	4.2	7.0	11.9	27.6	109.3	211.1	312.9	0.49
		CV	0.04	0.05	0.06	0.07	0.09	0.16	0.15	0.10	0.08	49.0
	W	TIB	0.9	2.0	3.3	5.1	7.8	12.7	30.0	92.5	175.5	0.31
		CV	0.06	0.09	0.11	0.14	0.18	0.28	0.59	0.33	0.22	41.4
	Wc	TIB	0.9	2.1	3.7	5.8	9.2	16.6	52.0	141.1	231.4	0.47
		CV	0.06	0.09	0.11	0.13	0.16	0.24	0.38	0.20	0.16	43.6
	C	TIB	1.0	2.5	4.5	7.5	13.1	33.7	131.7	237.2	342.7	1.00
		CV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.4
	Cc	TIB	1.0	2.4	4.1	6.6	10.7	21.0	78.8	173.1	267.3	0.45
		CV	0.01	0.02	0.04	0.07	0.11	0.23	0.25	0.15	0.12	47.1
	A	TIB	1.0	2.5	4.5	7.5	13.1	33.7	131.7	237.2	342.7	1.00
		CV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.4

	Ac	TIB	1.0	2.4	4.2	6.9	11.6	25.2	101.5	201.9	302.3	0.61
		CV	0.02	0.02	0.03	0.04	0.07	0.15	0.15	0.09	0.07	48.3
RULE C	H	TIB	0.9	2.1	3.7	5.9	9.3	16.9	54.8	142.2	232.7	0.36
		CV	0.06	0.09	0.11	0.13	0.17	0.27	0.44	0.24	0.19	44.4
	MH	TIB	0.9	2.1	3.6	5.7	8.9	15.9	48.5	130.5	219.1	0.32
		CV	0.06	0.10	0.12	0.15	0.19	0.30	0.52	0.29	0.22	43.9
	L	TIB	1.0	2.4	4.3	7.1	12.0	28.5	112.0	213.8	315.6	0.42
		CV	0.04	0.06	0.07	0.09	0.12	0.21	0.21	0.14	0.11	49.4
	W	TIB	0.9	2.0	3.3	5.1	7.7	12.7	30.0	92.6	175.5	0.31
		CV	0.06	0.09	0.11	0.14	0.18	0.28	0.59	0.33	0.22	41.4
	Wc	TIB	0.9	2.1	3.6	5.6	8.9	16.4	48.2	132.1	220.7	0.37
		CV	0.06	0.10	0.12	0.15	0.19	0.31	0.52	0.28	0.21	44.3
	C	TIB	1.0	2.5	4.5	7.5	13.1	33.7	131.7	237.2	342.7	1.00
		CV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.4
	Cc	TIB	1.0	2.4	4.3	7.1	12.2	28.7	116.1	219.2	322.2	0.85
		CV	0.01	0.02	0.02	0.03	0.04	0.06	0.05	0.03	0.03	48.4
	A	TIB	1.0	2.5	4.5	7.5	13.1	33.7	131.7	237.2	342.7	1.00
		CV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49.4
	Ac	TIB	1.0	2.4	4.2	7.0	11.9	27.0	109.3	211.1	312.8	0.57
		CV	0.02	0.03	0.04	0.05	0.06	0.11	0.10	0.07	0.06	47.9

Table 3 The Summary of the result(K=100,a=0.0007,EIi=1)

Implications

The implications drawn from this tentative analysis are as the following.

(1) The gap of the information base restricts the information generation: the more the skewness, the lesser the generation. The structure with high CV and Max.(the upper row figure) shows the trend. The trend is independent of the rule. Rule A tends to increase the gap among the members for most of the structures. The larger gap means that the members alienated from the communication are delayed to accumulate their information base to reduce the generation efficiency. We might conclude that as the largest information base holders increase their shares of the information base,the system's total information base decreases. If the power originates from the information gap, the structures or the rules which bring up the information gap would be desirable. Therefore, if we want to implementing something by the power, such structures or rules would be suitable. The structures such as W,Wc, H,MH and rule A are among them. On the other hand, if we want to generate more information to stimulate creation or good idea generation , the opposite rules such as rules B and C or the structures like C,A,Cc and Ac might be needed. The rules might offset the characters of the structures somewhat.

(2) The structures with many members who have only one channel are sensitive to the rules: The information gap of the

and A generate the same amount of information under any of the rules. If we assume the communication between adjacent members only,the structures with each member's having the equal number of channels achieve the same amount of information base. Such structures have strong and stable information generation properties free from the communication rules or behaviors.

(3) The structures that are liable to form the order of monotonically and significantly decreasing information bases from the largest information base holders to the end members are sensitive to the change of rules: L structure increase its total information base dramatically by switching of the rule from A to B. On the other hand Cc structure decreases it by the switch from A to B remarkably. But Ac structure that looks like Cc doesn't so much. The point is that L structure changes the distribution of the information base of the order into an uniform one by adopting the rule of diminishing the gap. It means that rule B (also rule C) destroys the order. Cc structure tends to form the order by adopting rule B which is going to alienate the farest members. Under rule A, the larg-information base members who play the role of a linkage with the other circle are oriented to communicate with the counterpart of the other circle to make it possible for the farest members to form a cicle of communication with adjacent members

It makes them to accumulate their information bases and reduces the gap or destroys the order. In the structure of Ac, the largest information holders who link with the other all channel have channels with all members of their own all channel. Therefore even under the rule of B as the members who are not the linking ones have all equal positions to communicate with the linking members, they don't form the order. It reduces the unfavorable effects which might be brought up by switching A to B.

The implications above might be a part of the whole possible implications that can be derived from the result of the analysis. The inqury into the rest must be our future assignment.

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