7

A MONTE CARLO APPROACH TO DIFFUSION

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The nebula-like cluster is a common trait in the spatial picture of man's attributes. Take any atlas showing economic or cultural elements and you will find an endless sequence of spatial distributions which have a concentrated core surrounded by a border zone of outward-decreasing density.

There is nothing such as one single and simple explanation of the "nebula-distribution." But nevertheless, one particular process which creates this type of distribution—temporarily or as an end result—seems to be highly significant: diffusion of techniques and ideas through the network of social contacts.

The Neighborhood Effect

On the empirical level, the author has tried to get hold of the spatial aspects of diffusion by seeking out different kinds of innovations which for some reason have been recorded over a period of time from the very moment when the new item was first introduced.

The ideal case for analysis is one in which every adopter as well as nonadopter of the spreading trait can be individually discerned. This is possible in the literal sense only in microscale. As an example, a very small area (depicted in Fig. 1*a–b*) is chosen, and the introduction of two different farm techniques is followed over five years.

In the first case, the item is a subsidy which the government from 1928 and onward granted the farmers of small units (less than twenty acres of tilled land, forest not taken into account) for fencing in and improving new pasture acreage at the edge of their woodland. The purpose was to persuade the farmers to give up their time-honored habit [of] graz[ing] . . . cattle in the open forest during the summer season, a practice which caused severe damage to the young trees. A more efficient grazing could also help to increase milk production, which was much needed on such small units. The aid given consisted of a sum of money presented without other provisos than that the

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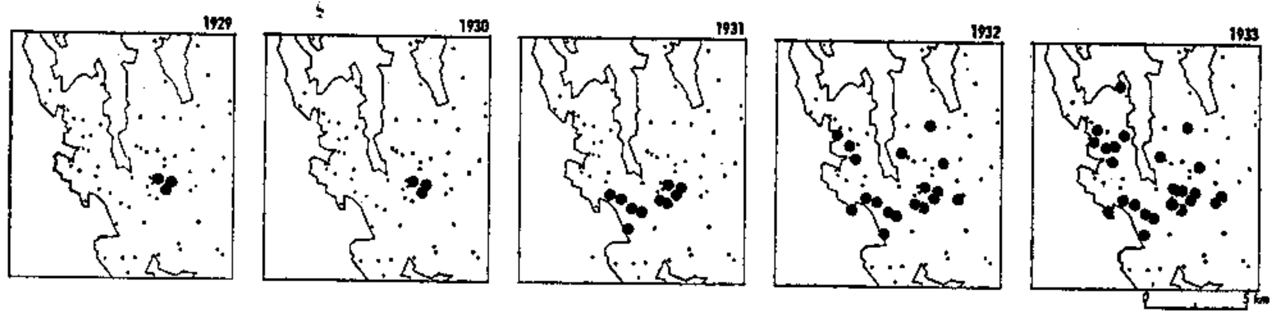

FIGURE 1A. *Spread of subsidy for improved pasture on small farms.* Small points: potential adopters. Black dots: adopters.

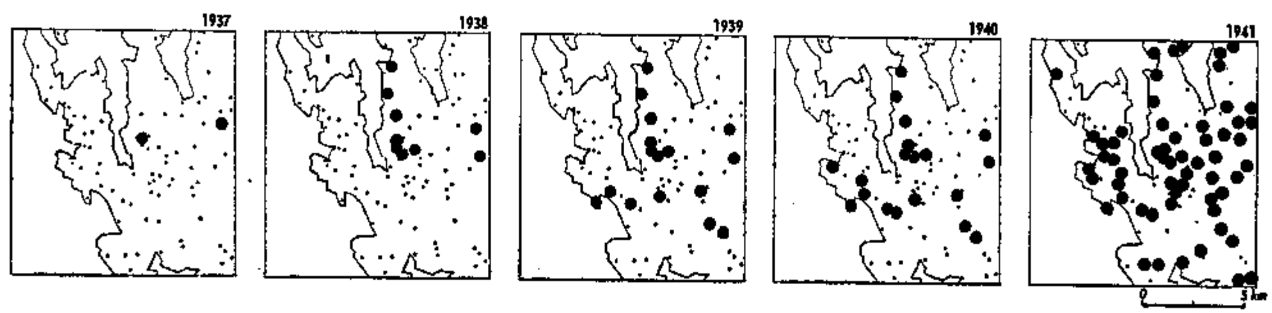

FIGURE 1B. *Spread of systematic control of bovine tuberculosis.* Small points: potential adopters. Black dots: adopters.

measures had to be taken within a certain . . . time. Incidentally, this innovation has up to now caused marked changes in the visual rural landscape in parts of Sweden.

In Fig. *1a*, small points indicate farms entitled to get a subsidy if asked for. A black circle represents a farm which has received the subsidy after request.

In 1929, three farms forming a cluster had adopted the new government-aided practice. No followers appeared during the next year, but in 1931 a new cluster was added immediately to the west of the first one. In 1932, further adopters came forth immediately to the north of the existing group. Next year, again we find additional ones in radial directions.

The second series of maps (Fig. 1*b*) show for the same area how another new farm technique was introduced a few years later. The item is the systematic control of cattle for detecting bovine tuberculosis. Also, this innovation was subsidized inasmuch as the government paid for the first examination of the stock on the request of the owner, irrespective of the size of the farm. In this case, the small points are somewhat more in number, since all farms have to be considered as potential adopters of the innovation.

1937 saw two adopters in the area. These two gained, in 1938, followers in the immediate vicinity. In 1939, new clusters were added south and southwest for the core. In 1940, again only a few adopters appear, but this happens in close connection to the existing group. So in 1941 the entire area is explosively covered. If, however, we divide the year in[to] shorter periods, we will find that there is a spatial order also in this speedy development.

The two processes are similar as to the spatial course of events. Of particular interest are the reactions among the farmers on the longish, rather isolated peninsula in the western part of the area. There, in both cases, the innovations literally move step by step from south to north.

Ample material can be brought forward which shows that the demonstrated process is a typical one. A start is made by a rather concentrated cluster of adopters. This cluster expands step by step in such a way that the probability of new adoptions always seems to be higher among those who live near the earlier ones than among those who live further away. The potential adopters become "blackened" with a spatial continuity [reminiscent] of the development of a photographic plate seen under the microscope. A convenient term for the phenomenon could be borrowed from this physical process: "neighborhood effect."[1]

The neighborhood effect brings itself out not only on the grass-root level, as in the case of innovations among farmers, but in a hierarchy of scales. Examples can be given covering areas from regional up to continental size in which the same general trends repeat themselves time and again. Of course in each case "nearness" has to be interpreted in relation to the extent of the whole area under observation.

The Network of Social Communication

The spatial order in the adoption of innovations is very often so striking that it is tempting to try to produce theoretical models which simulate the process and eventually make certain predictions achievable. In the following, some experiments in this field will be demonstrated.[2]

It is self-evident that nobody can adopt an innovation without first having gained knowledge about its existence. (We do not consider the inventor's case.) This does not mean that information about a novelty immediately—or ever—causes the adoption of it. But nevertheless, information is so important that an understanding of the geographical structure of social communication is a prerequisite for diffusion models including the space aspect. Such understanding involves many things: the spatial range, the "fields of influence," of newspapers, radio and television broadcasts, books, ordinary talk, and observation. It is no wonder that George Kimble in his essay on the "Inadequacy of the Regional Concept" maintained that although ideas "can be a most potent force in shaping the geographical ensemble" they "cannot be measured or card-indexed or dissected." It is doubtful if the situation is as bad as that. In any case, does the neighborhood effect indicate that the importance of mass media should not be exaggerated. The situation is therefore simplified, insofar as we are left with mainly one means of communication to concentrate upon, namely, the direct—or, if you prefer, primitive—face-to-face communication between individuals.

The talking and listening individual is part of a huge, world-embracing network of links. A good many observations suggest that this network has a definite spatial structure which probably is rather stable, that is, the links connect different places with probabilities which presumably change only slowly and thus to some extent are predictible.

From daily experience we know that the links in the network of private communications must differ in spatial range between different socioeconomic groups. As a demonstration, and entirely arbitrar[il]y, we may consider three main groups operating in international, regional, and local range.

Some individuals are wholly bound to the local range, others operate in the regional and local range, and still others more or less in all three ranges. Those belonging to a wider range and at the same time having links in common with lower ones form the channels through which information disseminates between the levels.

In the following, attention is concentrated on the local level. To begin with, we are interested in face-to-face communication as a function of distance and as a function of geographical anisotropy. The sample region is a rural area in southern Sweden, . . . of which Fig. 1 covers only a small part.

In the sample region, two sets of data have been used as [an] indirect means of investigating face-to-face communication: (*a*) telephone traffic, (*b*) local migration.

TELEPHONE TRAFFIC

Our assumption is that telephone calls which are not commercial well reflect the structure of private communication links in general. The telephone is very common in the area. Data about telephone[s] were collected all through Sweden several times in recent decades. For six-days periods, the destination of every call from all local exchanges (having thirty to 100 subscribers) was recorded up to a thirty-mile distance. Also, long-range calls were recorded, but in less detail. The main weakness of this material for our purpose is that the number of calls between subscribers within exchange areas was not included in the census. This means that we can get no idea about conditions close to the origin (a one- or two-mile radius) for comparisons with calls directed out from the exchange area.

A typical six-day distribution of calls of a small farmers' village (Svenningeby, forty-one subscribers) is given below.

Distance km	*Outgoing calls*		*Incoming calls*	
	Abs.	Rel.	Abs.	Rel.
5–10	239	219,3	66	60,6
10–15	105	34,9	33	11,0
15–20	76	30,6	19	7,5
20–30	50	3,6	20	1,3
30–40	5	0,3	3	0,2
	475		141	

We notice that outgoing calls are far more frequent than incoming ones. From the spatial distribution, one can conclude that the former ones contain as an important part the farmers' ordering of services from central places in the area, whereas the latter ones better reflect scattered "fraternal" contacts.

The number of calls decreases rapidly—and in the outgoing case somewhat unevenly—with increasing distance. This effect is particularly strong when measured in relation to the increasing number of potential destinations as we proceed outward in the distance zones (relative figures in the table).

For the sample region taken as a whole, the relative frequency of calls decreases on the average very nearly with the square of the distance.

LOCAL MIGRATION[3]

Local migration was included after the following considerations. Movements between farms in a rural area occur in mainly three situations: marriage, exchange of farm laborers between farms, exchange of farms between farmers.

In all three cases, opportunities are evenly scattered in proportion to the distribution of farms and occur in an almost constant number from year to year, at least over short periods. All such movements have to be preceded by personal negotiating, which is believed to take place within the framework of already existing connections. Further, the one who moves tends to keep contacts back in the environment which he left. All in all, there is reason to believe that the distribution of local migrations as to distance well reflects characteristics of social contacts on the whole. Further evidence in this direction are certain striking similarities between deviations from the inverse distance rule in the migration data and in telephone-traffic destinations.

Local population movements from 1935 through 1939 *within* and *out from* a part of the sample area having about 1500 inhabitants distributed themselves in this way:

Distance km	*Moving units*[4]	*Units per sq km*
0,0–0,5	9	11,39
0,5–1,5	45	7,17
1,5–2,5	45	3,58
2,5–3,5	26	1,38
3,5–4,5	28	1,11
4,5–5,5	25	0,80
5,5–6,5	20	0,53
6,5–7,5	23	0,52
7,5–8,5	18	0,36
8,5–9,5	10	0,18
9,5–10,5	17	0,27
10,5–11,5	7	0,10
11,5–12,5	11	0,15
12,5–13,5	6	0,07
13,5–14,5	2	0,02
14,5–15,5	5	0,05

The gradient of local migration in relation distance is less steep than was the case of telephone traffic. One conceivable explanation may be that telephone traffic is influenced by the fact that the cost of calls increases by steps at fixed boundaries with increasing distance.

From observations of local telephone traffic and local migration, it seems permissible to conclude that the communication links of the average individual on the local level very rapidly decrease in number with increasing distance or, in the sample region, roughly with the square of the distance. This information will be used as input in our simulations of diffusion. Thus the communication matrix is not estimated from our observations of diffusion, but inferred from independent sources, a procedure which is looked upon as particularly important when it comes to comparisons between observations and simulations.

THE DIFFUSION MODEL I

We are going to simulate diffusion of an innovation within a population by the aid of the Monte Carlo technique. In this connection the Monte Carlo approach may be said to imply that a society of "robots" is created in which "life" goes on according to certain probability rules given from the start. The technique can best be described as a game of dice in which the gaming table represents a part of the earth's surface, the pieces represent individuals living in the area, and the rules of the game constitute the particular factors which we want to study in operation. The dice produces step by step new situations within the range of variation which is implicit in the rules. The dice is the motive power of life in the model.

In practice, the random element does not stem from a dice, but from tables of random numbers or from random numbers produced in an electronic computer.

We start on a gaming table or "model plane" which is supposed (*a*) to have an entirely even population distribution and (*b*) to be an ideal transportation surface.

This isotropic model plane is divided into square cells which are supposed to be inhabited by the same number of individuals, N, in each. Every individual is a potential adopter of the hypothetical innovation.

The new element is spreading from one single individual living at the center of the model plane. In this process, only face-to-face communication between pairs of individuals is considered. Newspapers, radio, television, books, public lectures, and demonstrations are nonexistent in the model situation.

The following rules are adopted as governing life in the model:

1. Only one person carries the item at the start
2. The item is adopted at once when heard of
3. Information is spread only by telling at pairwise meetings
4. The telling takes place only at certain times, with constant intervals (generation

intervals) when *every* adopter tells one other person, adopter or nonadopter

5. The probability of being paired with an adopter depends on the geographical distance between teller and receiver in a way determined by empirical estimate.

The second postulate is at . . . first glance rather unrealistic. It is, indeed, very improbable that people react without delay in that way. But still, it was considered important to start with this simple assumption in order to see how far it can be shown useful.

Also, the fourth postulate, assuming a constant interval of time between tellings, is unrealistic. It [would have] been closer to known facts to assume some kind of probability distribution over time. This makes it, however, considerably more difficult to work out the program, and very little is gained by such a complication at this stage.

According to postulate 4, the tellings of the first carrier, and later on the further tellings of the future adopters, have to be directed to definite receivers in the surroundings. Addresses to the receivers are provided by the aid of random numbers and a "target" with symmetrically arranged probabilities of hits, "the mean information field":

P_1	P_2	P_3	P_4	P_5
P_6	P_7	P_8	P_9	P_{10}
P_{11}	P_{12}	P_{13}		
	and	so	on	

where $P_{13} > P_8 > P_7 > P_3 > P_2 > P_1$ and $\sum P_1 = 1$.

The grid is floated over the model plane, so that the teller is every time located [in] cell number 13.

Individuals living in the same cell run the same risk of being hit.

To find an address is thus a two-step procedure. In the first step, a random number η from a rectangular distribution locates the cell i according to the rule

$$\sum_{r=1}^{i-1} P_r < \eta < \sum_{r=1}^{i} P_r$$

In the second step, a new random number from a rectangular distribution with the range 1 to N gives the receiver in the cell.[5] If he happens to be identical with the teller, a new address is sought instead.

Input Data I

It is now assumed that the cells on the model plane are 5×5 km and have $N = 30$ inhabitants.

The target is constructed from data of local migration, with P-values as below:

.0096	.0140	.0168	
	.0301	.0547	
		.4431	
	and	so	on
			Σ 1.0000

With a start in M 14, a typical run of the simulation comes out as in Fig. 2, where the distribution and number of adopters are given in successive generations (g_0 excluded).

In the first stages, the number of adopters forms a geometrical progression, each generation having twice the preceding number of adopters ($g_n = 2^n$). From g_5 and onward it more and more often happens that tellings become directed to individuals who are already adopters or that two or more tellings in the same generation converge on the same individual. This effect is of course implicit in assumptions 1–4, but comes earlier in the process and has definite spatial consequences because of the distance bias introduced in assumption 5. After some time, individuals in the central cells contribute less and less to further growth.

After a few generations, the distribution of adopters becomes rather irregular. The starting point does not coincide with the center of gravity. However, the neighborhood effect makes the distribution in g_n always strongly dependent on the situation in g_{n-1}. A secondary center, as that in Q 13–14 or in O 15, has its roots back at single jumps earlier. The distribution of the carriers in the very first generations creates the skeleton of the later morphology of the permeated region.

This simulation is of course possible to com-

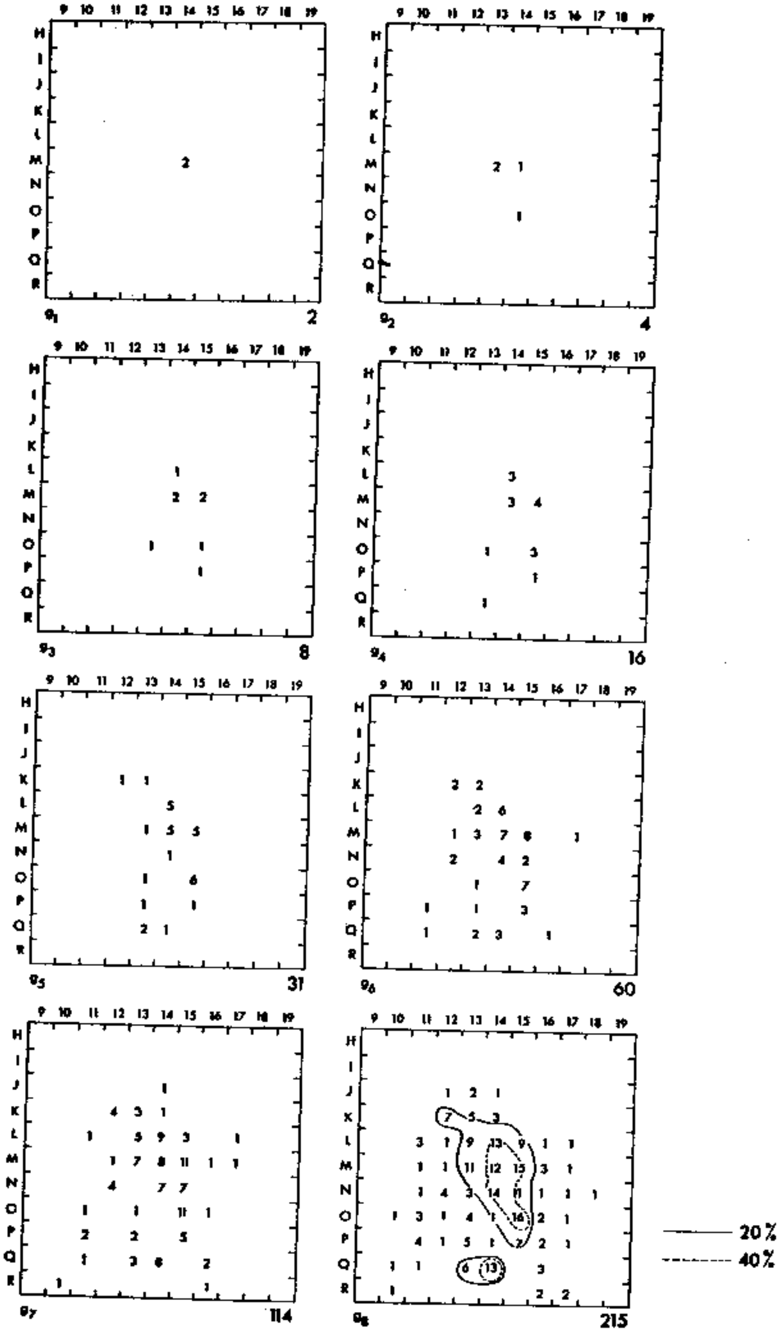

FIGURE 2. *Run of simulation under isotropic conditions.* (Even distribution of potential adopters and no barriers to communication.) For g_5 isolines indicate relation between adopters and potential adopters.

pare with empirical data only in very general terms. It is too idealized. But more runs of this kind nevertheless have their importance, because they make it possible to study the variation of outcomes on an isotropic plane without distorting factors outside the fundamental set of postulates.

Let us now go back to empirical observations, namely, the introduction of the subsidized pasture land of which Fig. 1*a* showed only a minor part. Figure 3 exhibits what happened in the entire sample region. The square cells indicated at the edges of every map are 5 × 5 km. The figures give the absolute number of farms where the innovation had been adopted from 1929 through 1932. In the last graph is also indicated the percentage of adopters in relation to all farms entitled to receive the subsidy.

Earlier [it] was said that as a rule it is unrealistic to assume that people are willing to adopt an innovation immediately after having received information about its existence, as was assumed in our battery of postulates. But if we ever can come close to the realization of such a postulate, it is likely to be in connection with government subsidies given to farmers. It is difficult to conceive of a situation provoking a lower resistance to a new idea.

If fact, there are some rather striking similarities between the simulation and the empirical data. In spite of the fact that farmers entitled to the subsidy are very evenly scattered over the area, the development of the new item was not at all even. We find a distinct difference between the western and the eastern parts of the region. And it seems not to be too much to say that the morphology of the distribution in 1932 can in outline be discerned already [in] 1929, a relationship through time of a kind which was evident in our simulation. Superficially seen at least, the actual growth process is similar to what was demonstrated in the run of our model. We find an outward spread from a few centers rather than an even and simultaneous condensation over the whole area. One or a few adoptions in an earlier, empty area may later on give rise to a secondary core.

So it seems to be worthwhile to take a further step and try to work on a model plane which is not isotropic, but has some of the irregularities of the actual sample region, in particular (*a*) unevenly distributed population and (*b*) barriers to communication.

INPUT DATA II

We are now going over to a more complicated application, which is supposed to approach actual conditions closer. The model plane was this time given the same shape as in Fig. 3. N was distributed according to the actual number of farmers entitled to subsidies in our sample region. In order to handle the boundary conditions properly, the model plane was further enlarged with two rows of cells all around, every cell having its full number of farms. This made it possible for the item to spread outside the sample region and then jump back again, something which certainly might happen in an actual case.

The target is supposed to be the same as in I. But this time N varies irregularly from cell to cell. Before deciding a new address, we therefore have to observe how the population is distributed in the surrounding[s], and then adjust our probabilities so that cells with many inhabitants get a better chance to become chosen as addresses than cells with few inhabitants. This was carried through in the following way:

The probability Q_i of a hit in cell i with population N_i is obtained from

$$Q_i = \frac{P_i N_i}{\sum_{i=1}^{25} P_i N_i}$$

If η is the random number from a rectangular distribution, the hit is located [in] cell i according to the rule.

$$\sum_{r=1}^{i-1} Q_r < \eta < \sum_{r=1}^{i} Q_r$$

A second random number from a rectangular distribution in the range 1 to N_i locates the receiver in the cell. If he happens to be identical with the teller, a new address is sampled instead.

The uneven population distribution is not the only deviation from isotropic conditions. In the actual geographical region, the road net is rather unevenly developed as well. Long lakes, fens, and deep forests separate the settle-

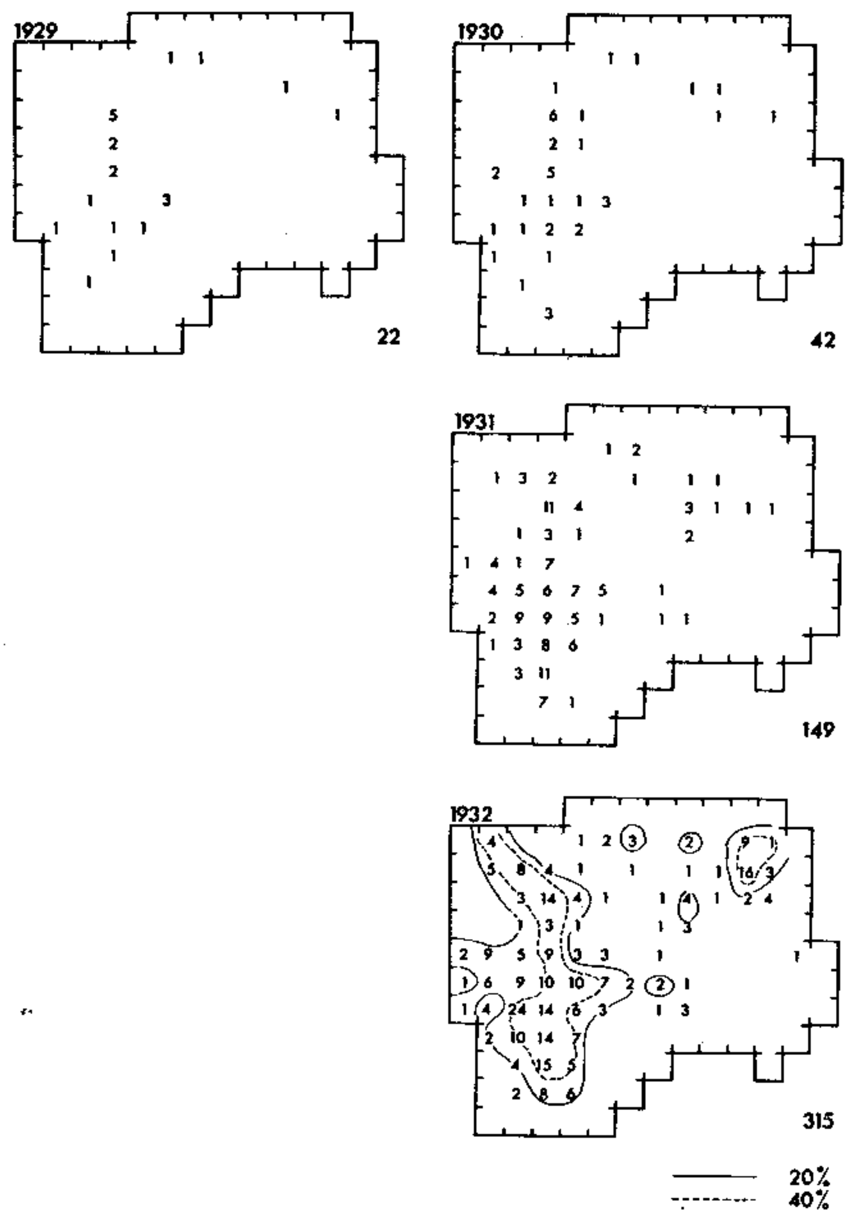

FIGURE 3. *Observed spread of subsidy for improved pasture on small farms.* Cells are 5 × 5 km in size. Figs. give the absolute number of adopters from the start up to the end of given years. Potential adopters have an approximately uniform distribution over the area. For 1932 isolines indicate relation between adopters and potential adopters.

ment groups. Some of these obstacles are likely to strongly affect communication habits. In order to disclose such irregularities, an analysis of telephone traffic between neighboring settlements as represented by exchange stations was carried through. It was found that the number of calls now exceeded and now fell below what could be expected, taking only geometrical distance into account. Of course considerable random fluctuations occur in a one-week sample, but the largest deviations must be highly significant, as they were consistent with the pattern of roads and physical obstacles.

Of particular interest now are the various zones and boundaries which form barriers to communication. Some of the long lakes seem to form absolutely deadening barriers. In other cases, contacts are only reduced in number. These irregularities have been incorporated with the model plane in a very simplified fashion as two types of barriers: zero contact and half contact (full and dotted lines, respectively in Fig. 4, upper left graph). It was necessary to locate these barriers between cells, even if sometimes a division of cells had been closer to observations.

Whenever an address was directed over a zero barrier, the telling was cancelled. When the address line passed a weaker barrier, it was on the average cancelled every second time by the aid of a new random number. Two weak barriers in combination were considered equal to one zero barrier. Also, a few other similar conditions had to be incorporated.

This device of course makes people near the barriers in the model less influential, gives them fewer contacts in the long run, than is the case in the center of an area open to communication in all directions. In the lack of empirical evidence, this assumption seems at least reasonable. An alternative—and less probable—course [would have] been to give them compensation in the direction away from the barrier.

Point 1 in the postulates of the initial model is not valid this time. Not one, single individual is chosen as the input situation, but twenty-two having the same distribution as the actual adopters in 1929.[6]

A stochastic process of this sort never repeats itself. A good many runs would be necessary to get a full idea of the distribution of different outcomes. Only three have been performed so far, as every run proved to be rather time-consuming.

In the three runs, the following development took place:

	Ser. 1	*Ser. 2*	*Ser. 3*	*Observations*
Input g_0	22	22	22	22 (1929)
g_1	38	36	42	42 (1930)
g_2	69	63	74	
g_3	115	108	128	149 (1931)
g_4	199	179	209	
g_5	318	294	322	315 (1932)

The three simulations follow each other quite well, and it is possible to find corresponding numbers in the actual growth process. The trouble is of course that there is no independent means available to compare the time scales. There is no reason to demand that the generations as defined here should coincide with even years.

Now the vital point is how . . . stages with corresponding sum total of adopters in the simulations and in the observed case show a similar areal distribution.

By mere inspection of Figs. 3–6, we can find that this is the case to a reasonable extent (cf. isolines in the end stages). There are obvious differences between each run and the given data, but there are also similar differences between the separate runs, something which is implicit in the stochastic nature of the model. But still, the similarities are such that it seems not to be entirely out of place to look upon the actual diffusion as just another of the possible realizations of our game.

Comparisons Between Simulation and Empirical Data

Because of the variable number of potential adopters in the cells, a direct comparison between absolute figures is not very useful. If the figures are converted to percentages, we get a more smooth picture, as illustrated by the isolines. Percentages also have disadvantages, owing to the small base in most cells.

The statistical distribution of the full set of percentages is given in Fig. 7, which is intended to provide a synoptical idea of the growth

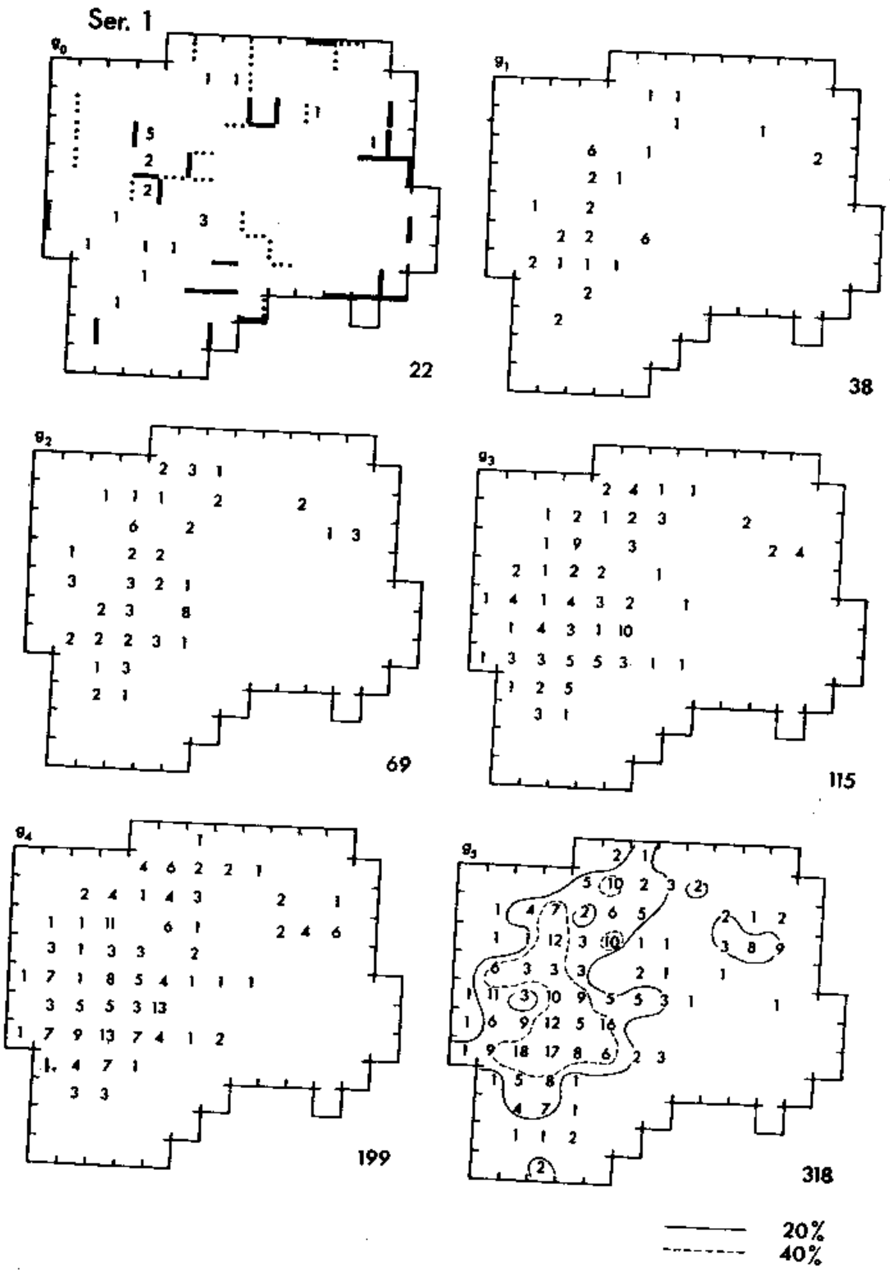

FIGURE 4. *First run of simulation under anisotropic conditions.* (Potential adopters and barriers to communication as in actual area.) Full line: no telling is allowed to pass. Dotted line: tellings reduced by factor two on the average. g_0 equals 1929 in the observed case (cf. Fig. 3).

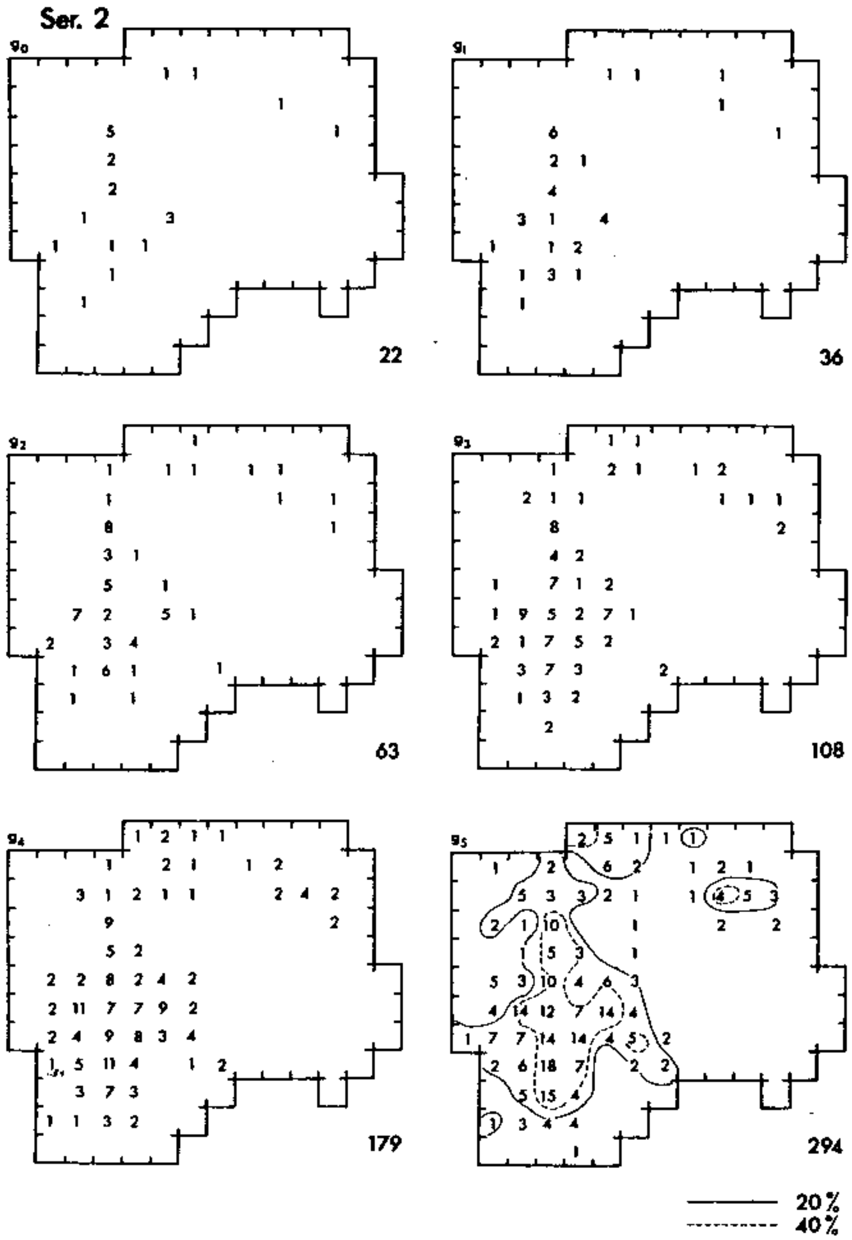

FIGURE 5. *Second run of simulation*

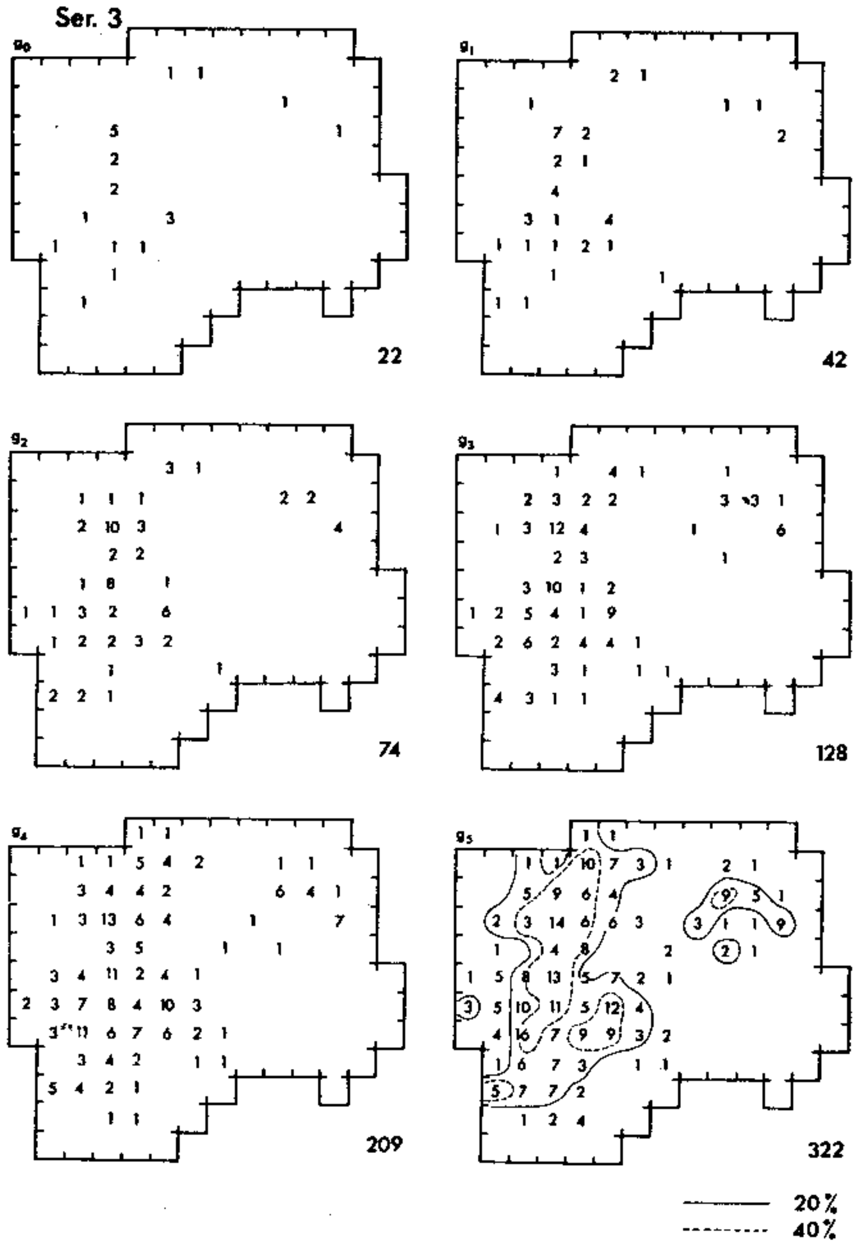

FIGURE 6. *Third run of simulation*

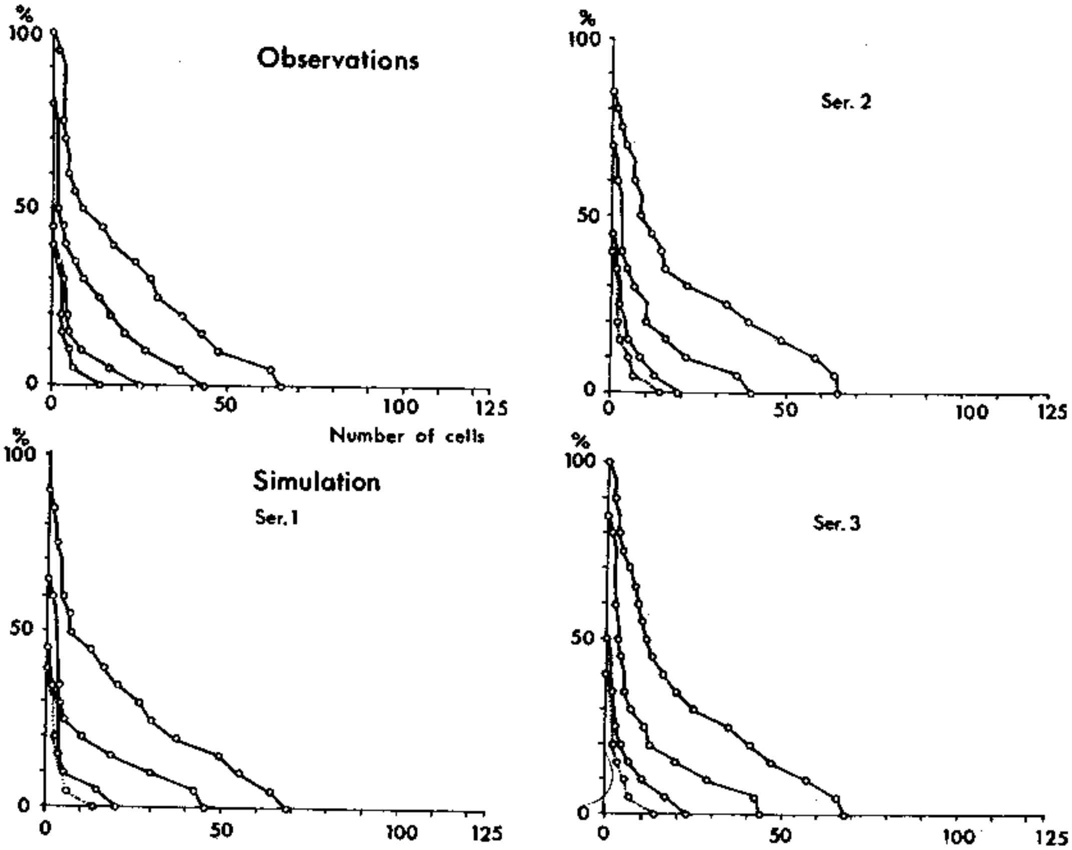

FIGURE 7. *Observations and simulations compared*. Curves show number of cells which have reached above a certain percentage of adoptions at comparable stages of observations and simulations. The initial situation—short left curve in each graph—is everywhere the same as it represents input values.

process in reality and in corresponding stages of the simulations. The horizontal axis represents percentages of adopters in relation to potential ones. The curves show year by year—or, in the case of simulations, generation by generation—in a cumulative way how many cells which have reached above a certain percentage of adoptions. Thus, for example, in 1932 (upper left graph, outer curve), sixty-five cells were above zero per cent, thirty-seven cells above 20 per cent, seventeen cells above 40 per cent, and one cell had reached 100 per cent.

The short and steep curve in the left corner is in all cases the same, and depicts the input situation as given by the data from 1929.

The course of the growth is in all four cases of a similar kind. The number of empty cells diminishes with an equal pace, and the curves have successively about the same slopes. Seen in this perspective, the simulation repeats quite well the history of the given case.

There is, however, also another point of view, namely, that of spatial patterns. The number of runs performed so far is by no means sufficient to give a full idea of the geographical distribution of different outcomes following a certain input situation. This being the case, it is for the moment hardly of most importance to compare individual figures in detail cell by cell, but rather to consider the overall pattern of spatial arrangements, in the data and simulations. The problem is essentially one of growth and form. In this realm, appropriate measurement techniques are sadly neglected.

An attempt will be made here to compare only the given situation of 1932 and the corresponding end stages of simulations. The statistical surfaces provided by the percentages are cut into pieces level for level, and the location of these levels is compared graphically.

Figure 8 shows the result. Four levels have been separated: empty cells (*o*), cells in the intervals 1–20 per cent, 21–40 per cent, and 41 per cent.

The top level is, with a few scattered exceptions, well concentrated to a narrow, north-south band in the western part of the sample region. Also, the zero-level stands out in a uniform manner as a concentration to the southwest corner, from which a ring extends along the edges of the region. The intermediate levels form two diffuse rings around the top level. In addition, there is a beginning of a secondary core in [the] northeast, mainly belonging to these two levels.

In the table below, the number of cells on every level is compared, and, further, the pairwise coincidences of corresponding levels [have been] counted cellwise.

The number of cells on every level varies to about the same extent between data and simulations as between the different simulations reciprocally. The coincidence of levels measured in cell units is above the zero level, somewhat less between data and simulations than between the pairwise compared simulations. This fact is also visually suggested by Fig. 8. The intermediate levels in the simulations show a clearer ring structure than corresponding observed levels.

The conclusion is that the simulations probably exhibit a more smooth picture than the given data. This is of course not unexpected. The actual case must include also other factors than pure face-to-face communications. And even these must be rather crudely depicted in the simulations, since the mean information field only in a very generalized way can approach the actual network of social contacts in the area.

But apart from minor details, it has been made reasonable to look upon the considerable difference in interest displayed for the innovation between eastern and western parts of the sample region as a function of diffusion through the network of private communication. Normally, geographers would be inclined to look for physical or economic background factors. It seems as if we have to include the possibility of spatial arrangements which owe their location and form to a rather randomly located initial stage which could as well have been found elsewhere.

Level	*Number of cells*		*Coincidences*
	Actual	*Sim. ser. 1*	
0%	60	57	46
1–20	28	31	11
21–40	20	21	6
41–	17	16	5
			68
	Actual	*Sim. ser. 2*	
0%	60	60	43
1–20	28	26	8
21–40	20	25	6
41–	17	14	8
			65
	Actual	*Sim. ser. 3*	
0%	60	57	43
1–20	28	27	7
21–40	20	25	4
41–	17	16	5
			59
	Sim. ser. 1	*Ser. 2*	
0%	57	60	44
1–20	31	26	10
21–40	21	25	7
41–	16	14	7
			68
	Sim. ser. 1	*Ser. 3*	
0%	57	57	46
1–20	31	27	15
21–40	21	25	10
41–	16	16	9
			80
	Sim. ser. 2	*Ser. 3*	
0%	60	57	45
1–20	26	27	12
21–40	25	25	10
41–	14	16	6
			73

Concluding Remarks

The model used so far is structurally a very simple one and has to be looked upon as a mere beginning. The present author has worked out a more complicated, and probably more lifelike, version which contains an element of resistance to change which seems to have

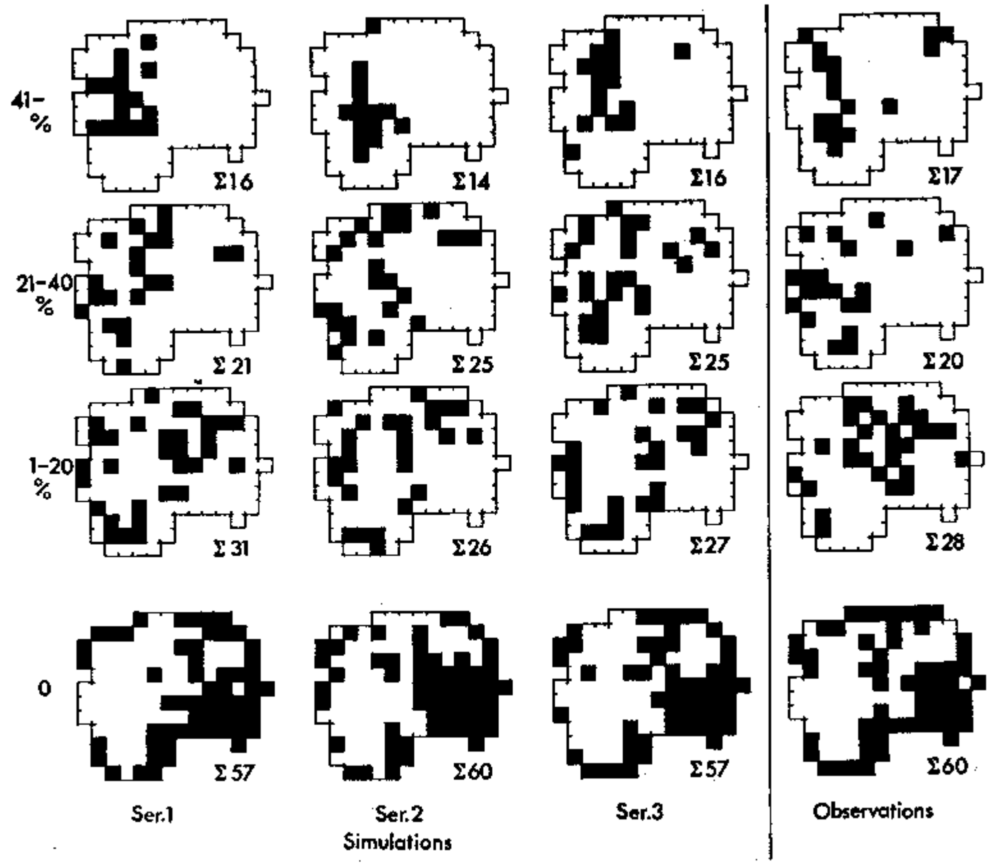

FIGURE 8. *Percentages of adoptions at the end-stages of simulations and observations split into levels as indicated at left*

important spatial consequences. So far this version has been tried only on an isotropic plane corresponding to Fig. 2. To bring this simulation over to an isotropic plane would call for a memory capacity of the computer which has not as yet been available.

The resistance implies that several tellings are required before adoption takes place. The resistance factor can in various ways be varied between individuals and between regions. Generally speaking, the resistance factor leads to a slower development over time, but also to a spatial concentration. The more spread out, erratic tellings have little chance to cause adoptions.

A further version under work in which the Monte Carlo approach may be the only practicable one is the very important case when competing tellings operate in the same area outgoing from different centers.

None of the cases mentioned have been carried through to a stage which allows comparisons with empirical observations along the lines discussed in this paper.

FOOTNOTES

[1] The phenomenon as such has of course been noticed many times. In American writings, reference should be made to J. Pemberton, "The Spatial Order of Culture Diffusion," *Sociology and Social Research*, **22** (1936), and E. C. McVoy, "Patterns of Diffusion in the United States," *American Sociological Review*, **5** (1940), 219–227.

[2] A full treatment is found in T. Hägerstrand, *Innovationsförloppet ur korologisk synpunkt* (Lund, 1953). Cf. also T. Hägerstrand, "Quantitative Tech-

niques for Analysis of the Spread of Information and Technology," in C. A. Anderson and M. J. Bowman, eds., *Education and Economic Development* (Chicago: Aldine Publishing Company, 1965).

[3] In Sweden, migration is recorded in full detail. It is possible from the population registers to follow each individual from dwelling to dwelling all his life. The data go back about 200 years.

[4] Single individuals or family groups.

[5] Several other routines for finding a receiver are conceivable. In the first instance, a system of concentric circles seems to be nearest at hand. In practice, however, the square cells are easier to handle, and this is particularly so when we are going to apply the model on unevenly distributed populations, as demonstrated later.

[6] The runs were performed on the electronic computer SMIL of Lund, and I am indebted to Prof. C.-E. Fröberg for taking care of the machine program. The random numbers were produced by a built-in routine.