Types of Diffusion In geographic writing diffusion has two distinct meanings. *Expansion diffusion* is the process by which information, materials, and so on, spread from one place to another. In this expansion process the things being diffused remain, and often intensify, in the originating region; that is, new areas are added between two time periods (time t_1 and time t_2 are both located in a way that alters the spatial pattern as a whole). [See Figure 13-2(a).] A typical example would be the diffusion of an improved crop, such as the IR-8 strain of hybrid rice, described earlier in our discussion of the Green Revolution in Chapter 9 (Section 9.3).

Relocation diffusion is a similar process of spatial spread, but the things being diffused leave the areas where they originated as they move to new areas. The movement of the black population of the United States to the northern cities from the rural South could be viewed as such a relocation process, where members of a population at time t_1 change their location between time t_1 and time t_2. [See Figure 13-2(b).] In a similar manner, an epidemic may pass from one population to the next. Figure 13-2(c) illustrates the two processes and shows how they can be combined. The El Tor outbreak is an example of diffusion by both processes. The strain diffuses by relocation through some areas (e.g., as it did in Spain, where small outbreaks were recorded in 1971), but it also diffuses by expansion because it remains endemic in the Celebes. In this chapter we are discussing interregional interaction and are therefore mainly concerned with expansion processes. Relocation diffusion is treated more extensively in the discussion of regional growth models in Chapter 21.

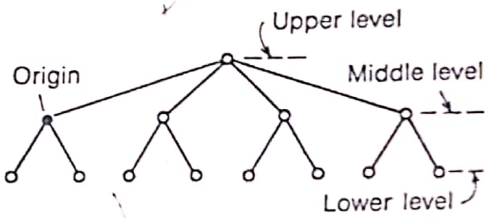
Expansion diffusion occurs in two ways. *Contagious diffusion* depends on direct contact. It is in this way that contagious diseases like measles pass through a population, from person to person. This process is strongly influenced by distance because nearby individuals or regions have a much greater probability of contact than remote individuals or regions. Therefore, contagious diffusion tends to spread in a rather centrifugal manner from the source region outward. This is clearly shown in Kniffen's study of the spread of the covered bridge over the American cultural landscape, described in Figure 11-11.

Hierarchic diffusion describes transmission through a regular sequence of orders, classes, or hierarchies. This process is typified by the diffusion of innovations (such as new styles in women's fashions or new consumer goods might think of this as a "Beatles pattern." A musical style beginning in a provincial city (Liverpool) moves to the national capital (London), then on to other capitals throughout the world. Finally, it reaches the local music store in small towns thousands of miles from its point of origin.

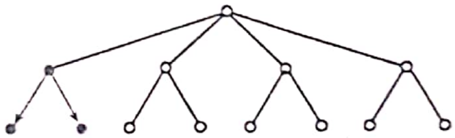
Michigan geographer John Kolars has traced the growth of the Sierra Club as a hierarchic diffusion process. The club was founded in 1892 in San Francisco and a separate chapter established in 1906 in Los Angeles. For the next quarter of a century growth was confined to California but a New York center was set up in the 1930s and one in Chicago in the 1950s. With the leap in interest in environmental protection in the last two decades, the Sierra Club has flourished. As we should expect from Figure 13-3(d), this has been accompanied by many new branches being set up in smaller cities. Around Chicago seven new chapters were set up between 1963 and 1973.

Diffusion Waves Much geographic interest in diffusion studies stems from the work of the Swedish geographer Torsten Hägerstrand and his colleagues at the University of Lund. (See Figure 13-4.) Hägerstrand's *Spatial Diffusion as an Innovation Process,* originally published in Sweden in 1953, was concerned with the spread of several agricultural innovations, such as bovine tuberculosis controls and subsidies for the improvement of grazing, in an area of central Sweden. This book was the precursor of various practical studies, particularly in the United States.

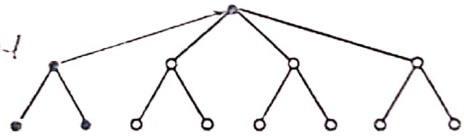
In one of his early studies of a contagious diffusion process, Hägerstrand suggested a four-stage model for the passage of what he terms "innovation waves" *(innovations-forloppet)*, but which are more generally called diffusion waves. From maps of the diffusion of various innovations in Sweden, ranging from bus routes to agricultural methods, Hägerstrand drew a series of cross-sections to show the wave form in profile. Here we discuss the wave in profile and then the wave in time and space.



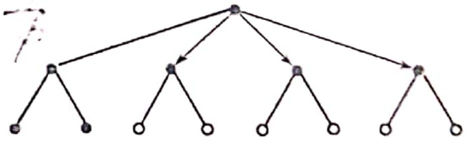
(a)



(b) Rapid downward spread from middle level



(c) Slow upward spread to upper level



(d) Rapid downward spread from upper level

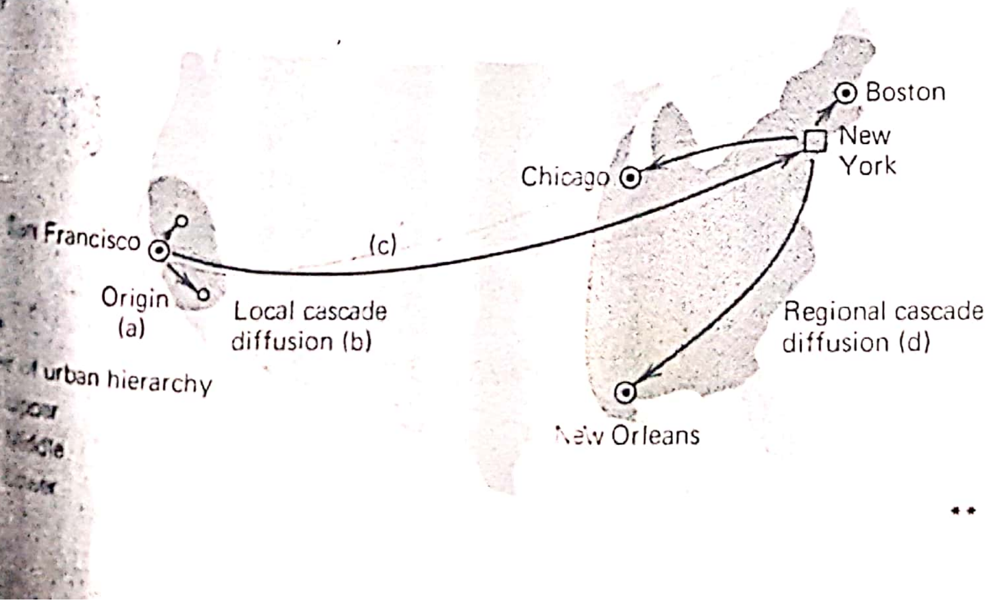
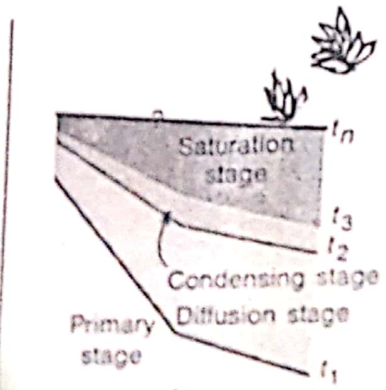


Figure 13-3. Hierarchic diffusion. These diagrams show the spread of an innovation through a hierarchy. The innovation begins on a middle level (e.g., a small county town) and spreads rapidly down to a lower level (e.g., villages in its vicinity) but more slowly to an upper level (e.g., a regional capital). Once there, its downward spread is again rapid. Downward spread through a hierarchy is termed *cascade* diffusion. The map (e) illustrates the spread process shown in (a) through (d) for a hypothetical diffusion beginning on the west coast.

Figure 13-4. Torsten Hägerstrand. Born in central Sweden in 1916, Hager-trand's doctoral work on spatial diffusion nodels provided a significant reinterpreta-ion of work on an area of long-standing eographic interest. Under his leadership, eographers at Lund Universtiy have onducted innovative work into a wide area f population geography, computer pplication, and—most recently—space-time udgets. He is currently professor of eography at Lund and vice-president of the nternational Geographical Union. [Photo by ony Philpott.]

igure 13-5. Diffusion waves profile. he graph shows four main stages in the pread of an innovation by diffusion. The *novation ratio* measures the proportion of population accepting the item.



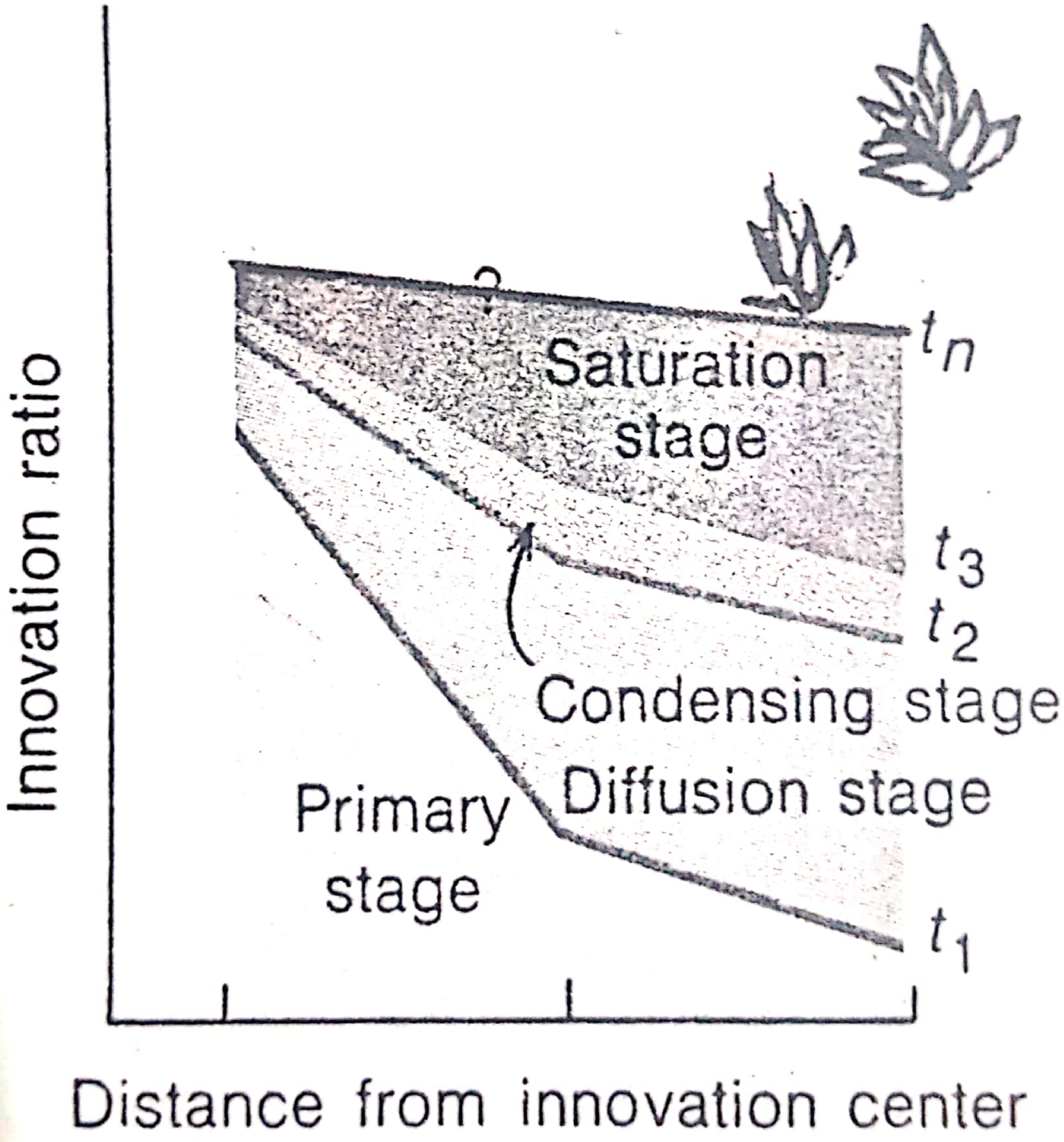
The Wave in Profile Diffusion profiles can be broken into four types, each of which describes a distinct stage in the passage of an innovation through an area. Consider Figure 13-5, which shows the relationship between the rate of acceptance of an innovation and the distance from the original center of innovation. The first stage, or *primary stage,* marks the beginning of the diffusion process. Centers of adoption are established, and there is a strong contrast between these centers of innovation and remote areas. The *diffusion stage* signals the start of the actual diffusion process; there is a powerful centrifugal effect shown by the creation of new, rapidly growing centers of innovation in distant areas and by a reduction in the strong regional contrast typical of the primary stage. In the *condensing stage* the relative increase in the number accepting an item is equal in all locations, regardless of their distance from the innovation center. The final, *saturation stage* is marked by a slowing and eventual cessation of the diffusion process. In this final stage the item being diffused has been accepted throughout the entire country so that there is very little regional variation.

Since Hägerstrand's original work, other Swedish geographers have carried out parallel studies to test the validity of this four-stage process. For instance Gunnar Tornqvist has traced the spread of televisions in Sweden by observing the growth of TV ownership from 1956 to 1965. Using information obtained from 4000 Swedish post office districts, he demonstrated that television was introduced into Sweden relatively late, yet within 9 years about 70 percent of the country's households had bought their first set. Tornqvist's results broadly confirm Hägerstrand's analysis. The diffusion process slows down thus indicating the beginning of the saturation phase, at the end of the study period.

The Wave in Time and Space More advanced work on the shape of diffusions in space and time has confirmed their essentially wavelike form. Figure 13-6 is based on American geographer Richard Morrill's work. By fitting generalized contour maps (called *trend* surface maps described on page 30 to the original Swedish data, he showed that a diffusion wave first has limited height (reflecting a limited rate of acceptance). It increases in both height and extent, and then decreases in height but increases further in total area. The gradual weakening of the wave over time and space is both time-dependent (as the simultaneous slackening of acceptance rates shows) and space-dependent (as the effect when the innovation wave enters inhospitable territory, strikes barriers, or mingles with competing innovation waves shows). The nature of the medium through which the wave is traveling may cause it to speed up or slow down, and a wave traveling from one center of innovation will lose its identity when it meets a wave coming from another direction.

The exact form of wave may be difficult to spot when diffusion data are plotted. There may be an apparently chaotic distribution of locations and dates. Geographers have experimented with mapping techniques designed

Figure 13-5. Diffusion waves profile. The graph shows four main stages in the spread of an innovation by diffusion. The *innovation ratio* measures the proportion of a population accepting the item.



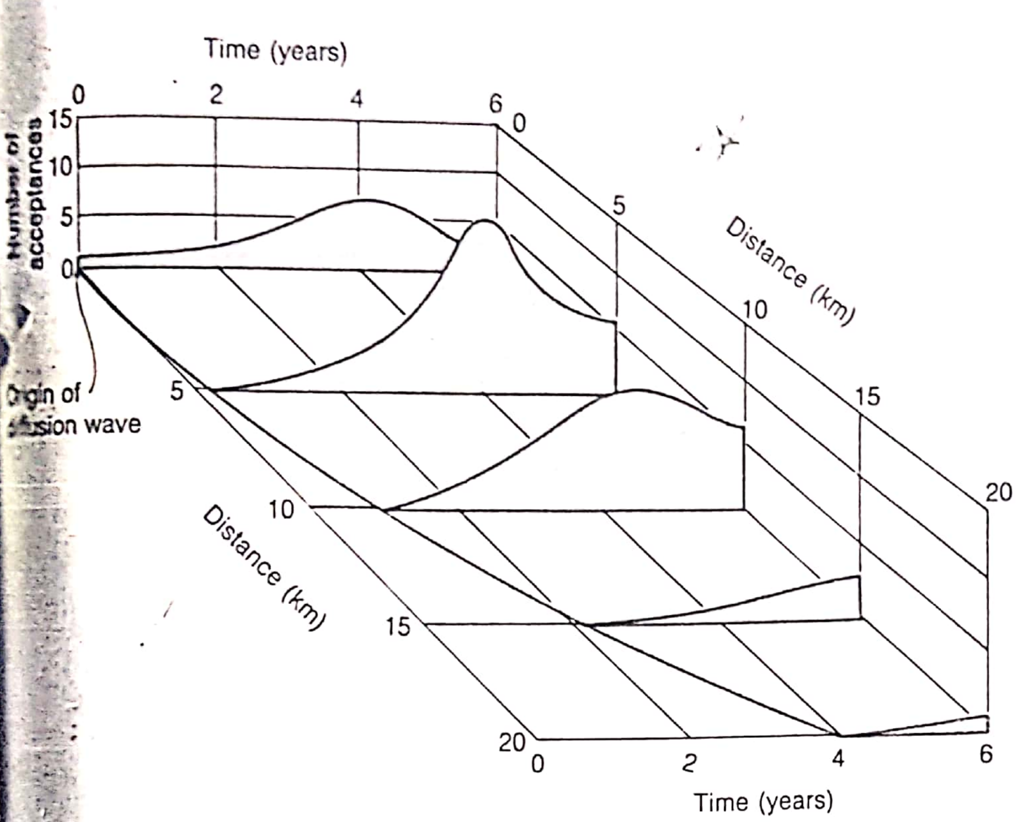


Figure 13-6. Diffusion waves in time and space.
Waves of innovation change character with distance from the time and point of origin. In the case shown the maximum height of the wave (i.e., the largest number of new acceptances of the item being diffused) occurs at a point 5 km from the time and origin in space and 4 years from the origin in time. Although individual waves will vary, some moving very slowly and some very rapidly, a large number appear to follow the general shape shown here. [After R. L. Morrill, *Economic Geography* **46** (1970), p. 265, Fig. 12.]

ter out local variations so that the main form of the waves can be observed. For example, the spread of agrarian riots in Czarist Russia from 1905 to 1910 has a very spotty pattern. Using maps to filter out irrelevant data, two broad centers of unrest emerge: the southeastern Ukraine and the Baltic provinces. The location of the two centers is related to a high level of local tension caused by extreme contrasts in prosperity, the size of farms, and conditions of tenancy. Outward diffusion from the two cave areas follows different patterns. As Figure 13-7 indicates, rioting spread more rapidly along the Baltic coast from the northern hearth, and in gentler, ripplelike movements from southern hearth. The intersection of waves from other centers may create plicated patterns and make data difficult to interpret.

TREND-SURFACE MAPS

Geographers use trend-surface maps as a device for separating *regional trends* (regular patterns extending over the whole area under study) from *local anomalies* (irregular or spotty variations from the general trend with no regular pattern). Thus trend-surface maps are like filters which cut out "short-wave" irregularities but allow "long-wave" regularities to pass through. Thus the contours in Figure 13-7 show the general form of the spread of riots in Russia but cut out confusing local variations.

13-2
The Basic Hägerstrand Model

m his empirical studies Hägerstrand went on to suggest how a general ational model of the process of diffusion could be built. We shall look at how the first and simplest of his models was constructed.

ct Fields If we take any of the examples of spatial diffusion in the past pages, we see that the probability that an innovation will spread is related tance. Distance can be measured in simple geographic terms, as when we re the number of meters between trees affected with Dutch elm disease d the campus. Alternatively, distance can be measured in terms of a

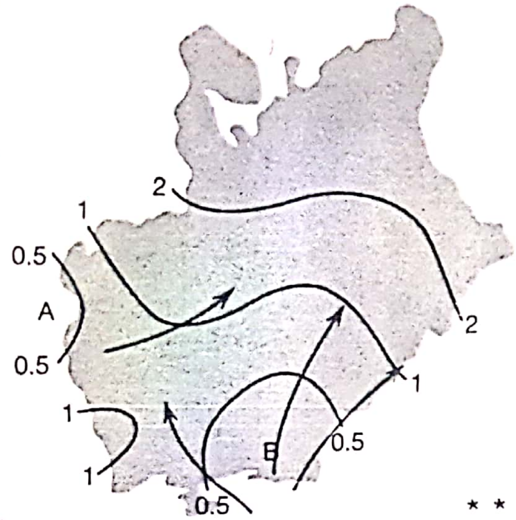


Figure 13-7. Multiple waves.
The arrows indicate the spread of agrarian riots in Russia from 1905 to 1907, an example of diffusion from multiple centers. This is termed *polynuclear* diffusion in contrast to *mononuclear* diffusion (where diffusion waves originate from a single source). [From K. R. Cox and G. Demko, *East Lakes Geography* **3** (1967), p. 11, Fig. 2. Reprinted with permission.]

hierarchy: E.g., the lower-level centers in Figure 13-3 are two "steps" aw from the upper-level center. Let us take the first method and use it to measu the spread of information through a human population.

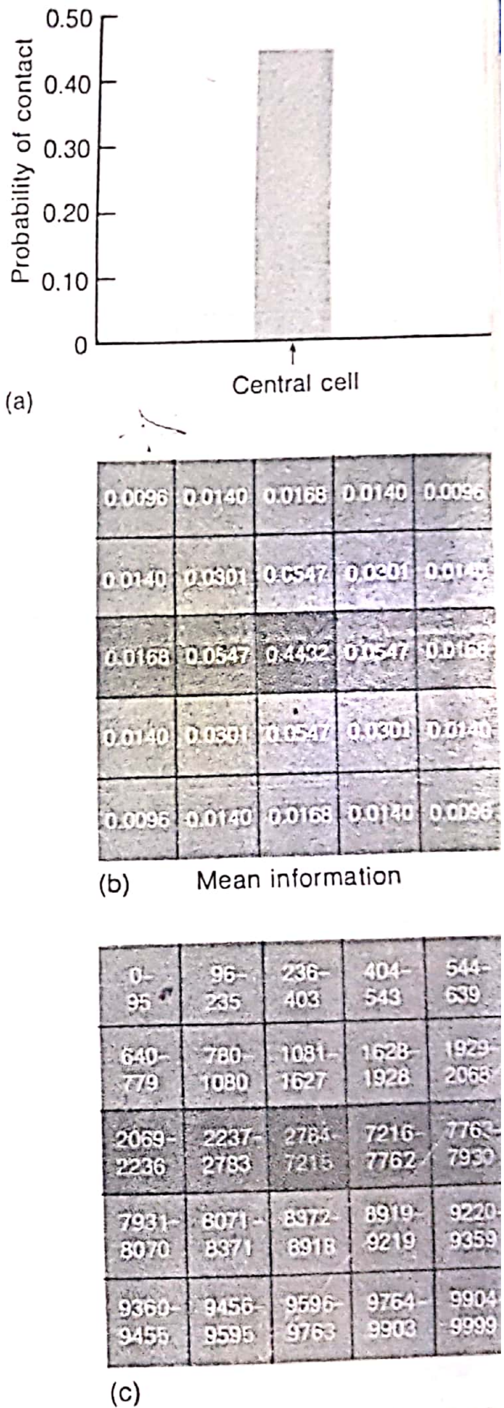
Let us begin by making the simple assumption that the probability o contact between any two people (or groups, or regions) will get weaker th farther apart they are. If we call one person the *sender*, we can say that th probability of any other person receiving a message from the sender is in versely proportional to the distance between them. Near the sender the probability of contact will be strong, but it will become progressively weak as the distance from the source increases. The exact form of this decline wit distance is difficult to judge, but the evidence on telephone calls indicat that it may be *exponential*. That is, it may fall off steeply at first but then ev more slowly. (Check back to Section 7-1, if you wish to refresh your memor on exponential curves.) Thus, we expect the volume of calls to fall off in th ratio 80, 40, 20, 10, 5, and so on with the first, second, third, fourth, fif kilometers. This is, of course, an idealized decline and actual patterns will b less regular. Geographers term this spatial pattern a *contact field*, drawn their language from the use of gravitational and magnetic "fields" in phys

In models of cascade diffusion we can retain the exponential contact fie but replace geographic distance with economic distance between cities in a urban hierarchy or with social distance in a social-class hierarchy. Distan may not be symmetric in the hierarchic cases; for example, population m gration up the hierarchy (from small to large towns) may be easier th migration down the hierarchy. [This implies that the socioeconomic distan between levels depends on the direction of movement.]

The contact fields in epidemics may be very complex. For instance, stud of measles indicate that the probabilities of contact (and thus infectio *within* a given group like a family or the students at an elementary school m be random. However, the probability of contact *between* such groups ma exponentially related to distance in the way we have already described. F example, research on southwest England showed that the probabilit measles outbreaks in an area immediately adjacent to an area that had alre reported cases was about 1 in 8. With further distance from the infected a the probabilities of infection fell steadily to about 1 in 30.

Mean Information Fields How can we translate the general idea of a co tact field into an operational model that can be used to predict future p terns of diffusion? Hägerstrand considered the problem in his early rese and he formulated various models to simulate diffusion processes. Fig 13-8 illustrates how he used probabilities of contact to determine a me *information field* (MIF), that is, an area, or "field," in which contacts c occur. Superimposing of the circular field shown in cross section in Fig 13-8(a), on a square grid of 25 cells, enabled him to assign each cell a p ability of being contacted. As Figure 13-8(b) indicates, the probabilit of contact for the central cells is very high, in fact, over 40 percent ($P = 0.4432$). For the corner cells at the greatest distance from the center, the probability of contact is less than 1 percent ($P = 0.0096$).

To make the grid operational we add together the probabilities assigned to the MIF cells. Thus, the upper left cell is assigned the first 96 digits within the range 0 to 95; the next cell in the top row has a higher probability of contact ($P = 0.0140$) and is assigned the next 140 digits within the range 96 to 235, and so on. Continuing the process gives the last cell the digits 9903–9999, to make a total of 10,000 for the complete MIF [Figure 13-8(c)]. As we shall see shortly, these numbers are important in "steering" messages through our simple distribution of population.



0.0096	0.0140	0.0168	0.0140	0.0096
0.0140	0.0301	0.0547	0.0301	0.0140
0.0168	0.0547	0.4432	0.0547	0.0168
0.0140	0.0301	0.0547	0.0301	0.0140
0.0096	0.0140	0.0168	0.0140	0.0096

(b) Mean information

0–95	96–235	236–403	404–543	544–639
640–779	780–1080	1081–1627	1628–1928	1929–2068
2069–2236	2237–2783	2784–7215	7216–7762	7763–7930
7931–8070	8071–8371	8372–8918	8919–9219	9220–9359
9360–9455	9456–9595	9596–9763	9764–9903	9904–9999

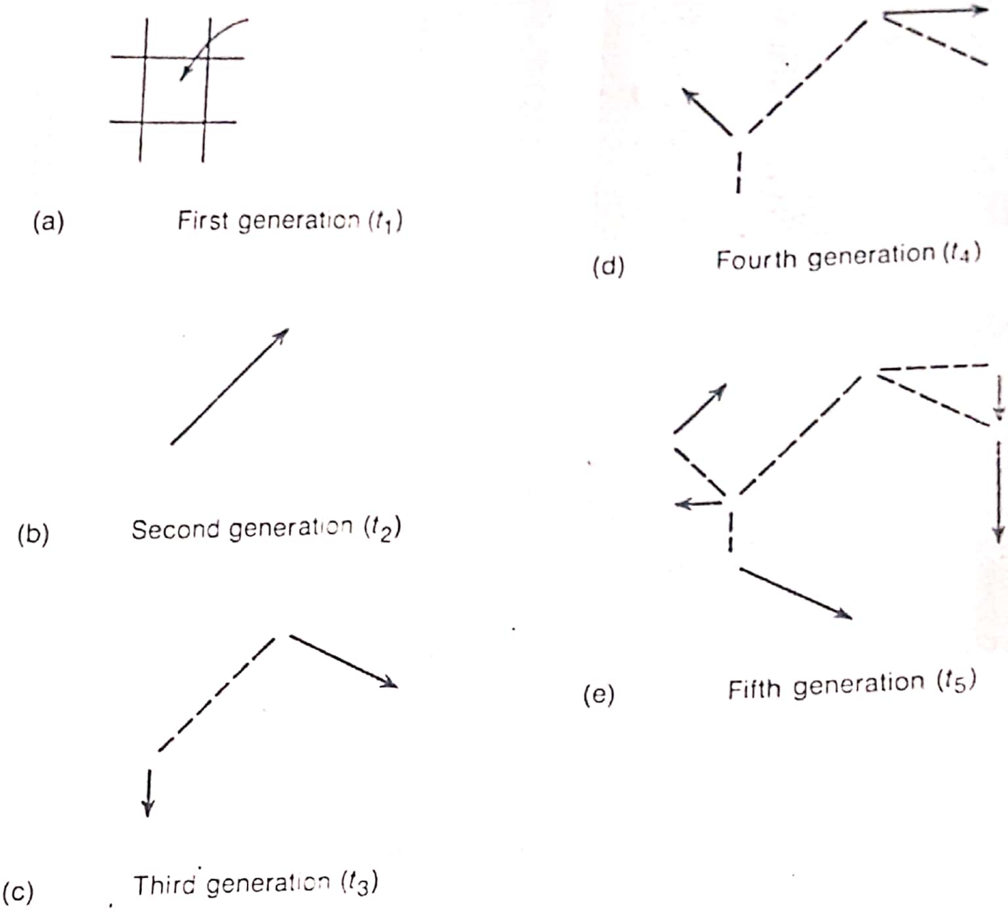
(c)

Figure 13-8. Mean information fields in the Hägerstrand model of diffusion. The probability of contact with distance (a) superimposed on a square 25-cell grid (b). The probabilities for all the cells in the grid are summed to give (c) a mean information field.

Rules of the Hägerstrand Model We can present the basic structure of the Hägerstrand simulation model in terms of formal rules. The rules given here refer only to the simplest version. They can be relaxed to allow modifications and improvements.

1. We assume that the area over which the diffusion takes place consists of a uniform plain divided into a regular set of cells with an even population distribution of one person per cell.
2. Time intervals are discrete units of equal duration (with the origin of the diffusion set at time t_0). Each interval is termed a generation.
3. Cells with a message (termed "sources" or "transmitters") are specified or "seeded" for time t_0. For instance, a single cell may be given the original message. This provides the starting conditions for the diffusion.
4. Source cells transmit information once in each discrete time period.
5. Transmission is by contact between two cells only; no general or mass media diffusion is considered.
6. The probability of other cells receiving the information from a source cell is related to the distance between them.
7. Adoption takes place after a single message has been received. A cell receives a message in time generation t_x from the source cells and, in line with rule 4, transmits the message from time t_{x+1} onward.
8. Messages received by cells that have already adopted the item are considered redundant and have no effect on the situation.
9. Messages received by cells outside the boundaries of the study area are considered lost and have no effect on the situation.
10. In each time interval a mean information field (MIF) is centered over each source cell in turn.
11. The location of a cell within the MIF to which a message will be transmitted by the source cell is determined randomly, or by chance.
12. Diffusion can be terminated at any stage. However, once each cell within the boundaries of the study area has received the message, there will be no further change in the situation and the diffusion process will be complete.

re 13-9. Simulated diffusion. opening stages of the Hägerstrand l are illustrated by a mean information The numbers refer to contacts mined by drawing random numbers. contacts are *internal* (i.e., with the cell ich the MIF is centered), a circle is in that cell.



(a) First generation (t_1)

(b) Second generation (t_2)

(c) Third generation (t_3)

(d) Fourth generation (t_4)

(e) Fifth generation (t_5)

Using the Model The key to putting this model into use is in rules 10 a 11. In each time interval the MIF is placed over *each* source cell so that t center cell of the grid corresponds with the source cell. A random num between 0000 and 9999 is drawn and used to direct the message, follow rules 4 to 6. *Random numbers* are sets of numbers drawn purely by "chan (e.g., by rolling a dice). They can be taken from published tables of rand numbers, or generated on a computer, or, for small problems, drawn fro hat. We show this process in Figure 13-9. In the first generation the num 0624 is drawn from a table of random numbers and a message is passed t cell that lies to the northeast of the original adopter, located in the sou cell.

Figure 13-9 goes on to present the first few stages in the diffusion proce each generation the MIF is recentered in turn over each cell that has message. Because the Hägerstrand model uses a random mechanism, ea experiment or trial produces a slightly different geographic pattern. If we thousands of such trials (using a computer), we would find that the sum of the different results matched the probability distribution in the original MI that is, we should arrive back at our starting distribution. In order to rea benefits of the model, it should be applied not to simple, predictable diffusions whose end result is known, but to complicated, unpredictable diffusions whose end result is in doubt.

13-3
Modifying The Hägerstrand Model

If we think about the rules of the basic Hägerstrand model, we can see that they represent a considerable simplification of reality. Areas where diffusions take place are not uniform plains with evenly spread populations; innovations are not adopted the instant a message about them is received; information is not passed solely by contacts between pairs of people; and so on. Hägerstrand was fully aware of these complications, and he used his basic model to provide a logical framework for more realistic versions of the diffusion process. Hägerstrand's later variants of his model contain significant modifications. Others have been added by American researchers.

Some of the modifications introduced into the original model are minor technical improvements in its structure. For instance, regular square cells can be reshaped to fit other regular divisions (hexagonal units have been adopted in some versions), but irregular areas present more of a problem. Adaptation of the contagious diffusion model to cascade processes involves substituting a hierarchy of settlements for an isotropic plain. Probabilities must be assigned to the links between the settlements rather than to cells.

Abandoning the Uniform Plain Some of the modifications can be simply made. Let us relax rule 1 and assume that the distribution of population is not uniform and that there are a variable number of people within each cell. The probability of contact is then a function both of the distance between the source and destination cells and of the number of people in each cell. Thus, we can multiply the population in each cell by its original contact probability to find a joint product. The ratio between the joint product of any cell and the sum of the joint products for all 25 cells in the MIF gives us a new contact probability based on both population and distance. (See the marginal discussion of weighting contact probabilities.) We have to buy this added realism at the cost of some tedious arithmetic, particularly because the new probabilities must be recomputed each time we move the MIF grid. On the other hand, such computations can be readily done by a computer.

Although this procedure may seem complicated, we are simply putting back into the model the geographic reality which the original assumption of a uniform plain took out. If we were concerned with understanding the spread of a cultural artifact (e.g., TV ownership) through a region, one of our first concerns would be the distribution of population and thus of potential purchasers for the product.

WEIGHTING CONTACT PROBABILITIES

If we assume that the probability of contact in a diffusion model is a function of both the distance between the source and destination cells and the number of people in each cell, then we can estimate that

$$C_i'' = \frac{C_i' N_i}{\sum_{i=1}^{25} C_i' N_i}$$

where C_i'' = the joint probability of contact with the ith cell based on the MIF and population,

C_i' = the original probability of contact with the ith cell based on the 25-cell MIF,

N_i = the number of people in the ith cell, and

$\sum_{i=1}^{25}$ = the summation of all $C'N$ values for the 25 cells within the MIF, including the ith cell.

These revised values for the probability of contact (C'') must be recomputed each time the MIF grid is moved to allow for spatial variations in the population.

Varying the Resistance to Innovations In discussing the impact of religious beliefs in Chapter 11 we noted their importance in insulating a group against change. One of the examples we used was the persistence of some sev teenth-century cultural traits in the present-day Amish communities in th United States. Can the model be adapted to incorporate factors of this kin

Well, it can be if we relax another of the original rules, in this case rule The statement that adoption of an item takes place as soon as a message received by the destination cell is an oversimplification. From research o agricultural innovations we know that there is generally a small group people who are "early innovators" and another small group of "laggards"; fr majority of a population adopts an innovation after the early innovators a before the laggards. In the case of spatial diffusions of population ove territory, this implies that settlements are established sporadically at fir The sporadic phase of settlement is followed by a period when everyone ge on the bandwagon, and eventually by a period of restricted settlement as th number of suitable unsettled locations in the territory diminishes. In the ca of spatial diffusions of an innovation throughout a population, there a regional variations in the time of acceptance of the new item or way of doi things. For example, Figure 13-10 shows extreme regional variations in th time of adoption of tuberculin-tested (TT) milk by farmers in the countie England and Wales. In some southern counties, 50 percent of the milk so off farms in 1950 was TT milk; the proportion of TT milk in the milk sold the far southwest had reached this level eight years before. Another examp of varying resistance to change is illustrated in Figure 13-11.

We can approximate the symmetric course of the diffusion process S-shaped curves. (See the discussion on p. 310 of innovations and logi curves.) Standardized *resistance curves* of this type were used by Hägerstr to take into account resistance to innovations. After one message, probability of acceptance was very low (0.0067); after two messages, it rose nearly one-third (0.300); and after three, to nearly three-quarters (0.7 From then on the rate of acceptance fell again. The probability of accept

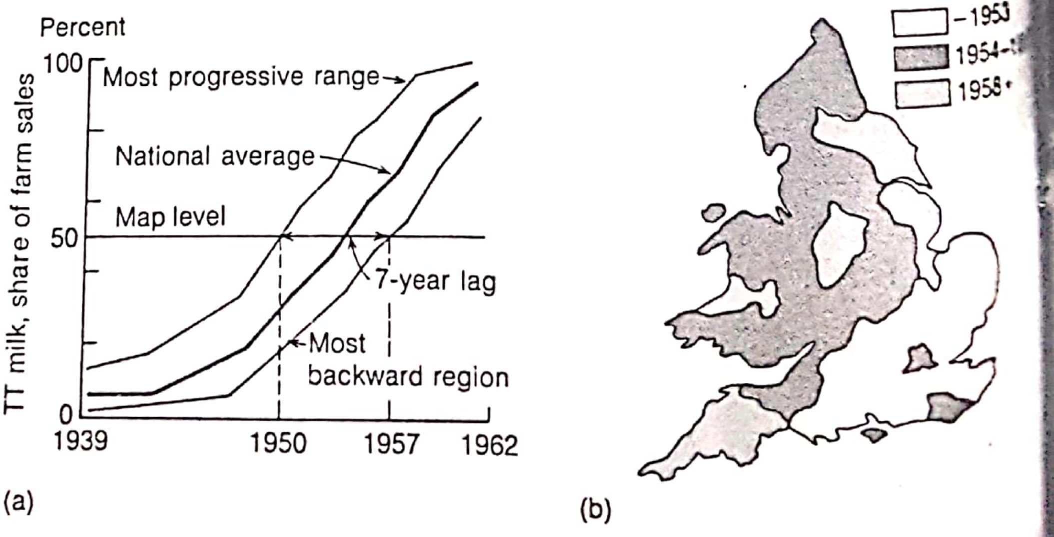
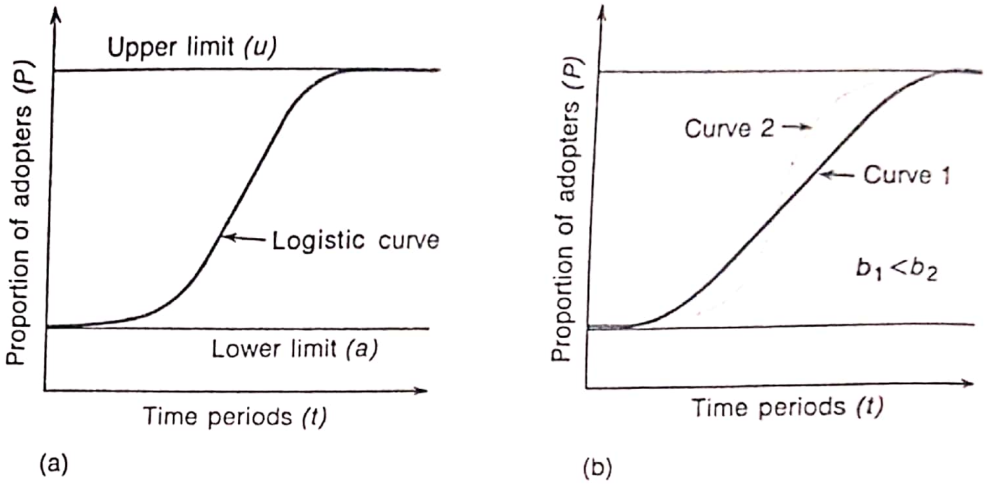


Figure 13-10. **Resistance to change.** Regional variations in adoption rates are illustrated by (a) the diffusion of tuberculin-tested (TT) milk on farms in England and Wales. The map (b) shows the year by which each county had achieved 50 percent TT milk production. [Data from Milk Marketing Board. After G. E. Jones, *f Agricultural Economics* **15** (1963), pp. 89–490, Figs. 6, 7A.]

ATIONS AND LOGISTIC VES



(a)

(b)

ne resistance of a population to adopting an innovation usually follows an S-shaped curve. [See diagram (a).]

This curve can be approximated by a *logistic distribution* given by the equation

$$P = \frac{u}{1 + e^{(a - bt)}}$$

where P = the proportion of the population adopting an innovation,

u = the upper limit of the proportion of adopters,

t = time,

a = the value of P when t is zero,

b = a constant determining the rate at which P increases with t, and

e = the base (2.718) of the natural system of logarithms

Thus, with u = 90 percent, a = 5.0, and b = 1.0, the proportion of adopters will be 4 percent at t = 2, 28 percent at t = 4, 66 percent at t = 6, 85 percent at t = 8, and so on. As diagram (b) shows, the constant b has a critical effect on the form of the innovation curve. Low b values describe smooth innovation curves (curve 1), whereas higher b values describe rates of acceptance that ha a slow-initial buildup, explode rap in a middle period, and enter a fin period of slow consolidation (curv [See P. R. Gould, *Spatial Diffusio* (American Association of Geographers, Commission on College Ge raphy, Resource Paper 4, Washing D.C., 1969).]

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resistant to change, like the Amish, we can increase the number of mess sent to any appropriate large number. (If a community were wholly resistan change, the number of messages needed would be infinite!)

Adding Boundaries and Barriers In the original model, messages mov outside the boundaries of the study area were considered lost and had effect on the situation (rule 9). In later models a boundary zone over hal width of the MIF grid was created so diffusion could proceed by way of th external source cells. More important modifications were involved in introduction of internal barriers that act as a drag on the diffusion pro Like the other modifications we have discussed, such barriers allow obs variations in both the natural environment and the cultural mosaic incorporated into the model.

At the University of Michigan, Richard Yuill programmed the H

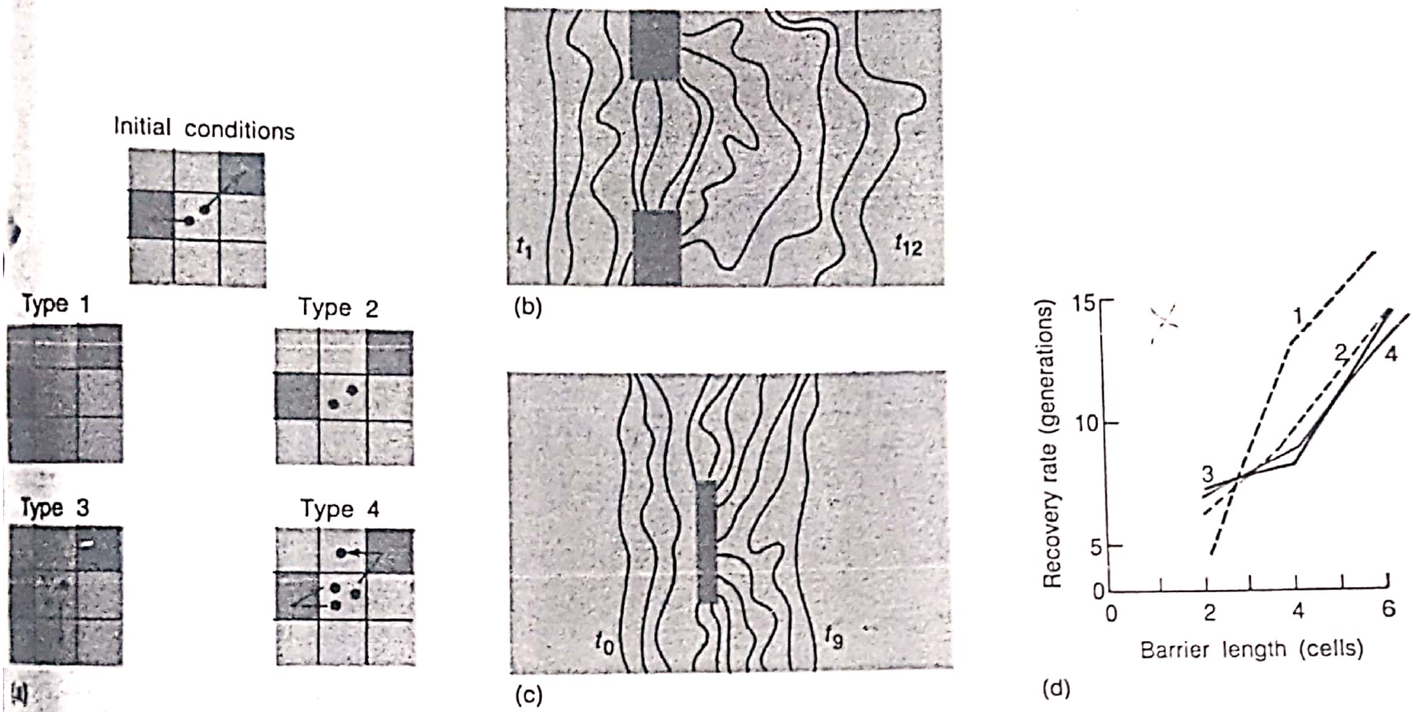


Figure 13-12. Barriers and diffusion waves.

Four types of barrier cells (a) are used in this simulation model. In (b) diffusion waves pass through an opening in a bar barrier. In (c) diffusion waves pass around a bar barrier. The graph (d) shows the recovery rates around bar barriers constructed from the four different types of barrier cells. "Recovery rate" is the time taken for the straight line of the diffusion wave front to re-form. [From R. S. Yuill, *Mich. Inst. Univ. Comm. Math. Geogr. Disc. Papers*, No. 5 (1965), pp. 19, 25, 29.]

trand model to stimulate the effect of four types of barriers on the diffusion of information through a matrix of 540 cells within a 9-cell MIF. Figure 13-12(a) shows the 9-cell grid with the barrier cells indicated. Four types of barrier cells that provide a decreasing amount of drag are considered: a *superabsorbing barrier* that absorbs the message but destroys the transmitters; an *absorbing barrier* that absorbs the message but does not affect the transmitters; a *reflecting barrier* that does not absorb the message but allows the transmitter to transmit a new message in the same time period (see the arrows in the figure); a *direct reflecting barrier* that does not absorb the message but deflects it to the available cell nearest to the transmitter.

Each situation was programmed separately and the results plotted. Figure 13-12(b) shows the advance of a linear diffusion wave through an opening in a barrier. The time taken for the original line of the wave to reform determines the *recovery rate.* Varying types of barriers and gaps of varying widths were investigated. In the example shown, the line of the wavefront has recovered by about the eleventh generation (time t_{11}). Another type of barrier is presented in Figure 13-12(c). Here the diffusion wave passes around the barrier and reforms after about nine generations. The recovery rate of a wavefront is directly related to both the type and the length of the barrier it encounters; the curve for a superabsorbing barrier is quite different from the curves for the other three types of barriers. [See Figure 13-12(c).]

Yuill's work expands and develops modifications already begun by Hägerstrand. The original model postulated what was, in effect, a row of absorb cells around the preiphery of the study area. The internal barriers in Häg strand's model were represented by the lines between the cells. Such barr could be adjusted to be absolutely effective (i.e., to allow no messages to g through) or 50 percent effective (i.e., to let one out of two messages cross th barrier). With such *permeable barriers* we can replicate a variety of envir ments. Thus, the original assumption of isotropic movement can be broug into line with known patterns. In other words, we can build *low-resistan corridors* into the model to allow faster diffusion in certain directions, a we can also build into the model *high-resistance buffers* to slow down dif sion across barriers.

To sum up, the basic Hägerstrand model can be easily modified to make fit more closely to the realities of the geographic world. To the changes population density and barriers discussed here, we can add such furth refinements as variations in the "infectiousness" of the element be diffused.

3-4
Regional Diffusion Studies

Many of the applications of Hägerstrand's model stem from his own pi neering work in Sweden. Here we review two of the applications of th model to regions with contrasting environmental conditions. We look first the spread of cultural attitudes (farmers' attitudes toward farm subsidie and then at the spread of a cultural group (the Polynesians).

Farm Subsidies in Central Sweden In the late 1920s the Swedish gove ment introduced a scheme to persuade farmers to forego their traditio practice of allowing cattle to graze the open woodlands in summer. Gra was proving to be a problem because it restricted the growth of young tre To encourage fencing and improvements in pastureland, the governme offered a subsidy. Figure 13-13 presents computer maps of the central part Sweden and indicates areas where farmers accepted the subsidy during th years 1930 to 1932.

The maps indicate that in 1930 a few farmers accepted the subsidy in th western part of the region but there were scarcely any takers in the east. Th next two years brought a rapid increase in the number of acceptors in the w but little change in the east. The sequence of maps suggests a spatial diffus process in which distance is an important factor. To stimulate this pro Hägerstrand built a model using the 1928–1929 distribution of adopters a starting point. The basic model was modified in two ways. First, the pote number of adopters (i.e., farmers) in each cell was added; second, barriers th were 100-percent and 50-percent permeable were added to simulate the b

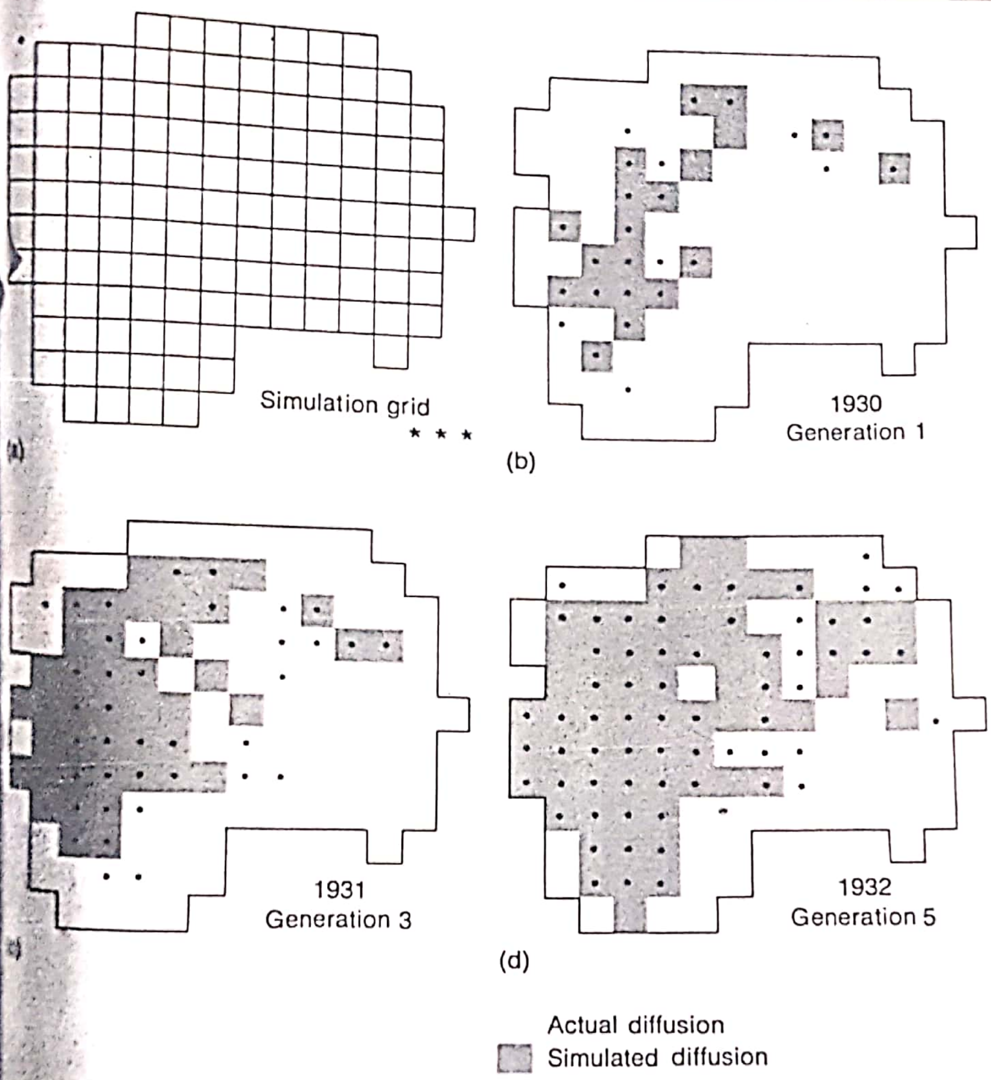


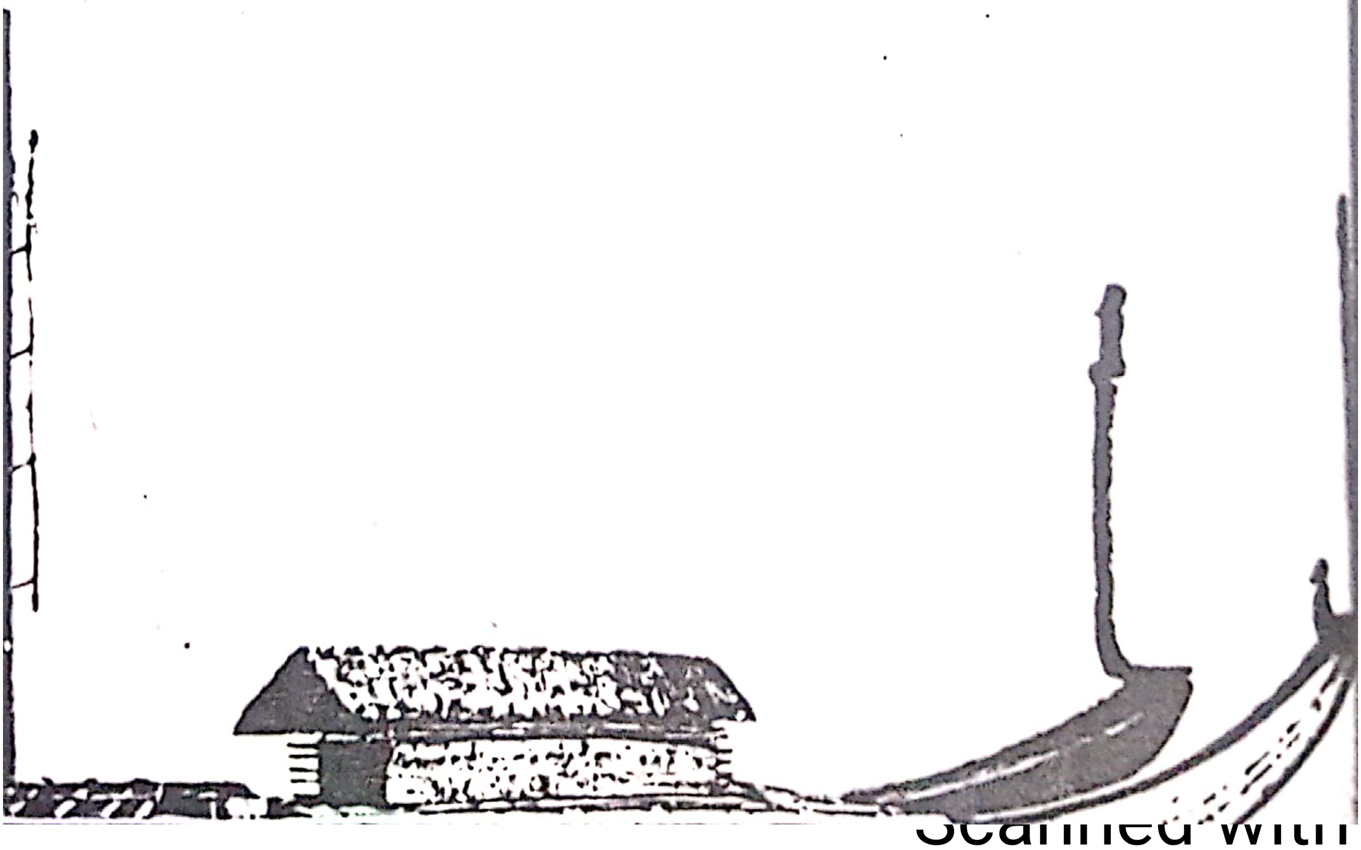
Figure 13-13. Simulating diffusion on a grid.
Here we see Hägerstrand's simulated diffusion and the actual diffusion of a decision by farmers in central Sweden to accept a farm subsidy. For simulation purposes the test area was approximated by a regular grid (a). The data for the three trial years shown in (b), (c), and (d) are part of more extended study. [After T. Hägerstrand, *Northw. Univ. Stud. Geogr.*, No. 13 (1967), pp. 17, 23, Figs. 6, 9.]

north-south lakes that lie across the region. Figure 13-13 compares the simulated diffusion process with the actual one. Because of the random element in the model, we should not expect the simulated pattern to match exactly the actual pattern. But the degree of matching is close, and both the general form of the expansion process and the location of the major clusters of adopters in the western areas are correct.

Kon-Tiki Voyages in the Pacific When Thor Heyerdahl undertook his now historic voyage on the raft *Kon-Tiki* from the coast of Peru to the Tuamotu Islands, he was carrying out a single experiment: He was testing whether it was possible to cross the Pacific in such a craft. To analyze thoroughly the possibilities of contact, between South America and different island groups by this means would require too many voyages to be feasible. When direct experiments prove too costly, too risky, or unlikely for other reasons, we ma be able to turn to computer simulation for answers to our questions. Fo example, nearly 30 years ago, in Project Manhattan (the name for the atomi bomb project), the atomic radiation from bombs was simulated mathematically. Heyerdahl's trans-Pacific migration exemplifies a spatial simulatio that can be approached by means of the Hägerstrand model.

The central issue to decide is how the Polynesians came to discover and settle on the islands of the central Pacific. This question has recently attracted considerable attention from anthropologists, navigators, and geographers; but the sparsity of evidence has led to a clash between two schools of thought. The first holds that the colonization process involved intentional two-way voyages and hence a high degree of navigational skill on the part of the Polynesians. (See Figure 13-14.) The alternative view was that colonization was largely accidental, by travelers drifting off course.

To test the probability of interisland contact as a result of accidenta drifting about, a group of investigators at London University (Levison, War



and Webb) constructed a computer simulation model of the drift process. The stages in their computer program are shown in Figure 13-15. There are four main elements in the model: (1) the relative probabilities of wind strength and direction for each month, and of current strength and direction for each 5° square of latitude and longitude in the Pacific Ocean study area; (2) the positions of all the islands and land masses in the study area, together with their sighting radius; (3) the estimated distances that would be covered by ships given various combinations of wind and current strength; and (4) the relative probabilities of survival of ships during certain periods at sea. Sighting radius (the distance out to sea from which islands can be seen) was built into the model on the assumption that, once land had been sighted, a landfall could be made. During each daily cycle voyages are started from given hearth areas like the coast of Peru, and a simulated course is followed until it ends in either a landfall or the death of the voyagers. By simulating hundreds of voyages from each starting point, we can map the relative probability of contact with different island groups as a potential contact field.

The simulation program has already been run for various Pacific Island groups and for locations on the coasts of South America and New Zealand. Preliminary results indicate that the probabilities on interisland links from the accidental drift of ships differ from one area to another. Wind and current patterns create environmental boundaries which make drifting in certain directions highly unlikely. Some of these boundaries coincide with long-standing anthropological breaks in the geographic pattern of ethnicity and culture like that separating the Micronesian people of the Gilbert Islands and the Polynesian inhabitants of the Ellice Islands. Other low probabilities of tact coincide with important linguistic boundaries.

The computer model for this research simulates activities that cannot be erved at first hand and are too complex to be simulated by manual ulations. It confirms that certain existing population distributions are ible purely as a result of voyagers drifting off course. However, there ain certain hard cases, notably the Hawaiian Islands, whose settlement remains a mystery.

We began this chapter with El Tor and skateboards and ended it with -*Tiki*. Between, we have seen how the general notions of spatial diffusion be simulated by probabilistic models—most of them developed from the of Swedish geographers. These models help to throw some light on the of diffusion by which past cultural changes have occurred. Modern communication media have made the power and significance of the of change we have studied immense. The TV antenna signifies the toward a global village where change no longer requires mass ments of people but spreads far more rapidly through the subtle osmosis ssages carried by the mass media. The long-term implications of the of innovation generated and reinforced by mass media for the persis- of the cultural variety of human beings on the planet Earth may be se.

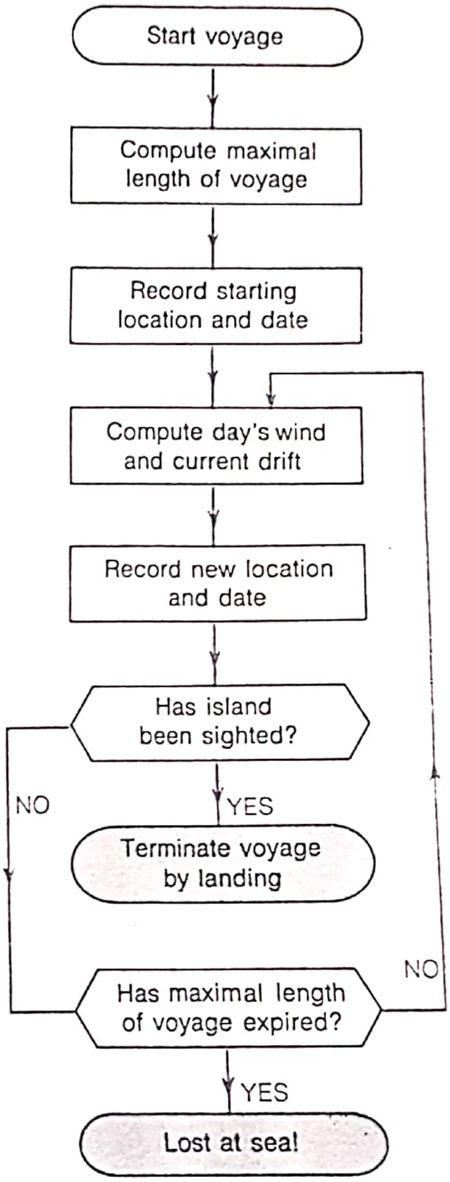


Figure 13-15. Polynesian voyaging. This flow chart shows the main elements in a computer program developed to simulate Pacific "drift" voyages. [After R. G. Ward, *et al.*, *Information Processing* **68** (1969), p. 1521, Fig. 1. Reproduced with permisision of North Holland Publ. Co., Amsterdam.]

Summary

1. The spread of culture between regions is studied by geographers as a diffusion process. Two types of diffusion are commonly recognized: contagious diffusion and hierarchial diffusion.

2. By studying a series of innovation profiles Hägerstrand developed the concept of innovation waves, each containing a primary stage, diffusion stage, condensing stage, and saturation stage. Fitting mathematical trend surfaces to diffusion data shows that they may be regarded as an innovation wave through time and over space. Mathematical smoothing of wave forms has enabled geographers to identify diffusion centers and repeating patterns.

3. Hägerstrand's simplest model for simulating spatial diffusion is one in which the probability of contact between two persons, one being a sender, declines with distance exponentially. In this model diffusion processes may be simulated by specifying the probability of contact by use of a mean information field (MIF) in which random numbers are used to direct messages. This basic simulation model assume standard but unreal conditions; real world condition require modifications to fit more complex variable Specific examples indicate that resistance to innova tion may be shown as an S-shaped resistance curv Such curves may be represented mathematically logistic curves.

4. Ways in which the basic Hägerstrand model may b relined are illustrated by the work of Yuill, who pr grammed four types of barriers to the diffusion information. These are: superabsorbing barriers, ab sorbing barriers, reflecting barriers, and direc reflecting barriers. Those which eventually allo passage of information through are termed perme ble barriers.

5. A number of empirical studies of regional diffusio in contrasting environmental situations indicate th utility of simulation models in studying cultur change. Typical of such studies is Levison, Ward an Webb's use of a modified Hägerstrand model to te alternative hypotheses about trans-Pacific migratio

Reflections

1. Gather data for your local area on (a) the location and (b) the date of foundation of any one sort of public institution (churches, banks, schools, colleges, and so on). Map the data and try to identify the kind of spatial diffusion processes that appear to be operating. Do contagious or hierarchic processes seem to be more important?

2. Imagine you are opening a new chain of motels or hamburger restaurants (e.g., Holiday Inns or McDonalds) in your state. Where would you try to locate the first five establishments? Why would you pick these locations? Compare your results with those of others in your class and identify any common locations you all wish (a) to adopt or (b) to avoid.

. List the factors which affect the spread of family-planning information in a developing country like India. How many of these factors could you incorporate into the Hägerstrand model innovation diffusion?

Check how information spreads in a small group by planting a rumor (e.g., that your instructor has just become the father of twins) with *one* other member of the class. At the beginning of the next class check (a) who now know from whom the information was obtained, and (c) wh the "telling" took place. Try to construct a tree like tha Figure 13-3, showing the way in which the rumor sp through the class.

5. Look carefully at the first four phases of Figure 13-9. W would the pattern of diffusion have looked like if the seven random numbers had been 1920, 8520, 156 3223, 5059, and 2483?

6. Trace the loops in the simplified flow chart of Poly voyages in Figure 13-15. How accurate is such a likely to be? How might this type of model be used to other cultural diffusion processes?

7. Review your understanding of the following concep
   - expansion diffusion
   - relocation diffusion
   - contagious diffusion
   - hierarchic diffusion
   - random numbers
   - adoption curves
   - innovation profiles
   - contact fields
   - mean information field
   - barrier effects
   - simulation models