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Urban evolution, self-organization, and decisionmaking

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Abstract. A dynamical model of a central place system is described which, derived from the concepts underlying dissipative structures, takes into account the self-organizing aspects of urban evolution, and shows the importance both of chance and of determinism in such systems. A theoretical evolution is discussed together with the modified dynamics of different possible decisions showing the long-term consequences of these. A recent application of this new theory to the evolution of the Bastogne region of Belgium is briefly described, and conclusions are drawn as to the real difficulties involved in decisionmaking on the part of national, regional, and municipal authorities.

1 Introduction

In several recent articles (Allen, 1978; Allen and Sanglier, 1978; 1979a; 1979b), the authors have outlined new aspects in the modelling of the evolution of a system of central places. These are based on the concepts, only recently elucidated, that underlie the evolution of 'dissipative structures' in the physical sciences. This offers a new perspective in which the interdependencies of the different variables of the system give rise to its 'self-organization', where structure and organization can be 'created' as well as destroyed as the system evolves (Nicolis and Prigogine, 1977).

The evolution of such a system involves both the determinism dictated by the equations of the 'model' relating the chosen variables and the 'chance' or 'indeterminacy' that accompanies moments of instability when structural changes may occur. The possibility is related to the fact that the solutions of the dynamical equations can undergo successive bifurcations, which give rise to several possible solutions describing the state of the system, and correspond perhaps to quite different organizations and structures (Prigogine et al, 1977). It is near to these bifurcations that the role played by the fluctuations present in the system is vital in choosing the 'branch' or 'type' of solution that will be adopted, and thus breaking the ambiguity which the equations of the model permit. These considerations are illustrated in figures 1 and 2, and it is seen that broadly speaking they introduce the concepts of 'memory' or 'history' into the 'explanation' of the state of a system, as well as an 'uncertainty' or 'choice' as to its future evolution which will involve further bifurcations, which may invalidate simple 'extrapolated' predictions.

The dynamical equations that are used in our study, express the behaviour of the 'actors' of our system, and the interdependence of these gives rise to a process of self-organization (Allen et al, 1979a), such that its structures, articulations, and hierarchies are the result not of the operation of some 'global agent' intent on optimizing some 'collective welfare function', but instead of changing patterns as successive instabilities occur at bifurcation points.

In the case of a system of central places (Christaller, 1954; Izard, 1956; Lösch, 1954) the structure which is observed over a long time will correspond to a stable pattern of coexisting centres. Thus our equations may perfectly well permit the coexistence of two similar centres side by side, but it may not correspond to a stable situation. In such a case then, a small difference in size at some time, perhaps of random origin, will be amplified by the nonlinearities of the interactions, and one of the centres will be eliminated. It should be noted here that the measure of 'explanation' accorded by our approach to the observation of a particular spatial organization, is not as 'strong' as the usual 'causal' explanations of classical physics, as the observed structure is merely one of the many 'possible' structures compatible with the equations of the model. It is through the action of elements not explicitly contained in the equations (fluctuations or historical 'accidents') that the choices are in fact made at the various bifurcation points that occur during the evolution of any particular system. Thus the spatial organization of a system does not result uniquely and necessarily from the 'economic and social laws' enshrined in the equations, but also represents a 'memory' of particular specific, deviations from these average behaviours.

This view of self-organization takes into account the 'collective' dimension of individual actions, and emphasizes that individuals acting according to their own particular criteria may find that the resulting evolution of the system may carry them in an entirely unexpected direction, involving perhaps qualitative changes in the state of the system. We are far from the 'invisible hand' of Adam Smith, and this results from the fact that for nonlinear systems, the 'whole' is not given trivially by the sum of the 'parts'.

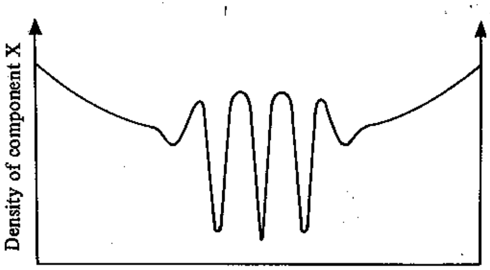


Figure 1. A dissipative structure. The case of a chemical dissipative structure is shown, where the reaction pattern undergoes a self-organization in which the stable structure is maintained by flows of the reacting components. Such a phenomenon can only arise in a nonlinear system maintained far from thermodynamic equilibrium.

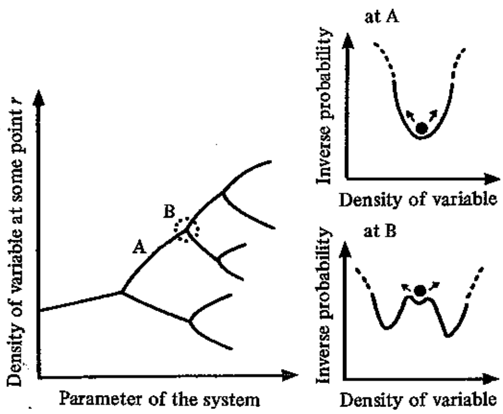


Figure 2. Chance and determinism in the evolution of a complex system. Far from a bifurcation point situation, such as at A, the system is deterministic in that fluctuations do not disturb the average trajectory. Near a bifurcation point, such as B, however, fluctuations are crucial in deciding the average trajectory, and hence chance plays a vital role.

2 The dynamics of central places

The basic variables of our model are the number of residents and the number of jobs in each locality, and the 'actors' of our system are individuals and employers, and the simple mechanisms we suppose can be summarized by saying that individuals tend to migrate under 'pressure' from the distribution of employment, and employers offer or take away jobs depending on the 'market available' taking into account the competition from other centres for the sale of a particular good or service.

The scheme of the interactions is shown in figure 3. The local population and potential employment capacity are linked through the 'urban multiplier'—a positive feedback. The concentration of employment offers 'externalities' and economies due to 'common infrastructure' which again gives rise to a positive feedback, whereas the competition for space between residents and entrepreneurs provides a negative feedback.

These basic mechanisms are expressed by two very simple equations describing the change of the population x_i, at the point i, and the evolution of the employment $\sum_k J_i^k$ offered at the point i.

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = bx_i\left(J_i^0 + \sum_k J_i^k - x_i\right) - mx_i + \tau\left[\sum_{j \neq i} x_j^2 \exp(-\beta d_{ij}) - x_i^2 \sum_j \exp(-\beta d_{ij})\right] \qquad (1)$$

which describes essentially a logistic growth of the population up to some limiting value which depends on the number of jobs that are offered at that point, J_i^k, for each level of activity k. The coefficients b and m take approximately into account the demographic change (birth rate and the death rate) as well as the mobility of the population in relocating residences under pressure from the distribution of available employment. The parameter J_i^0 corresponds to the basic 'carrying capacity' of the point i, derived from the basic sector of employment, and the terms J_i^k correspond to the jobs offered in successive levels of employment k, which may locate at the point i.

In addition to these terms, we have a term which expresses the competition for space which occurs as the number of residents at a particular point increases. This corresponds to the loop of negative feedback shown in figure 3.
Thus, in some sense the 'unpleasantness' of a point increases as the square of the population, and people who work at the point i choose to reside at the point j to an

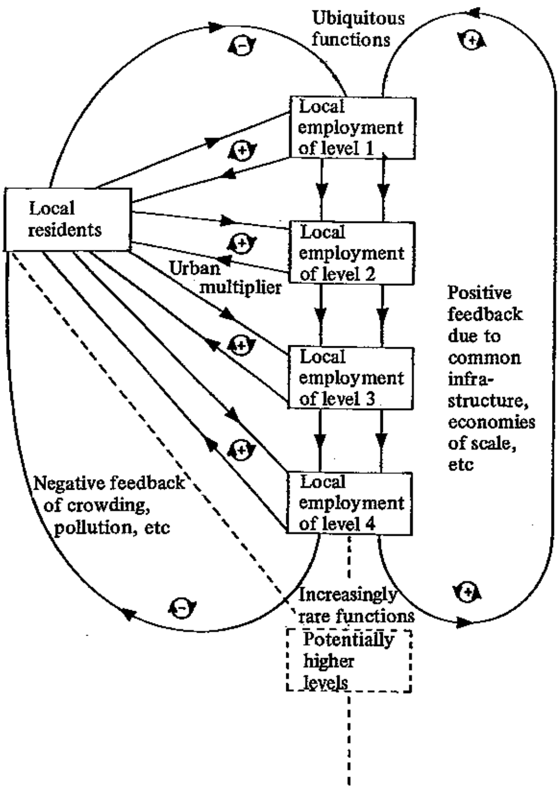


Figure 3. The simple interaction scheme making up our model of urban dynamics within a region. The signs indicate whether we have positive or negative feedback coming from a particular link.

extent depending on τ, measuring the size of the effect, and β which reflects the ease or difficulty of commuting a distance d_{ij}, and therefore changes with the availability of public transport, private cars, good roads, etc.

There is also a second equation describing the evolution of the distribution of employment in the system as entrepreneurs and decisionmakers expand or contract the supply of a good or service, k at i, in line with the perceived potential demand that will be directed towards the point i from clients at and around the point i.

$$\frac{\mathrm{d}J_i^k}{\mathrm{d}t} = \alpha J_i^k (M_i^k - J_i^k) , \tag{2}$$

where α is a measure of the rate at which entrepreneurs react to changes in the market for their goods. M_i^k is the employment that could be derived from the production of the good or service k at i, and is given by the number of jobs per unit of production, η_i^k, multiplied by the potential demand D_i^k, attracted to the centre i.

$$M_i^k = \eta_i^k D_i^k ,$$

where

$$D_i^k = \sum_j \frac{x_j \epsilon^k}{(P_i^k + \phi^k d_{ij})^e} \frac{A_{ij}^k}{\sum\limits_{i'} A_{i'j}^k} \tag{3}$$

where ϵ^k is the quantity of k demanded per individual at unit price, P_i^k is the price practised at i, ϕ^k the transportation cost or time per unit distance, d_{ij} the distance between the centre i and the client x_j, e is related to the elasticity of demand for k, and A_{ij}^k is the attractivity of the centre i as perceived by the clients located at j.

The precise form that we have used for A_{ij}^k is

$$A_{ij}^k = \left[\gamma - \frac{1}{\delta + \rho(x_i - x_i^{\mathrm{th}})}\right]^I \bigg/ (P_i^k + \phi^k d_{ij})^I .$$

This attractivity contains two basic terms. The denominator takes into account the fact that the attractivity of a given centre i, falls off with increasing price, P_i^k, and distance weighted by the costs of transportation. The numerator takes into account the fact that the attractivity of i for the function k increases with the intensity of activity at i, perhaps for reasons of greater choice, reduced costs, installed infrastructure, etc, but, of course, it eventually saturates at some upper level. The intensity of activity is supposed proportional to $x_i - x_i^{\mathrm{th}}$, that is the increase in population that occurs above x_i^{th} which is the threshold value at which the function appears at i. The parameters γ, δ, and ρ describe the manner in which this attractivity grows, and the upper level it attains.

The parameter I expresses the uniformity of response of the population to the different attractivities of centres, which is related both to the homogeneity of the population and also to the availability of information concerning the various factors which influence the choice. Thus if I is very large, it means that the least difference in the attractivities of centres as viewed by the x_j, will provoke a response where all the x_j are clients of the most attractive centre. A low value of I corresponds to a very weak perception and reaction to such differences.

It is important to see that the terms $A_{ij}^k / \sum\limits_{i'} A_{i'j}^k$ describe how the population distributed throughout the system is divided into the 'market areas' of the various centres offering the goods k. Clearly, summing over these different centres one obtains unity for a closed system (one could clearly put in the attractivity of external centres in the denominator and of external clients in the sum over j, changing the normalization). However, because of the term $1/(P_i^k + \phi^k d_{ij})^e$ which converts the number of clients into the quantity of goods flowing between i and j, by taking into account the distances involved, then one sees that the sum over the various centres i, offering the goods k will not be normalized and will depend on the particular distribution of centres. This gives a measure, in purely transportation terms, of the 'efficiency' of any particular structure of the central places in the region.

3 The simulations

We now turn to the evolution of the distribution of population and of economic activities for a region which was initially purely rural, with no substantial economic interactions between different localities.

Urbanization occurred progressively as three exporting economic activities were introduced into the region, activities of successively greater range and market threshold.

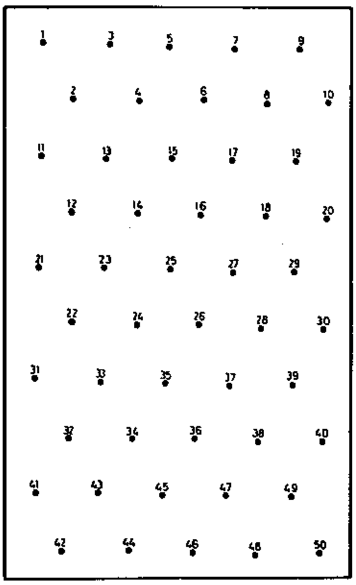
We performed our simulations on a triangular lattice numbered as in figure 4, and supposed for this particular study that the carrying capacity, or basic employment of each point was the same, which corresponded to the most general, or least particular, case.

The values chosen for the parameters were:

$b = 0{\cdot}003$,	$m = 0{\cdot}03$,	$\tau = 1$,	$\beta = 1{\cdot}5$,
$\alpha = 1$,	$P_i^k = 1$,	$\delta = 1$,	$\gamma = 1{\cdot}1$,
$\epsilon^1 = 0{\cdot}25$,	$\epsilon^2 = 0{\cdot}15$,	$\epsilon^3 = 0{\cdot}1$,	$\epsilon^4 = 0{\cdot}05$,
$\phi^1 = 1$,	$\phi^2 = 0{\cdot}15$,	$\phi^3 = 0{\cdot}1$,	$\phi^4 = 0{\cdot}01$,
$\rho^1 = 1$,	$\rho^2 = 0{\cdot}2$,	$\rho^3 = 0{\cdot}1$,	$\rho^4 = 0{\cdot}01$,
$x_1^{\mathrm{th}} = 60$,	$x_2^{\mathrm{th}} = 68$,	$x_3^{\mathrm{th}} = 85$,	$x_4^{\mathrm{th}} = 100$,

$J_i^0 = 60$ (all i), $\eta^k = 1$, $I = 10$.

In fact we performed simulations using many different parameter values and this showed us that behaviour similar to that observed for systems of central places, could be generated for a whole range of such values. The simulation we are going to describe here is a typical example of all these. Of course, this simulation represents one possible history for such a system, and which corresponds to a particular sequence of stochastic events.



Key to figures 5–10
- Centre having only function 1
- Centre with functions 1 and 2
- Centre with functions 1, 2, and 3
- Large centre having functions 1, 2, 3, and 4

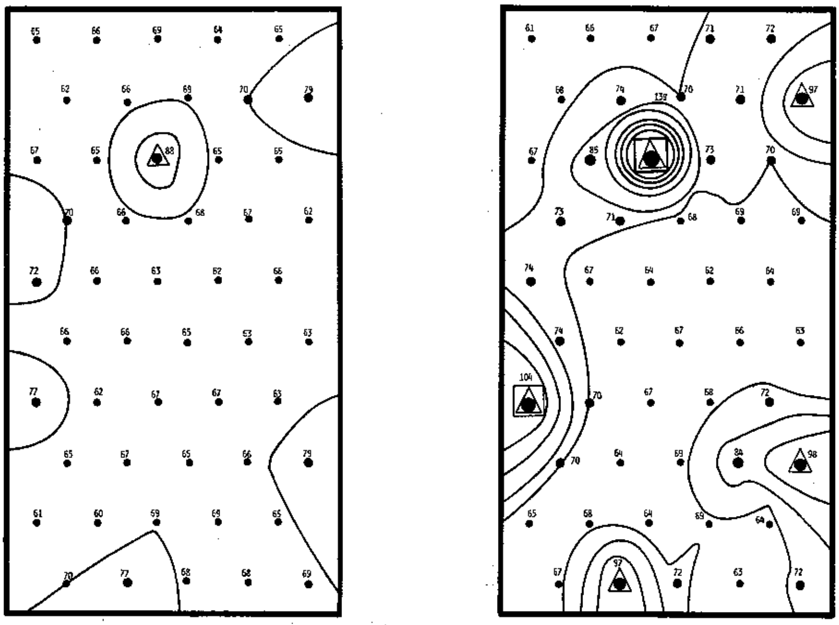
Figure 4. The numbering of the points on our simulation lattice, and the key to figures 5–16.

At $t = 0$, the points all had approximately 66 units of population. They are, however, subject to random fluctuations of the order of 5%, and when a point exceeds 68 it receives the second function and begins to grow if there is sufficient market.

For a particular computer run, after a number of such fluctuations, the situation as depicted in figure 5(a) was found at time $t = 4$, and five points were found to have received the function 2 and grown to a population greater than 75. These are the 'nuclei' of future cities, and already lay down the skeleton of the urban structure that will emerge.

In figure 5(b) the situation at $t = 12$ is shown. The structure that was only embryonic at $t = 4$ has 'solidified' and it is seen that five large centres are growing. The points 15 and 31 have already received all four functions considered in our simulation whereas points 10, 40, and 44 have 3 functions. In particular, the examination of the evolution around point 15 reveals how the crowding at this point results first in the build up of residential suburbs, with a coefficient or employment less than unity, and then how, later, a certain decentralization of economic functions occurs, as the short and medium range activities find sufficient market in the suburbs. This has important consequences for the evolution of the urban area as a whole, but during the interval $t = 12$ to $t = 20$ the central core density continues to grow, but attains a maximum at about this time.

Also of interest is the formation of a 'twin city' on the points 38 and 40 due simply to the particular sequence of events that the random fluctuations of our particular simulation has produced.

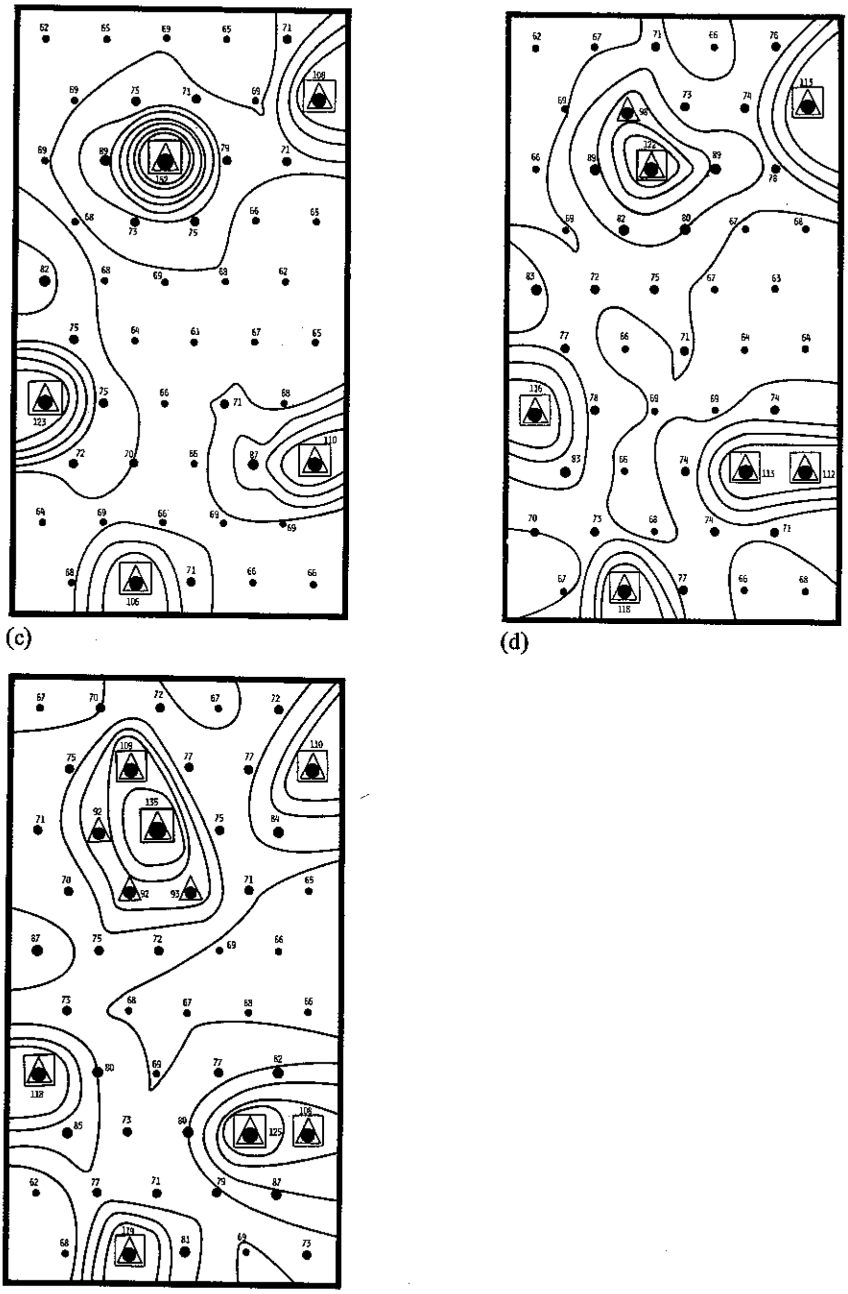


(a) (b)

Figure 5. (a) The distribution of population on a rectangular plane represented by fifty points at a time of 4 units. At the start of the time period, all points had 67 units. (b) The distribution of population at a time of 12 units. The structure is beginning to 'solidify' around five main centres. (c) At a time of 20 units, the central core density of the largest centre is going through a maximum (152). There is marked 'urban sprawl' around this centre too. (d) At a time of 34 units basic structure is essentially stable. Two centres have undergone central core decay.
(e) Between a time of 34 units and a time of 46 units the basic pattern is stable. Notice the shift in centre of the 'twin city' between a time of 20 units and a time of 46 units.

At $t = 20$ it is seen that five central places have received the 4 functions present in our simulation and have deformed the population density contours in consequence, the residences and economic functions sprawling outwards to a distance that depends on the size of the centre.

Between $t = 20$ and $t = 34$ the structure remains more or less unmodified. The second centre of the 'twin city' captures the fourth function, and because of its superior geographical situation begins to dominate its partner, which was by chance



(c) (d) (e)

Figure 5 (continued).

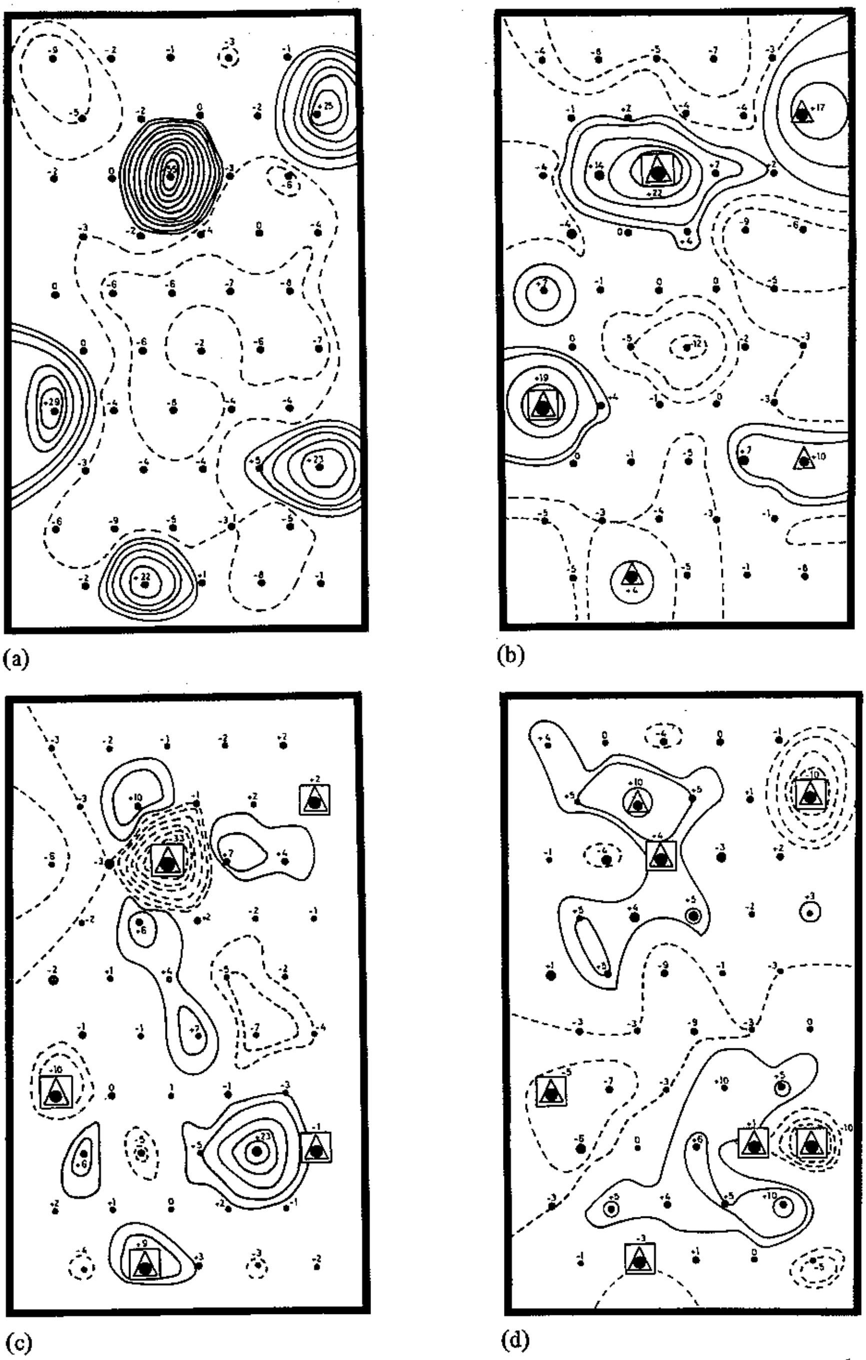


Figure 6. (a) This shows the above or below average growth that has occurred at each point in the particular period from $t = 0$ to $t = 10$. The above average growth is very strongly concentrated in the five points which become the dominant urban centres. (b) The growth for the time period 10–20 units. The above average growth is now spread out, corresponding to the formation of residential suburbs. The interurban space is suffering continued decline. (c) In the period 20–34 units two large urban centres suffer a severe decline of their cores, and above average growth is now almost exclusively concentrated in the interurban space. (d) The pattern of growth (solid lines) and decline (dotted lines) that take place between the times given by $t = 34$ and $t = 50$. This is under a scenario of 'no change'.

the first to appear. Another important feature is that the 'oldest' and largest centre on point 15 has, during this period, suffered a severe decline in its central core density. This results from the complex nonlinear dynamics of our system, whereby the residences of the population that is employed at 15 spread outwards, and then attract local economic functions into the suburbs. These, however, once present act as a source of local employment and in addition, act as a screen for the lower-order functions, diverting the clients of the central core which in consequence suffers a loss both of employment and of population.

Continuing the simulation from $t = 34$ to $t = 46$ shows us that the structure remains basically unmodified, although as the growth analysis will show there now occurs a polarization of the growth in the system between the upper and lower halves of our lattice.

In figure 6 we show the zones in which the growth is concentrated during the different periods of the evolution of our system. Initially, in the first period going from $t = 0$ to $t = 10$, it is seen that the growth is highly concentrated spatially in the five centres which are at the origin of the urban structure of the region. The areas of above average growth generally encompass only a single point, and this point has a very large growth rate. This can be referred to as the period of 'central urbanization'.

In the next stage, figure 6(b), which covers the period $t = 10$ to $t = 20$, it is seen that, while the central cores are still growing strongly, the 'growth plateaus' are much broader, which shows the effects of suburban growth, that is of urban sprawl.

In the period $t = 20$ to $t = 34$, however, figure 6(c) shows an entirely different pattern. Here, the central cores of 3 centres suffer a strong decline, and the remaining 2 grow very little. The zone of 'above average growth' is nearly all concentrated in the interurban region, and marks a period of 'counter urbanization'.

In the final period of our simulation, between $t = 34$ and $t = 50$, figure 6(d), it is clear the interurban growth of the preceding interval marks the beginning of real

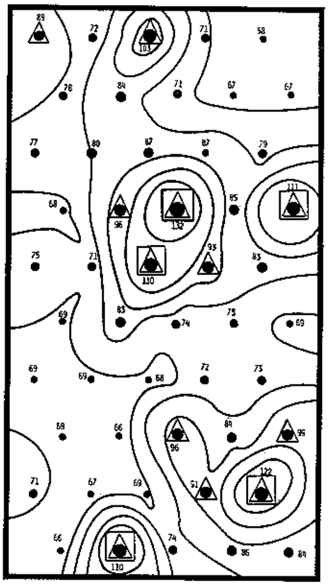


Figure 7. A quite different, but equally stable structure for the distribution of the population and of the economic activities, with identical parameters as for figure 5(e), starting from the same initially uniform state. The particular history of the fluctuations that occurred leads to quite different structures.

competition between the upper and lower halves of the lattice, and although the growth remains essentially nonurban it shows the effect of the competitive growth of the different parts of the urbanized area.

The same equations, and parameters, give of course quite different structures for each computer run, since the particular fluctuations that occur in each of them are different. But also we observed a certain regularity in the number of large centres and their size, it is their geographical position which is different. For example, figure 7 shows the structure attained after a long time, following different historical 'accidents'. This illustrates the role of chance and determinism in such evolutions.

4 Alternative strategies for decisionmakers

In this section we look at the effects on the global evolution of the system, of different decisions taken at time $t = 34$ for our first simulation figure 5. This allows us to demonstrate the potential of our methods in the examination of the effects of different decisions, where either local or global changes can be imposed on the system, and where we begin to see the possibility of studying quantitatively the most basic issues of government: who should a decision favour and how much, and at the expense of whom? And, what hierarchy of decisional power will lead to which local strategies, and what will be the impact of the latter on the evolution of the whole?

In this section, in the very simple, somewhat artificial urbanization example we have presented earlier, we shall demonstrate the principle on which such fundamental questions can be explored. The importance of this section should therefore be judged, not on the details of the particular example used, but on the basic human difficulties of a 'collective dimension' to individual acts, which is today perhaps the most important, almost wholly unanswered question facing our increasingly interdependent society.

Having explained the wider background of the discussion, let us turn to the example. Let us return to the simulation at $t = 34$ with an urbanization pattern as shown in figure 5(d). We shall investigate the effects of three different decisions, and afterwards the question of a decisional strategy.

First, let us suppose that the population of the region as a whole is fixed over the next period, and explore its relative growth and decline from the time $t = 34$ to the time $t = 50$. First of all, if there is no intervention, no decision, and all the parameters are unchanged then the 'growth and decline' zones are those shown in figure 8. We note that the system undergoes a certain 'polarization', and that in particular, the area across the centre of our region, which has no urban development continues to decline, and in terms of percentage change is most marked. This basic pattern of change is independent of the particular pattern of fluctuations that occurs.

Now, let us examine the effects on the growth/decline patterns of the system, of some governmental 'road building' program, or of some new technology, which has the effect of halving transportation costs (that is the values of $\phi^{(2)}$, $\phi^{(3)}$, $\phi^{(4)}$ relevant up to $t = 34$, are now halved). This is in fact a strategy that has been proposed in various countries in order to help arrest the decline of different regions. In the case of our simulation (and as is perhaps the case for those countries) the improved transport efficiency has the effect of accelerating the decline of the rural areas between centres, and of favouring most the largest centre, figure 9.

The third strategy which we shall examine concerns the possibility of directly interfering in the urban structure by the placing of a specific investment at a particular point. This corresponds to the idea of a 'New Town' or of the strategic development of a hitherto undeveloped centre, in the hope of generating self-sustaining economic growth in the otherwise declining zone.

The first important remark that must be made is that in all our simulations there are present small fluctuations of population and employment which test the stability of the basic structure, and could if this is not assured lead to the amplification of a particular fluctuation and the adoption of a new spatial pattern. However, we may see from the figures 5(b)–(e) that the basic structure becomes stable to these small fluctuations by about $t = 16$. Thus, we know already that if we wish to modify the pattern, and in particular to move to a structure without the 'declining rural hole' in the middle, then a perturbation of some larger size is required. In fact, in a series of computer simulations it was possible to ascertain that for almost certain self-sustaining growth at the chosen point 26, it is necessary to invest 19 units at time $t = 34$. If less than this is inserted then the chances are that it will simply waste away since the basic structure is stable.

In figure 10, we see the growth/decline pattern for a simulation where 19 units of population and employment were added to point 26. The investment flourishes, producing a remarkable increase of population and jobs at and around the point. Of course this is at the expense of other points which would otherwise have grown, but it can be shown that the final structure resulting at time $t = 50$ following the perturbation, is, considering only the transportation costs, more 'efficient' than otherwise, since there is less transportation required for the same total consumption as before, which means that the 'mean haul distances' are shorter and variations in the consumptions of goods between urban and rural areas is less marked.

However, before drawing any hasty conclusions about which strategy should be adopted, let us briefly examine the manner in which the administrative division of a region may affect which decisions are adopted. Consider the case where the lattice is divided into two separately governed districts: the upper and the lower halves.

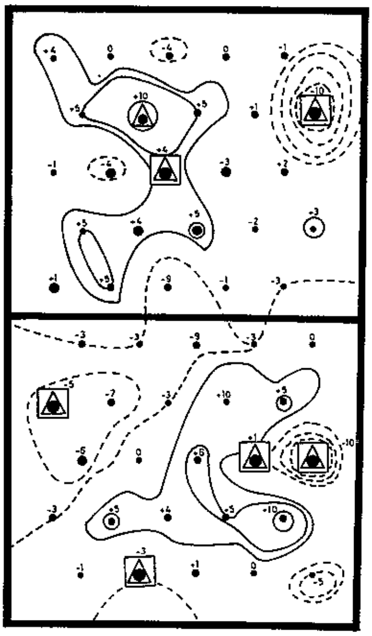


Figure 8. The urban centres compete among themselves and this leads to a polarization of the growth.

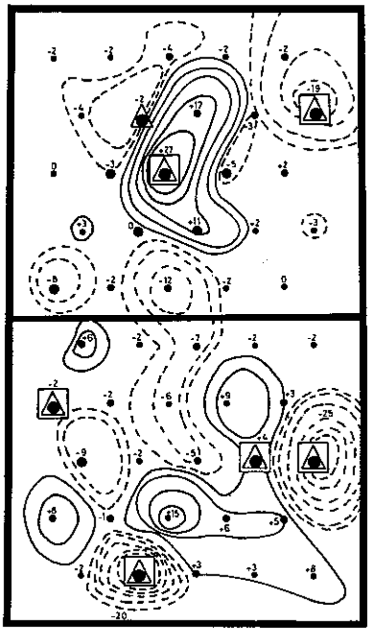


Figure 9. If the transportation costs are halved everywhere at time t of 34 units the system evolves as shown here between a time of 34 units and a time of 50 units.

Let us briefly discuss the consequences for each half of each of the three strategies. First, if there is no change, figure 8, then between $t = 34$ and $t = 50$ the relative growth of the two regions is:

upper half +11 , lower half −11 .

(This is the relative growth of population, and let us suppose that for some reason this growth is considered desirable for the region.) Let us compare the second strategy to this, in which transportation costs have been halved (figure 9). Greatest growth occurs in the largest centre (point 15), but this growth is in some way achieved at the expense of the district itself, since for the period $t = 34$ to $t = 50$ we find,

upper half −6 , lower half +6 ,

a reversal in the relative tendency.

The third strategy consists in placing 19 units of population on the point 26, which is in the lower half. Not surprisingly, when the investment pays off we find that the lower half gains greatly:

upper half −41 , lower half +41 .

From this we see that it would pay the lower half to invest the 19 units of population itself, rather than doing nothing, since it gains $41 - 19 + 11 = 33$.

However, we must realize that this result is dependent on the fact that the upper half does not 'riposte' in this simulation. Our model begins to show us the real complexity of decisionmaking, where the reaction of the other actors of the system to changing circumstances must be taken into account if it is desired to attain at least some partial objective. In the case of our particular example, the 'strategy' played by the lower half is to invest in a centre on its frontier with the upper, which causes a growth at the expense of the upper half. This basic idea of strategy

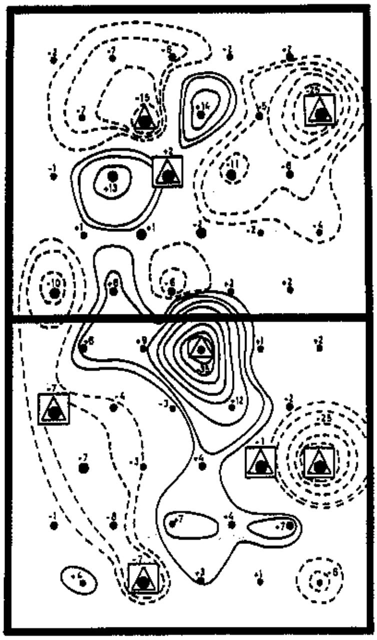


Figure 10. If a population is injected at the point indicated at time t of 34 units then the system evolves as shown here, between a time of 34 units and a time of 50 units.

corresponds clearly to many problems such as the conflict of two political parties where effort must go into attracting supporters from the middle ground, and similarly for competing firms with different ranges of products.

The importance of these results is not however, in their detail. It is rather in the principle which is demonstrated that in a complex system of interdependent entities, the decisions made by individuals, or by collective entities representing certain localities have a real effect on the evolution of the system and of everyone in it. This is the 'collective' aspect of individual actions which characterizes our society, and decisions should be made as far as possible in the knowledge of these collective effects, rather than finding that the 'system' is sweeping the various actors in a quite unexpected and undesirable direction, as a result of their individual behaviour.

This is the basic aim of the methods that we have described here, by choosing the various parameters so that they correspond to a particular urban hierarchy, it is possible to simulate not only the long term repercussions of a given strategy for the immediate locality involved, but also the consequence of that strategy for the region in which it is embedded.

5 A case study of the region of Bastogne

Let us turn to our regional model of the evolution of the Bastogne region of Southern Belgium (Allen et al, 1979b). In figure 11 we see the evolution of Belgium as a whole between the years 1947–1971. In the north we have a large, growing conurbation including Brussels, Antwerp, and Gent, with a very fast growing region stretching between these three cities and Amsterdam. In the south, particularly in Luxembourg, we have a sparsely populated and a declining region. It is in this area that we have made our initial study. The area is shown in figure 12 and we have divided it into 5 zones centred on the 5 main towns of the region. The interaction processes shown in figure 3 enable us to calculate the change in employment in each zone as determined by the number of people residing there, and the evolution of the number of residents in terms of the employment offered. This enables us to model the evolution of the employment and population of each zone between 1947–1971 and we show the comparison between the actual and the simulated evolutions in

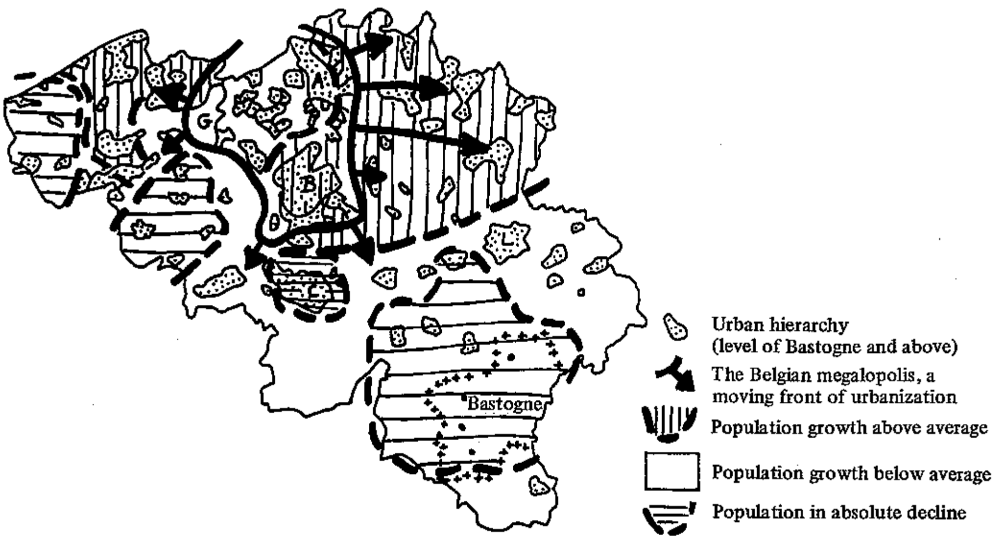
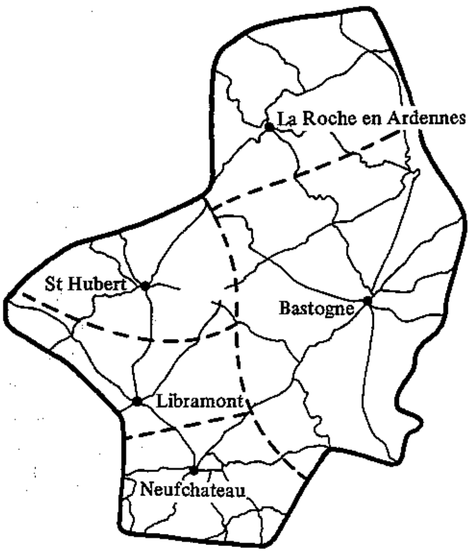


Figure 11. The evolution of the population (by arrondissment) in Belgium, during the period 1961–1970. (Source: private communication from URBS NOVA.)

figures 13 and 14. Thus, four of the five zones decrease continually in employment, and to a lesser degree in population while one, Libramont, increases in both. The calculation of the evolution of the five principal towns themselves, figure 15 agrees remarkably with reality, and we see that in terms of employment there is a dramatic difference between the behaviour of Libramont and of the others. This represents a major structural instability in the region, and its origin can be traced back to its choice as the principal railway halt in the region, figure 16.

This choice involved considerable 'historical chance' since the railway was constructed initially by English speculators interested in travelling from Ostend to Trieste in order to take ship to India! This fact, together with considerations of the relief of the area led the constructors to by-pass Bastogne itself, and only to connect it later with a branch line from Bertrix, crossing the main line at Libramont (Dagnelie-de Leener, 1958).



Key to figures 13–16

B	Bastogne
LR	La Roche en Ardennes
Li	Libramont
N	Neufchateau
St H	St Hubert

Figure 12. Map showing the area of our case study, with the five principal towns.

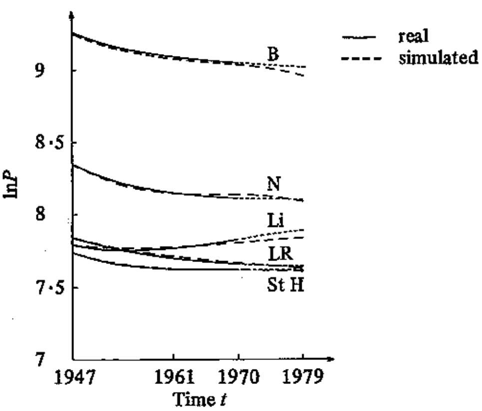


Figure 13. Comparison of the real and simulated evolution of the active populations (P) residing in each of our five zones. A key for the zones is given in figure 12.

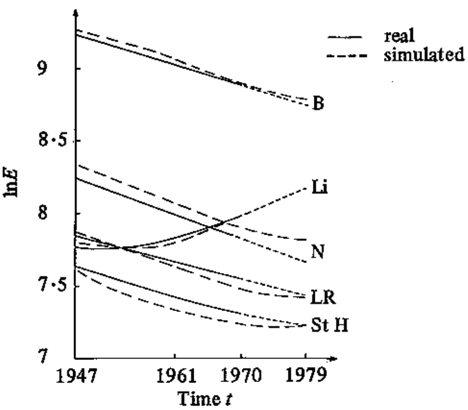


Figure 14. Comparison between the real and simulated evolution of the employment (E) in each of our five zones. A key for the zones is given in figure 12.

We see also how important a role is played by the framework of a decisionmaker, for if the region itself had planned a rail network, it would surely have been centred on Bastogne, the largest town, and the structural instability would never have occurred. A model such as ours can explore the probable consequences in the long term, of any such decision.

Of course, another point that should be underlined is that the evolution projected into the future is modelled by supposing some particular scenario, several of which may be possible potentially. Perhaps the Mayor of Bastogne can act on the system in such a way as to avoid the decline that the growth of Libramont may bring. Our model permits us to explore the 'force' which he would require in order to change the evolution appreciably, and in reality this may not be within his powers. It also shows us that the plans and designs made for any particular urban centre should take into account the evolution of that centre as part of the region in which it is embedded, and that the effects on the surrounding region of those plans and decisions made in the urban centre should also be evaluated.

The model provides the possibilities of estimating the long term effects of a particular decision made in a particular locality, and these for the changed evolution of the whole system.

In the above we have discussed the evolution of urban centres in a region, but we can equally well develop our method to look at the evolution of the internal structure of a particular centre. Clearly, if the 'natural' evolution within the centre is not taken into account, then any plan of design concerning some particular aspect will entail a series of events and changes not taken into consideration, often undesirable and simply not dealing with the initial problem. This work will be described in detail elsewhere (Allen et al, 1980) but let us simply say here that we must write down equations expressing the changes induced by the mutual interaction of the locational criteria of the different socioeconomic groups populating any particular locality: the different entrepreneurs, and types of residents. The intraurban evolution can then be explored by studying the changing spatial patterns of these various actors, under a scenario governing its interaction with the outside world obtained from a model of the regional evolution as above. Within such a framework it is then possible to explore the impact on the intraurban evolution of changes in, for example, the transportation network, or personal mobility, or due to sectoral changes in the urban economy. Also one may examine the long term effects felt by the different actors following the execution of a particular scheme or project.

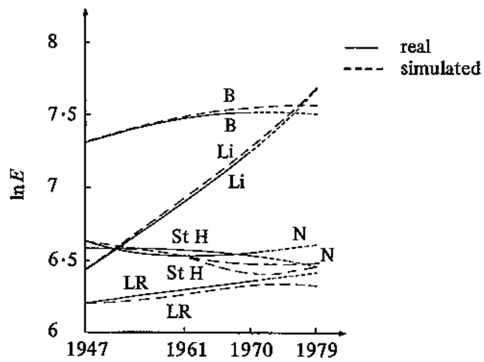


Figure 15. Comparison between the real and simulated evolution of the employment (E) in each of the five towns on which our zones are centred. The key for the zones is given in figure 12.

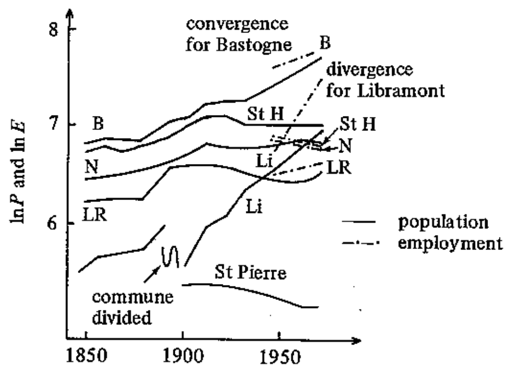


Figure 16. Evolution of the five main centres since 1850.

In order to illustrate briefly the complexity of the evolution described by our model, a complexity resulting from the mutual interaction of the actors each of which behaves according to a very simple relation, in figures 17 and 18 we see the spatial distributions of a six variable model, initially centralized, after a period of growth. The six variables chosen are jobs in heavy industry, in exporting and tertiary (business, banking, insurance, etc), in ubiquitous retail, and in specialized retail, and two types of resident; first, working and lower middle class, and second, upper and upper middle class. Whatever one feels about the existence of such divisions, if they correspond to some real differences in locational criteria, then plans and projects

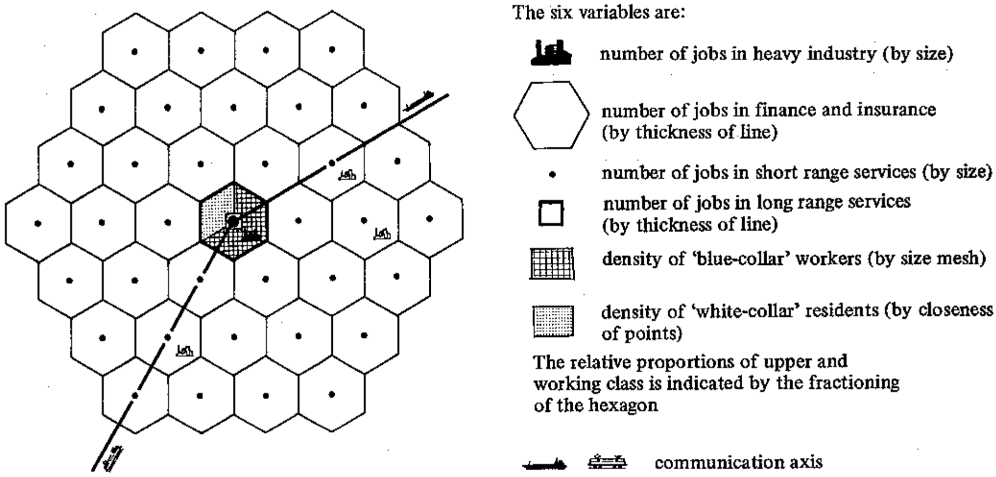


Figure 17. This shows the initial spatial distribution of the six variables.

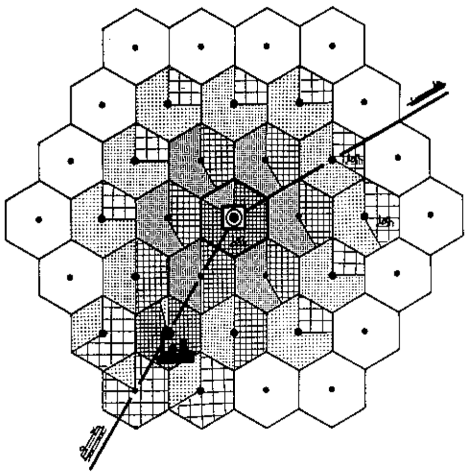


Figure 18. After 40 units of time, the initially centralized town has both grown in size and evolved to this unsymmetrical, diversified structure. Briefly, the locational criteria of heavy industry are such that, as the town grows, so the industry is driven out of the centre, its growth being localized at a point of good access to the outside world, represented here by the canal or railway. As industry generates employment largely for the working class, so their pattern of residences reflects this spatial distortion, which in turn interacts with that of the upper classes, and all this in turn on the size and distribution of local shopping centres. Clearly, for other values of the parameters intervening in the locational criteria of the actors, other structures are possible, and spatial instabilities are important in this creative evolution.

made in order to achieve some particular aim must be formulated knowing the evolution of the system and how this will probably be affected.

From such considerations, we begin to see clearly the real difficulties of living in an interdependent society. The evolution of any neighbourhood, town, or city can never be dissociated from that of the surrounding regions or the included elements, and the decisions, policies, and plans executed in any subunit of a whole will influence the evolution of all the other parts of the system. What liberty should therefore be accorded to the individual, the local community, the region, or the nation? At what level should policy decisions be evaluated, and whose money should be used to execute those decisions? Such questions lie at the root of all political debate, and of course there is no clearly discernible answer to them. However, for as long as the real long term consequences of a particular decision are a matter of pure conjecture, then policy remains a matter of conflicting ideals and political manoeuvre, which are not necessarily beneficial to the community. The further development of our models, while not answering the basic questions above, at least would allow different strategies to be assessed in the light of the real consequences.

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